Didar KOÇAK

M.S. Thesis In Chemistry

January 2012

SYNTHESIS, STRUCTURAL AND SPECTRAL PROPERTIES OF NOVEL OCTAKIS[3,5-BIS(TRIFLUOROMETHYL) BENZYLTHIO] SUBSTITUTED PORPHYRAZINE DERIVATIVES

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in

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January 2012
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APPROVAL PAGE

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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Assoc. Prof. Abdülhadi BAYKAL
Head of Department

This is to certify that I have read this thesis and that in my opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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January 2012

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ABSTRACT

Octakis[3,5-bis(trifluoromethyl)benzylthio] porphyrazinato magnesium carrying eight 3,5-bis(trifluoromethyl)benzylthio groups on the peripheral positions have been synthesized by cyclotetramerization of 2,3-bis[3,5-bis(trifluoromethyl)benzylthio] maleonitrile in the presence of magnesium butanolate. Its demetallation by the treatment with trifluoroacetic acid resulted in the metal-free derivative. Further reaction of this product with copper(II) acetate, zinc(II) acetate and cobalt(II) acetate has led to the metallo derivatives M = Cu(II), Zn(II), Co(II). These novel complexes were characterized by elemental analysis, together with FT-IR, ^{1}H NMR, ^{13}C NMR, ^{19}F NMR, UV-Vis and mass spectral data.

Keywords: 3,5-bis(trifluoromethyl)benzylthio; Porphyrazine; ^{19}F NMR spectroscopy; Zinc; Cobalt.

YENİ OKTAKİS[3,5-BİS(TRİFLOROMETİL)BENZİLTİYO] İÇEREN PORFİRAZİN TÜREVLERİNİN SENTEZİ, YAPISAL VE SPEKTROSKOPİK ÖZELLİKLERİ

Didar KOÇAK

Yüksek Lisans Tezi-Kimya Bölümü
Ocak 2012

Tez Yöneticisi: Doç. Dr. Ergün GONCA

ÖZ

Bu çalışmada periferal konumdaki sekiz adet 3,5-bis(triflorometil)benziltiyo sübstitüentleri içeren porfirazinler sentezlendi. Magnezyum butanolat içerisinde 2,3-bis[3,5-bis(triflorometil)benziltiyo] maleonitril, siklotetramerizasyon yöntemiyle reaksiyon sonucunda oktakis[3,5-bis(triflorometil)benziltiyo] magnezyum porfirazin sentezlendi. Metalsiz türevi trifloroasetik asit ile muamele edilerek elde edildi. Bu ürünün bakır(II) asetat, çinko(II) asetat ve kobalt(II) asetat ile reaksiyonlarına devam edilerek metalli porfirazinler elde edildi [M(II) = Cu(II), Zn(II), Co(II)].

Bu yeni komplekslerin karakterizasyonu ^{1}H NMR, ^{13}C NMR, ^{19}F NMR, FT-IR, UV-Görünür bölge, kütle ve elementel analiz gibi çeşitli spektral verilerle gerçekleştirildi.

Anahtar Kelimeler: 3,5-bis(triflorometil)benziltiyo; Porfirazin; ^{19}F NMR spektroskopi; Çinko; Kobalt.

ACKNOWLEDGEMENTS

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Finally, I am grateful to my father and mother who always supported and directed to me towards during my studies.

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LIST OF ABBREVIATIONS

Å	Angstrom
CMEs	Chemically Modified Electrodes
CV	Cylic Voltammogram
DCE	Dichloroethane
DCM	Dichloromethane
DDQ	2,3-dichloro-5,6-dicyanobenzoquinone
DMAE	2-(N,N-dimethylamino)ethanol
DMF	N,N-dimethylformamide
EAS	Electron Absorption Spectrum
EL	Electroluminescence
FRET	Förster Resonance Energy Transfer
GPC	Gel Permeation Chromatography
H_2OEP	2,3,7,8,12,13,17,18-octaethylporphyrin
H_2Pz	Metal-free porphyrazine
H_2TPP	5,10,15,20-tetraphenylporphyrin
HOMO	Highest Occupied Molecular Orbital
HpD	Hematoporphyrin Derivatives
IR	Infrared
L	Ligand
LCAO	Linear Combination of Atomic Orbital
LUMO	Lowest Unoccupied Molecular Orbital
M	Metal
$M(P)_2$	Bistetrapyrroles
$M(P)L_4$	Metal Monotetrapyrroles
$M_2(P)_3$	Tristetrapyrroles
MO	Molecular Orbital
MP	Metalloporphyrin
MPA	Metalloporphyrazine

MTAP	Metallotetraazaporphyrin
NLO	Non-linear Optical
NMR	Nuclear Magnetic Resonance
OL	Optical Limiting
OLEDs	Organic Light-emitting Diodes
Pc	Phthalocyanine
PDT	Photo Dynamic Therapy
PEG	Polyethyleneglycol
PH_2	Porphyrin molecule
Pyr	Pyrrole
Pz	Porphyrazine
QDs	Quantum Dots
TAPc	Amino Substituted Pc
TLC	Thin Line Chromatography
TP	Tetrapyrrolic
UV / VIS	Ultraviolet / Visible Spectrum
WE	Working Electrode

CHAPTER 1
TETRAPYRROLE COMPLEXES

1.1 PORPHYRINS

Porphyrins and their reduced or otherwise modified derivatives are unquestionably the ligands par excellence of biology. The most common examples are the hemes (found in hemoglobins, myoglobins, cytochromes, catalases, and peroxidases), chlorophylls, and bacteriochlorophylls (Vicente and Smith, 1999). Iron is the chelating metal found in hemes, and magnesium is found in the numerous chlorophylls and bacteriochlorophylls. In more highly reduced tetrapyrrole-derived natural products, other metal ions are found; these include vitamin B12 (containing cobalt) and factor 430 (containing nickel). The mechanisms utilized in the mode of action of many tetrapyrrole metabolites often involve changes in the oxidation state of the central metal.

Tetrapyrrole-derived macrocycles are able to accommodate the various oxidation state (and therefore metal ion size) changes due to the flexibility and adaptability of the basic chelating system. For the purposes of this treatise, only common routes to a number of very popular porphyrins will be discussed. Though methodology has been developed to enable the synthesis of the most complex porphyrins imagineable, discussion of the approaches to highly unsymmetrical natural porphyrins would be inappropriate to the organometallic focus of this volume. Instead, the discussion will be mostly focused on the two most common porphyrin types; these are the peripherally octasubstituted porphyrins exemplified by 2,3,7,8,12,13,17,18-octaethylporphyrin (H_2OEP) and meso-tetrasubstituted systems such as 5,10,15,20-tetraphenylporphyrin (H_2TPP) (Fig.1.1). Some variations on the themes of these two systems will also be mentioned; however, it should also be noted that, for example,

porphyrin and 2,3,7,8,12,13,17,18-octamethylporphyrin (Fig.1.2) are so insoluble in most organic solvents that they are rarely, if ever, used by porphyrin practitioners.

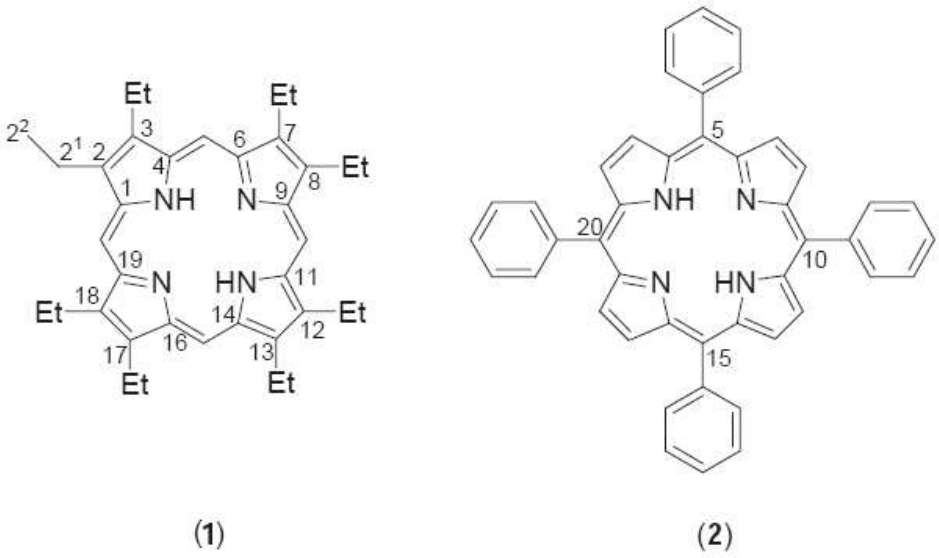


Figure 1.1 5,10,15,20-tetraphenylporphyrin.

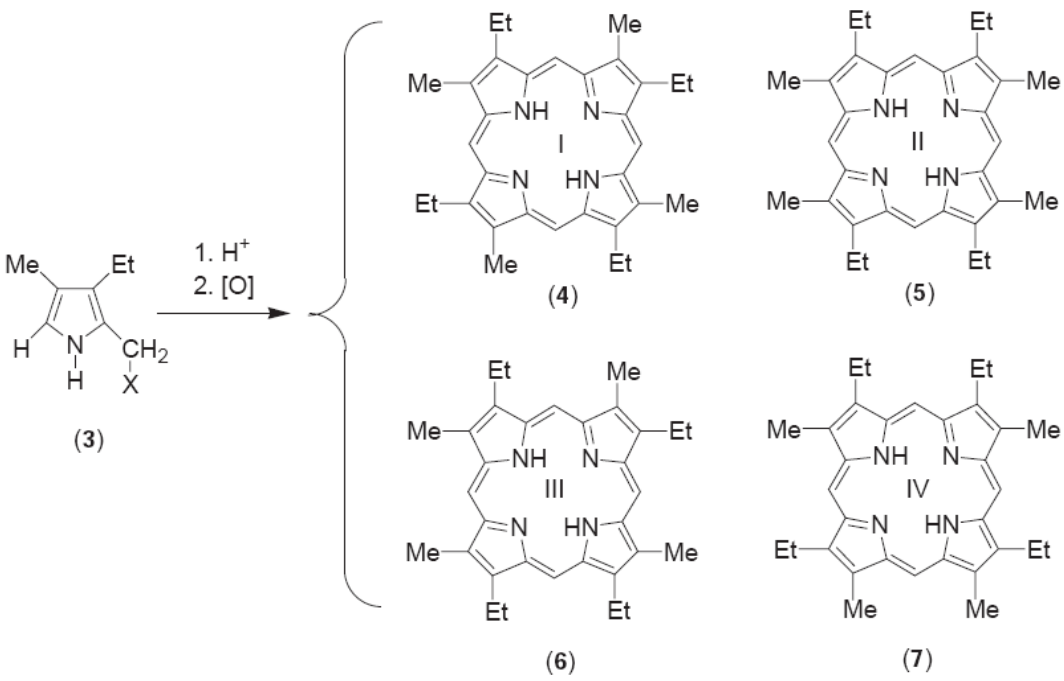


Figure 1.2 2,3,7,8,12,13,17,18-octamethylporphyrin.

1.1.1 Strategic Considerations in Porphyrin Synthesis

In designing a porphyrin synthesis, or indeed in making the decision about exactly which published approach to use, substituent symmetry considerations are of the utmost importance. Clearly, if all of the substituents on the pyrrole positions, or on the meso positions are identical, then tetramerization of a single monopyrrole is the method of choice. Porphyrins, perse, are comprised of a cyclic array or four pyrrole subunits linked by four methine carbons; one therefore needs to assemble four pyrroles and four linking (meso) carbons into one macrocycle. Thus, the origin and type of meso-carbon to be employed is also an essential component to be considered. Likewise, whether or not the future meso-carbons should be attached to the pyrrole component or added into the reaction mixture separately is an issue to consider.

Because of so-called pyrrole redistribution reactions (Mauzerall, 1960) that are acid-promoted, use of monopyrroles (e.g., **3**) which do not have identical 3- and 4-substituents will result in a mixture of porphyrins. Thus, pyrrole (**3**) gives a mixture of trivially named etioporphyrins I–IV when it is cyclotetramerized under acidic conditions. Such a mixture of ligands, similar as they are, still makes the characterization of a subsequent metal complex almost impossible, and should therefore be avoided.

Pure individual porphyrins such as (**4**-**7**) can, however, be synthesized using dipyrroles, and these approaches will be briefly discussed later in this section. If two dipyrrole units **8** and **9** with an appropriate future meso-carbon are reacted together with the intention of preparing porphyrin (**10**), there is actually a maximum of three possible products, (**10**-**12**) (Fig. 1.3). This is because the two dipyrroles can either react with themselves, or (as required) with each other. If the dipyrroles do not possess attached (future) meso-carbon atoms (e.g., **13** and **14**) and also bear an unsymmetrical arrangement of substituents (indicated by the A and B labels on each pyrrole oxidation levels, i.e., dipyrromethene or dipyrromethane, not defined), even greater mixtures can occur in this case, porphyrins (**15**-**20**) (Fig. 1.4). Such symmetry problems are common with all so-called [2+2] syntheses. However, if a porphyrin synthesis involving two dipyrroles is to be attempted, the symmetry problems can often be overcome if one of

the two dipyrroles is symmetrical about its interpyrrolic (**5**-) carbon atom (e.g., synthesis of (**6**) from (**21**) and (**22**)**,** Fig. 1.5).

1.1.2 Porphyrin Synthesis Using a Monopyrrole Tetramerization Approach

1.1.2.1 *2,3,7,8,12,13,17,18-Octaethylporphyrin [H_2OEP (1)]*

As mentioned above, the future porphyrin meso-carbons can be covalently attached to the monopyrrole being subjected to tetramerization, or added separately from the pyrrole. H_2OEP, (**1**),

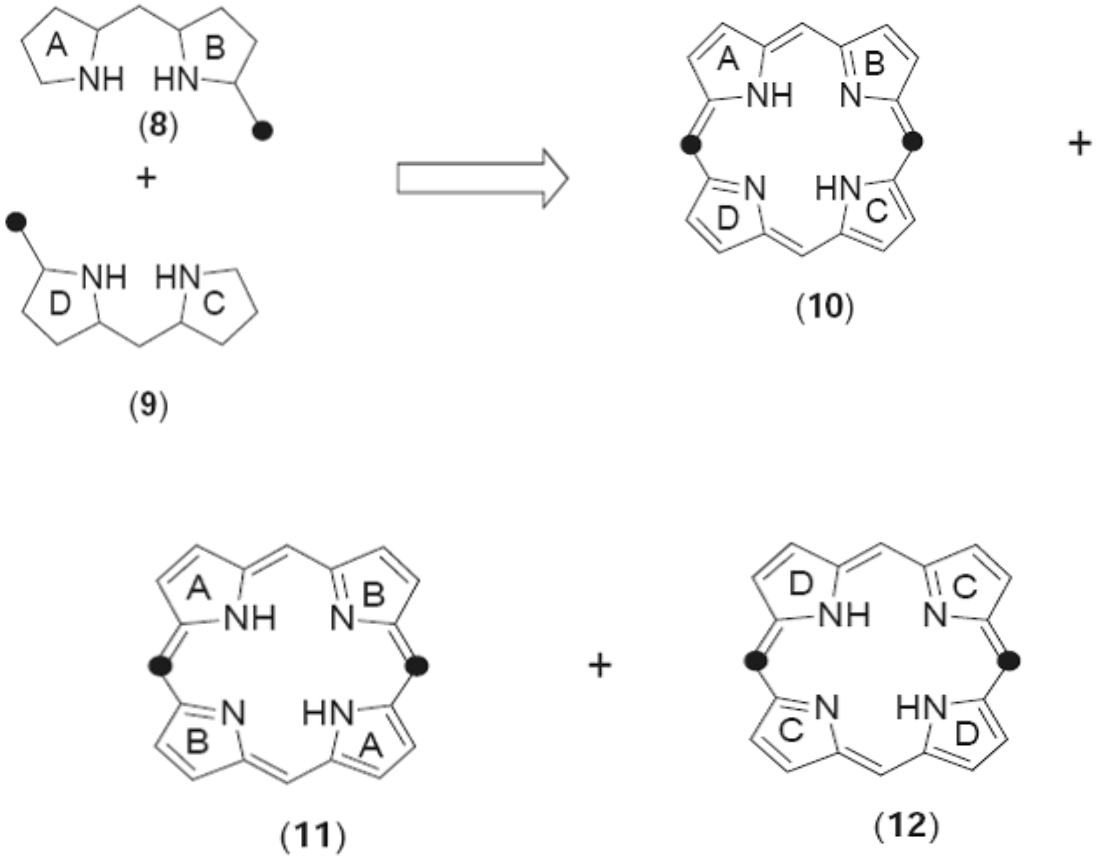


Figure 1.3 Preparing porphyrin.

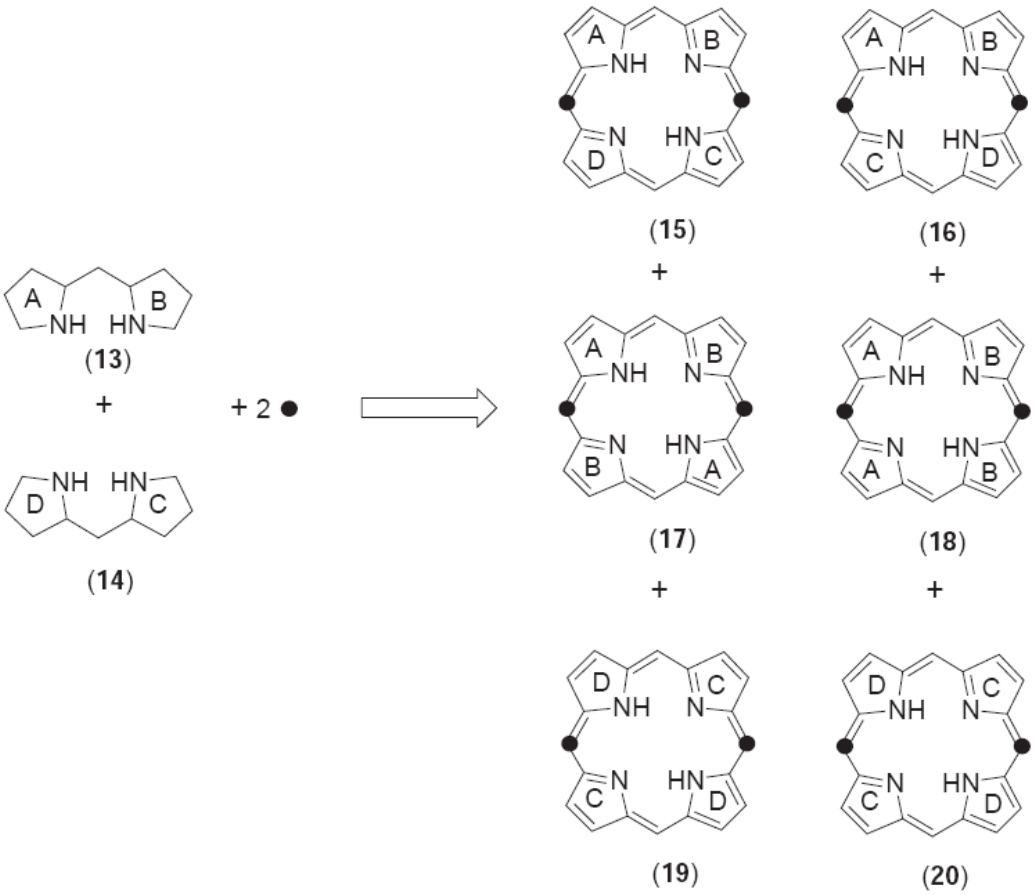


Figure 1.4 Unsymmetrical arrangements of substituents.

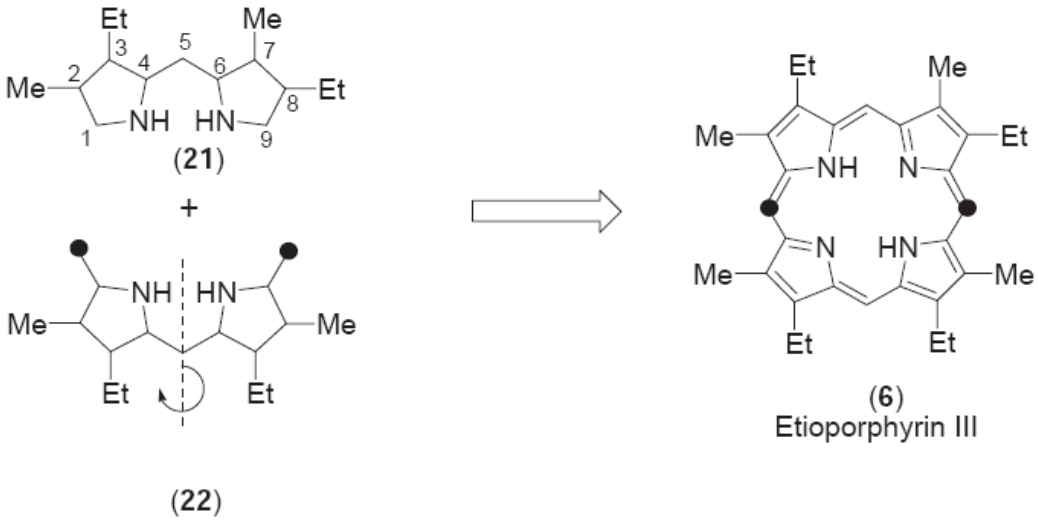


Figure 1.5 The symmetry problems can often be overcome if one of the two dipyrroles is symmetrical about its interpyrrolic (**5-**) carbon atom.

can be prepared using both of these methodologies. For example, cyclotetramerization of pyrroles (**23**) bearing 2-CH_2X substituents affords good yields of H_2OEP (Fig. 1.6). Since the 2-unsubstituted positions of pyrroles are nucleophilic, the benzylic X group must be a good leaving group; the methylene carbon of the 2-substituent (to which the X group is attached)

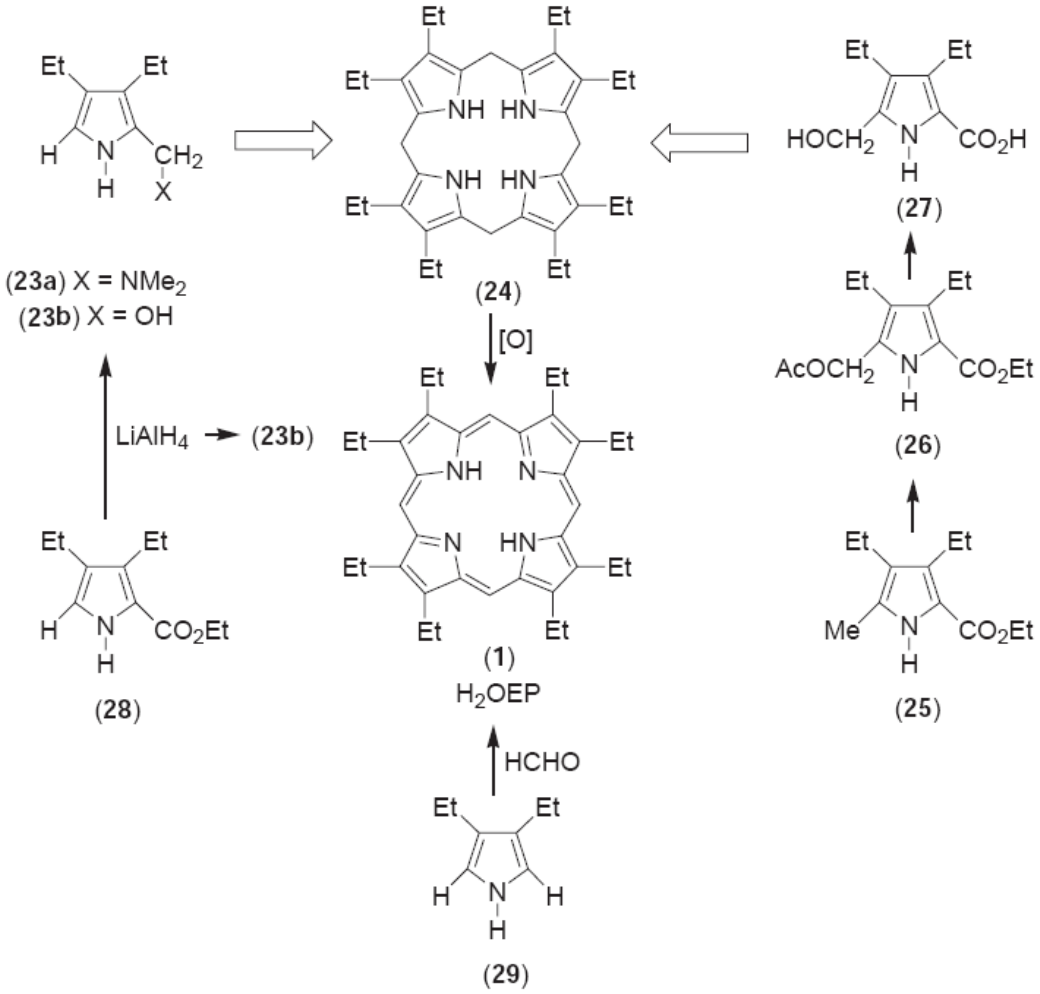


Figure 1.6 Cyclotetramerization of pyrroles (H_2OEP).

will eventually be the source of the 5-,10-,15-, and 20-carbons of the porphyrin (**1**). Mechanistically, such a cyclotetramerization would yield a porphyrinogen (**24**) after the condensation reaction, so an oxidation step is necessary in order to obtain the porphyrin.

Occasionally, adventitious air acts as the oxidant, but on other occasions an external oxidant (e.g., 2,3-dichloro-5,6-dicyanobenzoquinone (DDQ) or potassium

ferricyanide) is added. Numerous variations of the X group in the CH_2X of **23** have been investigated. Such groups can be directly attached to a 2-unsubstituted pyrrole, using, for example, formaldehyde and dimethylamine [or directly with (N,N-dimethylmethylene)ammonium iodide (Eschenmoser's reagent) **5, 6** which can be purchased] to give the 2-(N,N-dimethylaminomethyl)pyrrole (**23a**); heating of this in acetic acid gives agr eater than 50% yield of (**1**) (Eisner et al., 1957, Whitlock et al., 1968). Alternatively, oxidation of pyrrole (**25**) with lead (IV) tetraacetate gives **26**, which can be hydrolyzed to give **27** and then cyclotetramerized to give (**1**) in a little less than 50%yield by heating in acetic acid containing potassium ferricyanide (Inhoffen et all. , 1966). The Barton–Zard pyrrole synthesis **11** has significantly facilitated access to pyrroles such as **28**, and these can be reduced the the 3,4-diethyl-2-methylcarbinol (**23b**) simply by using lithium aluminum hydride. Cyclotetramerization of the pyrrole-2-methylcarbinol (**23b**) under acidic conditions, gives **1** in greater than 50% yield.

The second approach employs reactions of pyrroles in the presence of reagents that can separately provide the interpyrrolic carbon atoms. Thus, cyclotetramerization of 3,4-diethylpyrrole (**29**) with formaldehyde affords H_2OEP in yields as high as 75% (Sessler et al., 1991). It was mentioned earlier that the acid-catalyzed cyclotetramerization of pyrrole (**3**) results in formation of a mixture of the four etioporphyrin type isomers (**4**–**7**). This involves are distribution of the pyrrole subunits in intermediate pyrrole oligomers initiated by protonation of these electron-rich porphyrin precursors. Through a series of equilibria, the reaction produces a complex mixture of precursors, and eventually porphyrins. However, amethod has been developed which does produce only porphyrin from cyclotetramerization of a pyrrole; as might be expected, the key step in the development of this approach involves the avoidance of acid catalysts. Thus, treatment of 2-(N,N-dimethylaminomethyl)pyrroles (e.g., **30**) with methyl iodide gives **31** which has a very labile leaving group that can be displaced even under neutral conditions. Reaction of **31** in methanol containing potassium ferricyanide (as an in situ oxidant) gives a good yield of pure etioporphyrin I (**4**) (Fig.1.7).

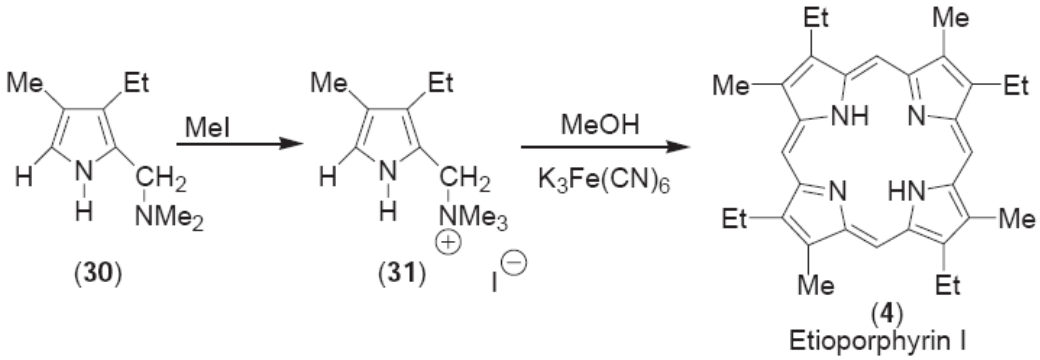


Figure 1.7 Etioporphyrin I.

A ‘‘one-pot’’ synthetic procedure which involves the combination of two different pyrroles to give a pure porphyrin with each type of pyrrole ring sited opposite to itself has been reported. Only one regiochemically pure porphyrin (**32**) is produced. For example, treatment of the 2,5-bis(N,N-dimethylaminomethyl)pyrrole (**33**) (obtained from 3,4-diethylpyrrole (**29**) by treatment with excess Eschenmoser’s reagent) with the 3:4-butanopyrrole (**34**) in methanol containing potassium ferricyanide, affords the porphyrin **32** (Fig. 1.8).

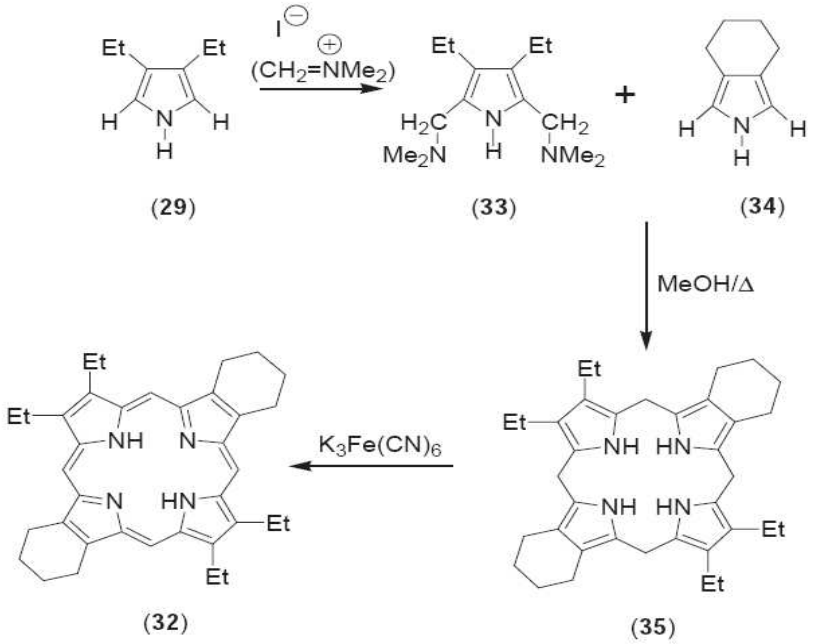
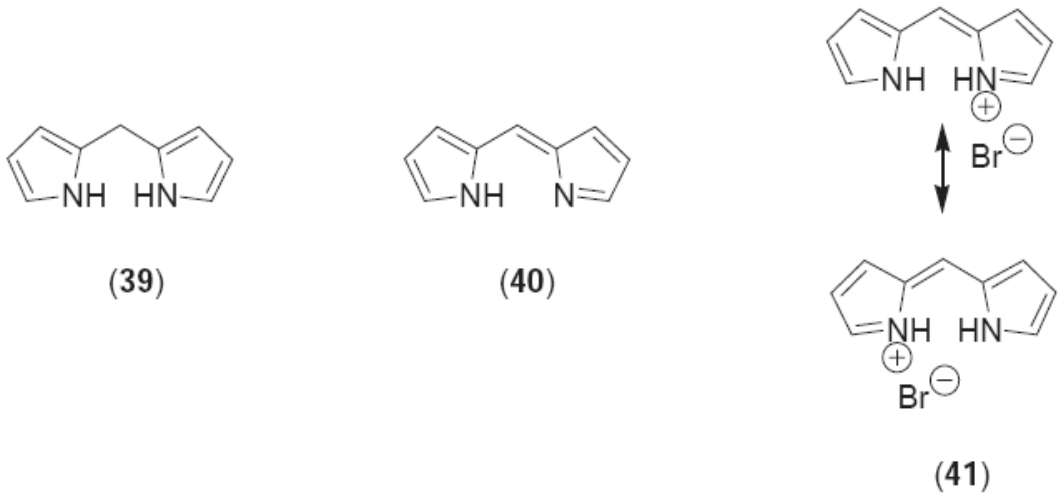


Figure 1.8 The 2,5-bis(N,N-dimethylaminomethyl)pyrrole with the 3:4-butanopyrrole in methanol, affords the porphyrin.

This reaction again proceeds through the porphyrinogen **35**, which is not isolated; the avoidance of acidic reagents and utilization of an in situ oxidant (potassium ferricyanide) avoids pyrrole ring redistribution reactions on the intermediate species (such as **35**) prior to porphyrin **32** formation.

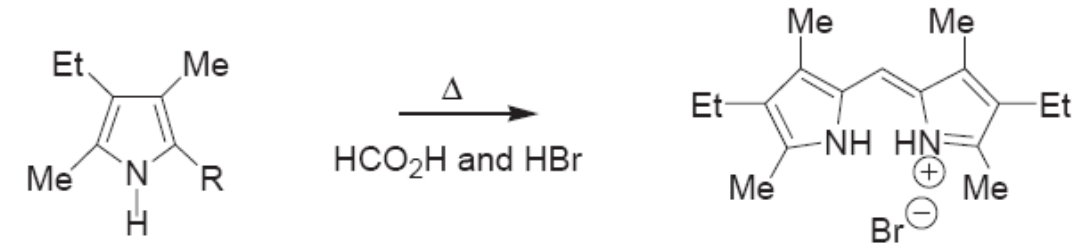
1.1.3 Porphyrin Synthesis Using Reactions of Dipyrroles

The two most common dipyrroles used in porphyrin syntheses are the dipyrromethanes (**39**) and dipyrromethenes (**40**); the latter are usually handled as their highly crystalline hydrohalide salts (e.g., **41**) (Fig. 1.9). Collectively, such syntheses of porphyrins using dipyrroles are known as [2+2] approaches.



(**39**) (**40**) (**41**)

Figure 1.9 Dipyrromethanes and dipyrromethenes.



(**43a**) R = H
(**43b**) R = CO_2H

(**42**)

Figure 1.10 Self-condensation.

The synthetically more useful unsymmetrically substituted dipyrromethene salts (e.g., **44**) are best obtained by the condensation of a 2-formylpyrrole (**45**) with a 2-unsubstituted pyrrole (**46**) in the presence of acid (usually HBr) (Fig. 1.11).

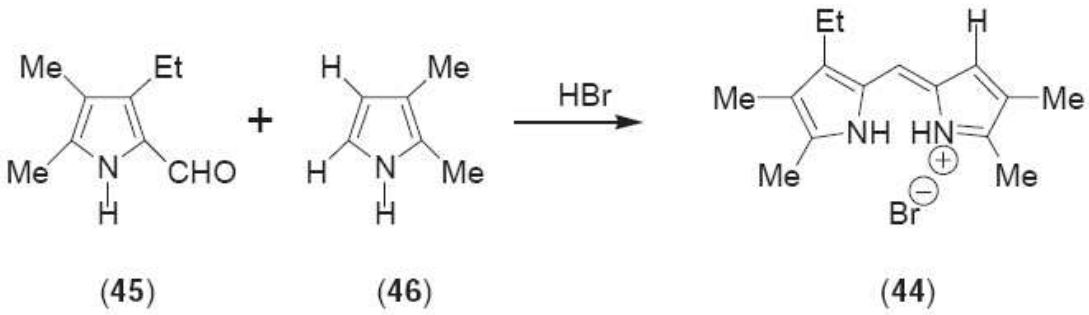


Figure 1.11 The preparation of unsymmetrically substituted dipyrromethene salts.

Heating of 2-bromomethylpyrroles (**47**) with 2-bromopyrroles (**48**) (synthesized by bromination of 2-unsubstituted pyrroles, (**49**)) in presence of bromine also gives good yields of unsymmetrical dipyrromethene hydrobromides (**50**) (Fig. 1.12).

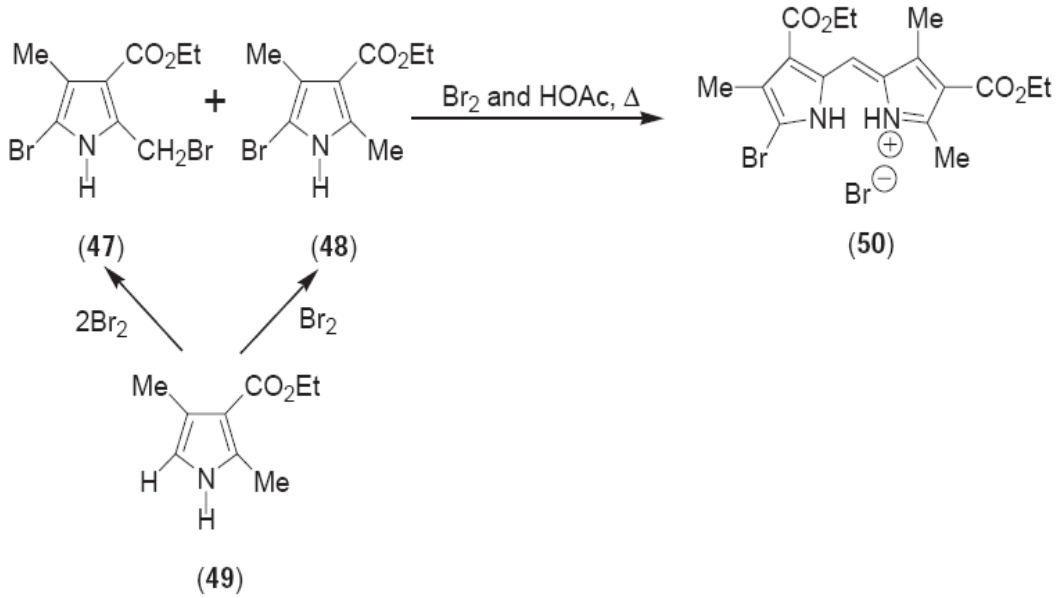


Figure 1.12 The preparation of unsymmetrical dipyrromethene hydrobromides.

1.1.3.1 *Using Dipyrromethanes*

1.1.3.1.1 Syntheses of Dipyrromethanes

Symmetrically substituted and unsymmetrical dipyrromethanes can be obtained by using a number of different approaches. Dipyrromethanes (e.g., **55** and **56**) which are symmetrically substituted about their meso- (i.e., 5-) carbon are obtained in moderate to good yield by self-condensation of bromomethylpyrroles (**57**) (obtained from the corresponding 2-methylpyrrole (**58**) by bromination) in hot methanol, **31** or by heating 2-acetoxymethylpyrroles (**59**) (obtained from the appropriate 2-methylpyrrole (**60**) by treatment with lead tetraacetate) in methanol containing a small amount of hydrochloric acid (to give (**56**)) (Fig. 1.13). 2-Unsubstituted pyrroles (e.g., **61**), upon treatment with formaldehyde, also give dipyrromethanes, e.g., **56** (Fischer et al., 1925).

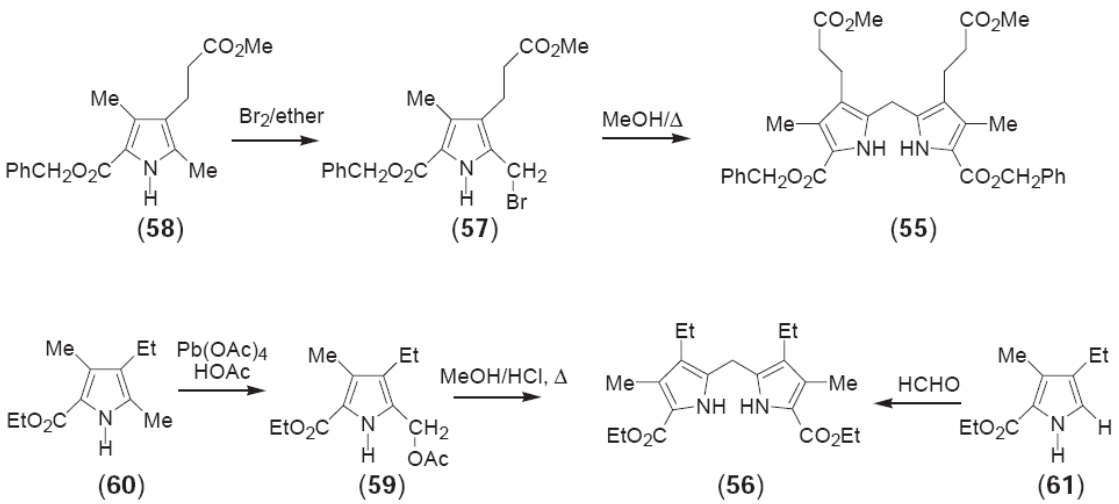


Figure 1.13 Dipyrromethanes.

Good yields of 5-substituted dipyrromethanes (e.g., **62**) are obtained by treatment of a 2-unsubstituted pyrrole (e.g., **63**) with dimethylacetals of aliphatic aldehydes in the presence of an acid catalyst (Fig. 1.14).

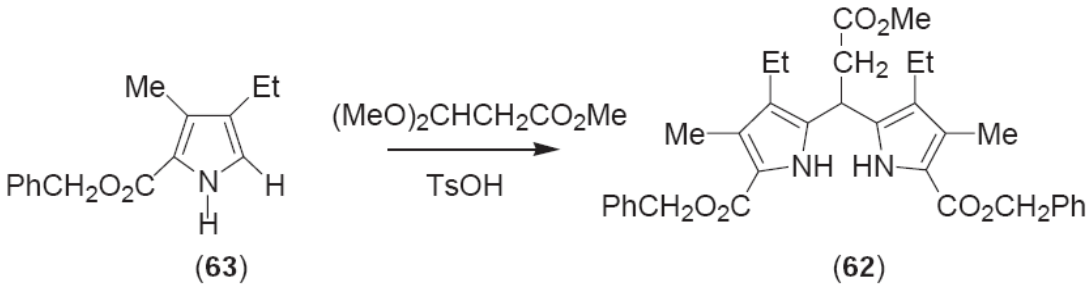


Figure 1.14 5-substituted dipyrromethanes.

The related 5-aryldipyrromethanes (e.g., **64**) can be prepared by treatment of an arylaldehyde (e.g., benzaldehyde) with excess 2-unsubstituted pyrrole (and even pyrrole **36**, itself) in the presence of an acid catalyst (Fig. 1.15).

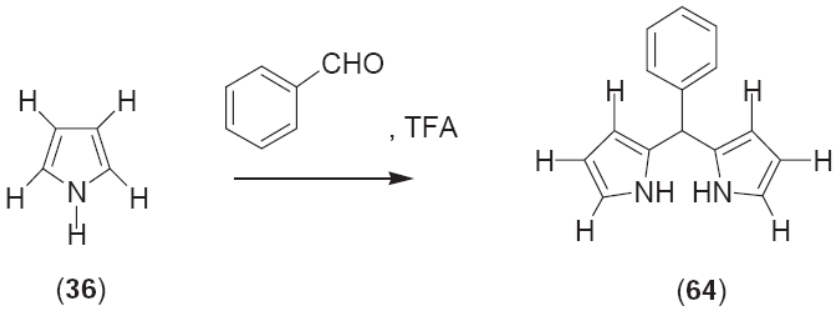


Figure 1.15 5-aryldipyrromethanes.

Dipyrromethanes, e.g., **65**, with an unsymmetrical arrangement of pyrrole substituents can be obtained in good yield by reaction of 2-acetoxymethylpyrroles (**66**) with 2-unsubstituted pyrroles (**67**) in methanol containing a small amount of toluene p-sulfonic acid (Fig. 1.16).

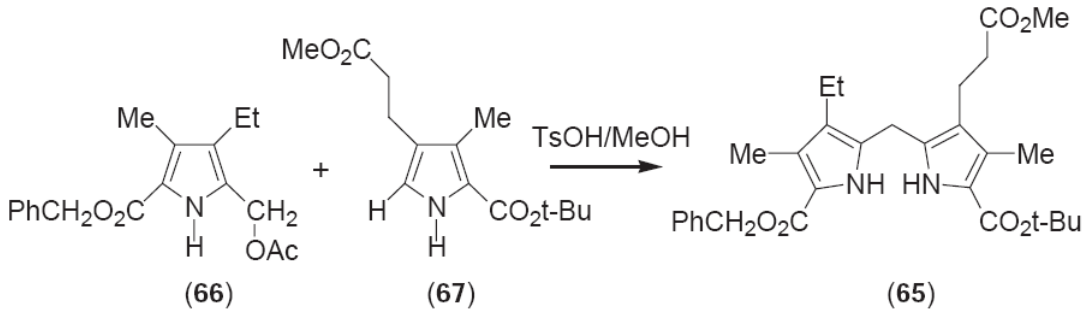


Figure 1.16 Dipyrromethanes, with an unsymmetrical arrangement of pyrrole substituents.

Alternatively, the same reagents can be heated in glacial acetic acid containing sodium acetate, or in glacial acetic acid alone. Acidic Montmorillonite K-10 clay has also been shown to be a very useful catalyst for syntheses of unsymmetrical (and symmetrical) dipyrromethanes from starting materials such as **66** and **67** (Freeman et al., 1999).

1.2 PORPHYRAZINE

Pc and Pz ligands can be modified through the partial replacement of the four pyrrole or isoindoline moieties (Elvidge et al., 1952). Core modified porphyrin compounds in which one or more of the pyrrole nitrogens is replaced by either a carbon atom or another type of heteroatom have been the focus of considerable research interest. This type of structural modification is less common in the Pc literature, however, due to the limitations imposed by the cyclotetramerization approach. Most of the research that has been carried out in this area involves the synthesis and characterization of AAAB compounds, typically referred to as three-quarters-phthalocyanines, and ABAB compounds, which are typically referred to as hemiporphyrazines (Fig. 1.17).

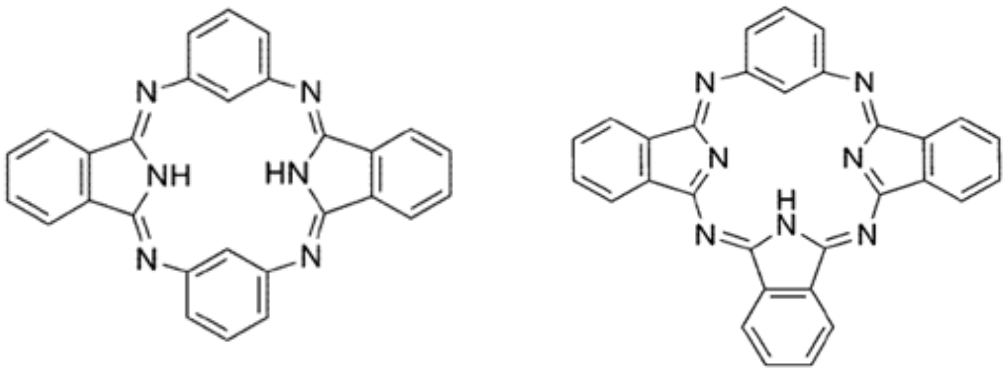


Figure 1.17 Molecular structures of dicarbahemiporphyrazine (left), an HPz, and *m*-benziphthalocyanine, a three-quarters-phthalocyanine (right).

In 1952, Elvidge and Linstead reported the first example of an HPz based on a cross-condensation of 2,6-diaminopyridine and 1,3-diiminoisoindoline to form an opp-di pyridine structure in which two of the isoindoline moieties of Pc are replaced by pyridines (Fig. 1.18).

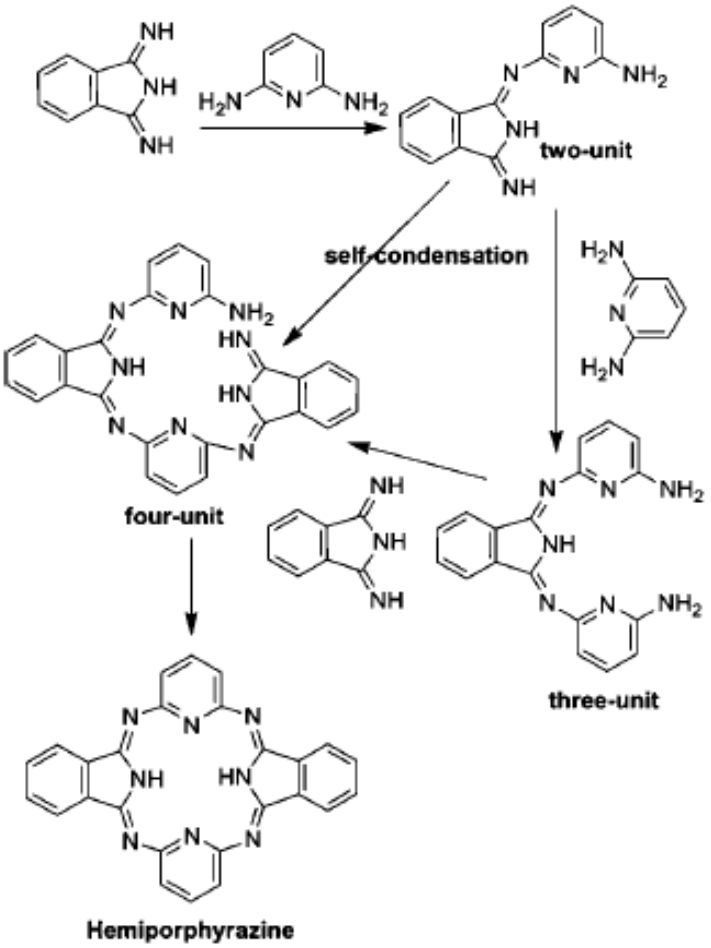


Figure 1.18 Formation of Hemiporphyrazines.

Almost simultaneously, Campbell applied for a U.S. Patent (Campbell, 1956). The synthetic strategy is analogous in concept to Idelson's subsequent patent for the selective formation of ABAB compounds (Fig. 1.19),

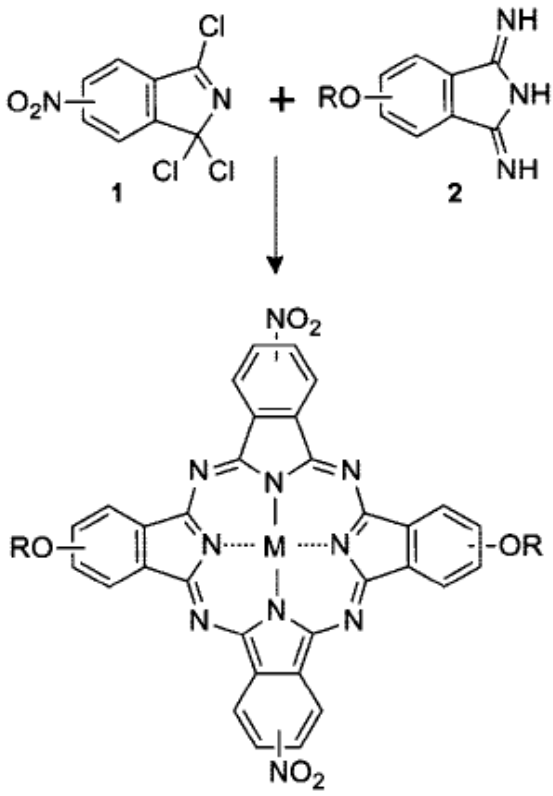


Figure 1.19 Selective Formation of an ABAB Structure from a Cross-condensation Reaction of 1,3,3-Cl-6-NO_2- Isoindolenine (1) and a 1,3-Isoindolediimine (2).

since the diamine compound can only react with the diiminoisoindoline precursor. The authors subsequently reported the formation of a series of free base macrocycles using 1,3-diaminobenzene, 2,7-diaminonaphthalene, 2,8-diaminoacridine, and 3,5-diaminopyridine.

1.2.1 Hemiporphyrazines

1.2.1.1 *Syntheses of Hemiporphyrazines*

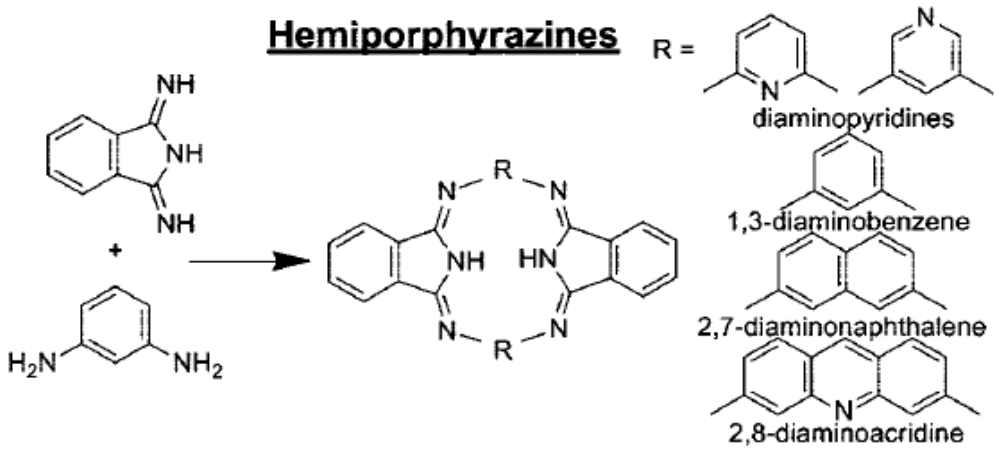


Figure 1.20 Synthesis of Hemiporphyrazines from a Series of Diamines.

Elvidge and co-workers also studied the synthesis of opp-di-*m*-benziphthalocyanine and explored the formation of metal complexes (Elvidge et al., 1952). Benziphthalocyanines are of particular interest in this regard, since organometallic complexes can be formed (Fig. 1.21).

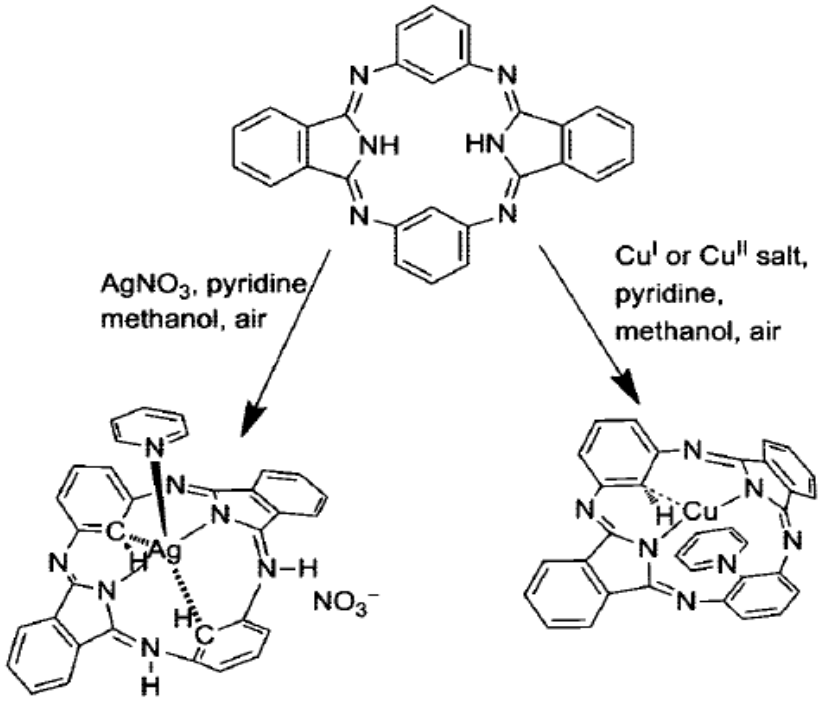


Figure 1.21 Synthesis of Dicarbahemiporphyrazine Metal Complexes.

Russian researchers subsequently reported a wide range of other HPz's based on the reaction of 1,3-diiminoisoindolines with 2,4-diamino-6-chloropyrimidine, 2,4-diamino-3-chloro striazine, 2,5-diaminothiadiazole, 2,7-diaminofluorene, 2,7-diaminophenylene sulfone, and 2,4-diamino-3,4-dicyanothiophene (Al'yanov et al., 1970). HPz's have recently been the subject of renewed interest by Ziegler and Durfee (Fig. 1.22).

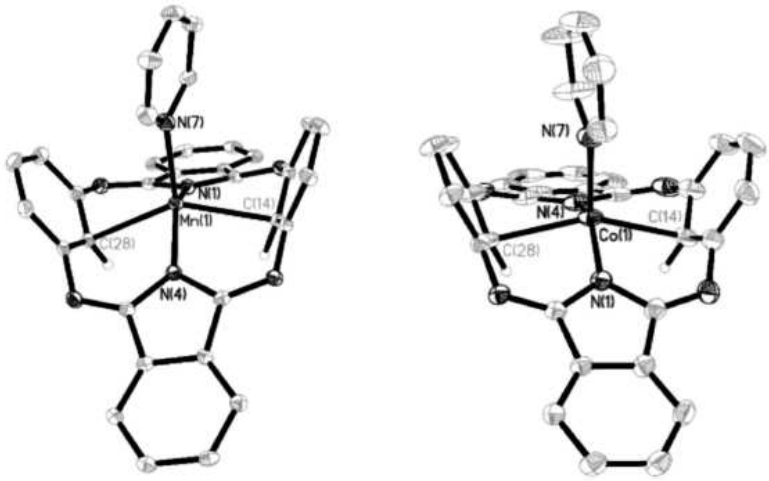


Figure 1.22 ORTEP diagrams of the Mn(II) and Co(II) complexes of dicarbahemiporphyrazine drawn at the 35% probability level. Hydrogen atoms are omitted for clarity except at the internal positions.

In 1957, Elvidge reported the synthesis of a threequarters- Pc with a benzene ring (*m*-benziphthalocyanine) based on a cross-condensation of 1,3-diaminobenzene and 1,3-diiminoisoindoline and a two step (3+1) synthetic strategy. Reaction of the -SCH_3 derivative of 1-imino-3-thioisoindoline with 1,3-diaminobenzene or 2,6-diaminopyridine results in the formation of three unit precursors, containing two isoindoles and one benzene moiety, which can then be reacted with 1,3-diiminoisoindoline (Fig. 1.23) (Elvidge and Golden, 1957).

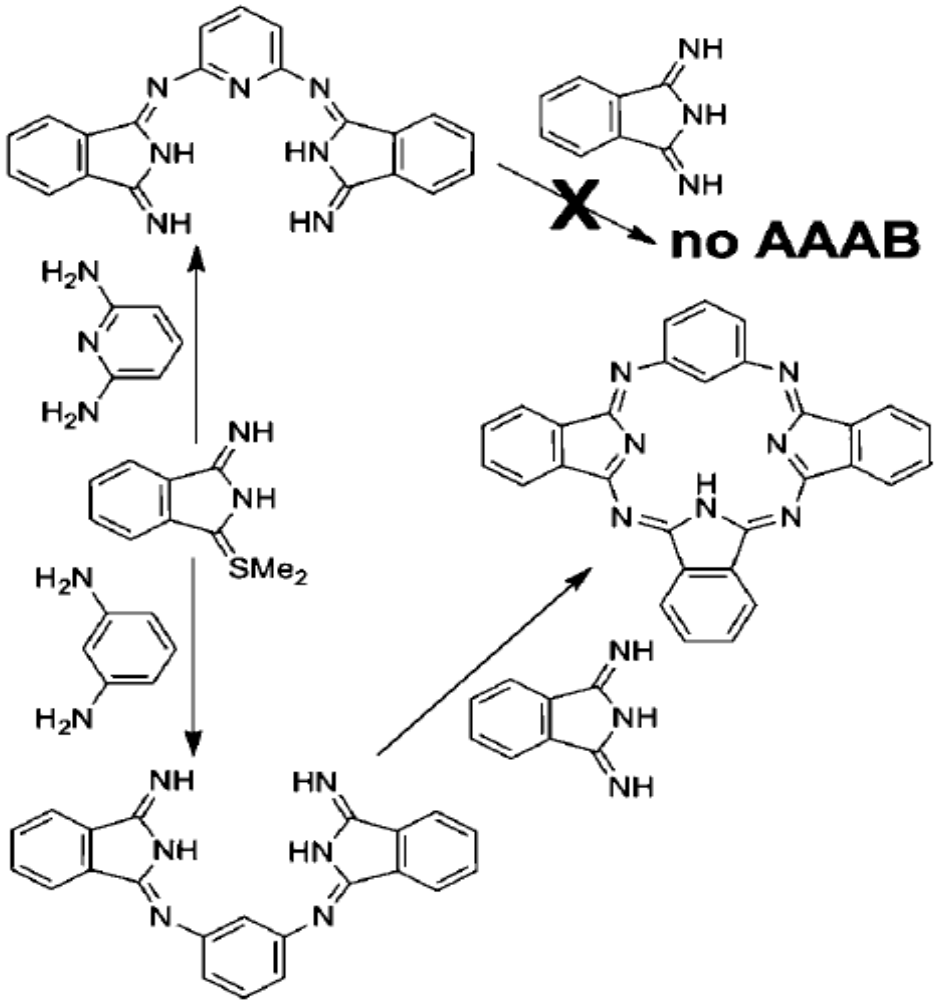


Figure 1.23 Formation of three unit structures.

Attempts to form a three-quarters-Pc compound containing a pyridine ring on this basis failed, as did attempts to form ABCB compounds because the three unit precursors split to form two unit compounds which preferentially undergo self-condensation to form symmetrical ABAB HPz products (Elvidge and Golden, 1957). In the late 1960s, Bamfield reported the first successful formation of a three-quarters-Pc containing a pyridine ring by using the Ni(II), Cu(II), and Au(III) complexes of a 2,6-bis(3′-imino-1′-isoindolinylidene amino)pyridine three unit. In the late 1980s, Torres and co-workers adopted this approach, building on earlier research by Russian researchers, to synthesize a wide range of 1,2,4-triazolephthalocyanines (Fig. 1.24)

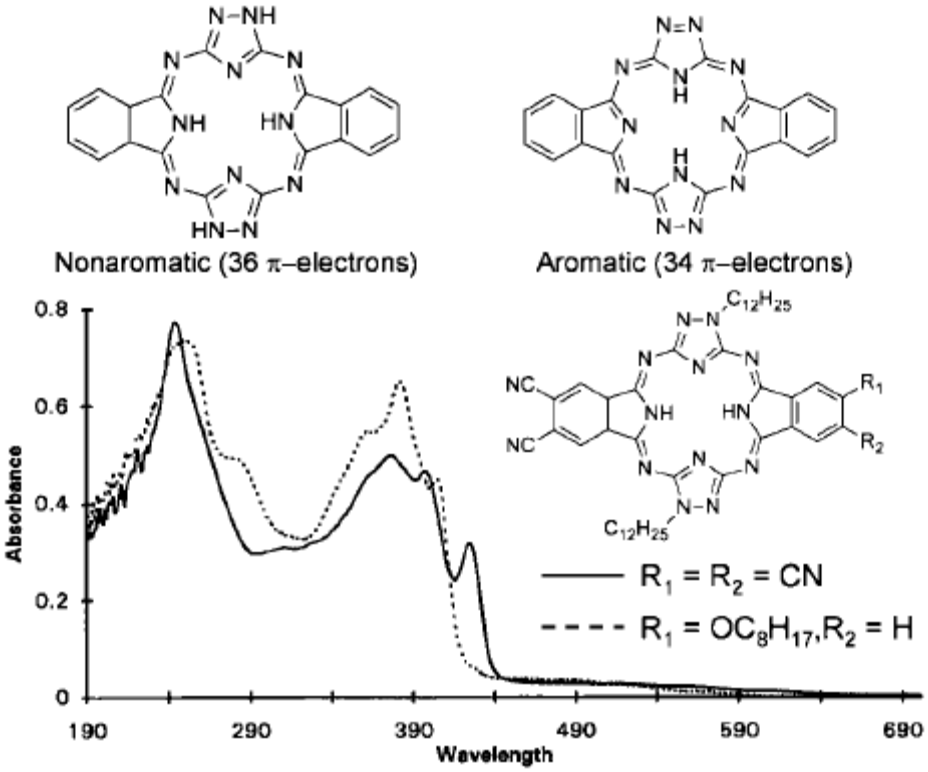


Figure 1.24 Non-aromatic and aromatic structures of triazolehemiporphyrazine (top). The non-aromatic structure is more stable due to instability arising from the structure that the triazole rings must adopt to enable aromatization. UV-visible absorption spectra of 8,21-didodecyl-2,3,14,15-tetracyanotriazolehemiporphyrazine (continuous line) and 8,21-octoxy-2,3-dicyanotriazolehemiporphyrazine (dashed line) in *ca.* 9×10^{-6} M $CHCl_3$ solutions (bottom).

and 1,2,4-triazoleporphyrazines, including many with ABCB structures. Cross-condensation syntheses were often also carried out. Torres and co-workers have reported that three unit precursors can also be combined to form ring expanded analogues with four isoindole and two triazole moieties. In 2001, expanded hemiporphyrazines with ABABAB structures containing three sets of alternating nitrogen and sulfur atoms at the core were reported by the Torres and Kobayashi groups based on a cross-condensation of 1,3-diiminoisoindoline and 2,5-diamino-1,3,4-thiadiazole. The ABABAB structure is believed to be energetically favored relative to a conventional ABAB structure due to the angles formed at the bridging nitrogen atoms. In recent years, Berezina and Vorob'ev have used a three unit precursor formed from 1,3-indandione and 2,5-diamino-1,3,4-thiadiazole to form HPz and three-quarters

phthalocyanine compounds with sulfur atoms replacing the metal coordinating pyridine nitrogen atoms of the parent HPz compound and carbon atoms replacing the pyrrole nitrogens. Peripheral pyridine and pyrazine rings have also been incorporated into the isoindoline moieties (Kulikov et al., 2004).

There is clearly scope for the synthesis of a very wide range of core modified HPz's. Given recent advances in Pc synthesis, the traditional hemiporphyrazine and three-quarters-phthalocyanine nomenclature for core modified ABAB and AAAB structures may prove to be inadequate. In recent years, Kobayashi and coworkers have reported the use of 1,8 dicyanonaphthalene as a precursor in conventional mixed condensations with phthalonitriles to form a series of compounds in which at least one of the five-membered pyrrole moieties of the Pc ligand is replaced by a six-membered ring. ABBB, AABB, and ABAB structures have been reported where A denotes the presence of a six-membered pyridine ring and B denotes an isoindoline moiety. Although AAAB and AAAA structures would normally be expected to form as well during mixed condensations (Fig. 1.25)

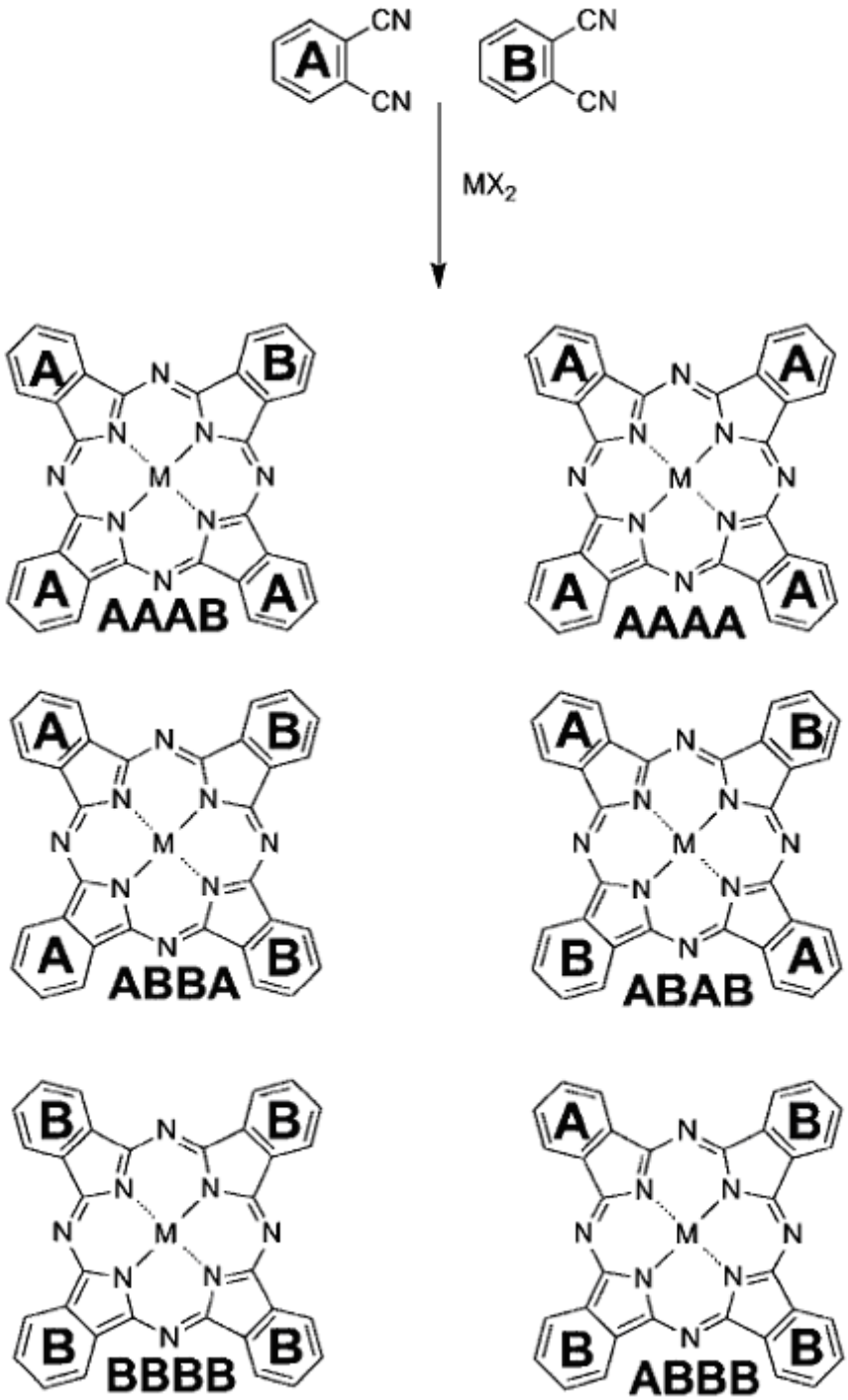


Figure 1.25 The products anticipated for a mixed condensation of two phthalonitriles A and B.

steric considerations probably prevent it in this context. The AAAB, AABB, and ABAB compounds are best described as core modified phthalocyanines, since they are formed

using the conventional cyclotetramerization approach to phthalocyanine synthesis and the AABB structure does not fit the existing nomenclature.

1.2.2 Seco-Porphyrazines

1.2.2.1 *Syntheses of Seco-Porphyrazines*

A second approach, which has been used to modify the π-system of Pz's at the peripheral bonds, involves partial oxidation rather than reduction to form *seco*Pz's (Nemykin et al., 2000). A *seco*Pz has been defined as being a Pz compound in which at least one of the outer peripheral pyrrole bonds has been broken and replaced by two acyclic substituents, which usually contain oxygen atoms (Fig. 1.26).

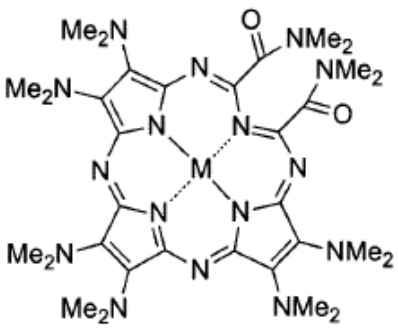


Figure 1.26 Molecular structure of 2,3,7,8,12,13,17,18-*octakis*-(dimethylamino)-2-*seco*Pz-2,3-dione.

In 1999, Barrett and Hoffman and co-workers reported the formation of a free base *seco*Pz, during standard Linstead condensation reactions of maleonitrile derivatives (Fig. 1.27)

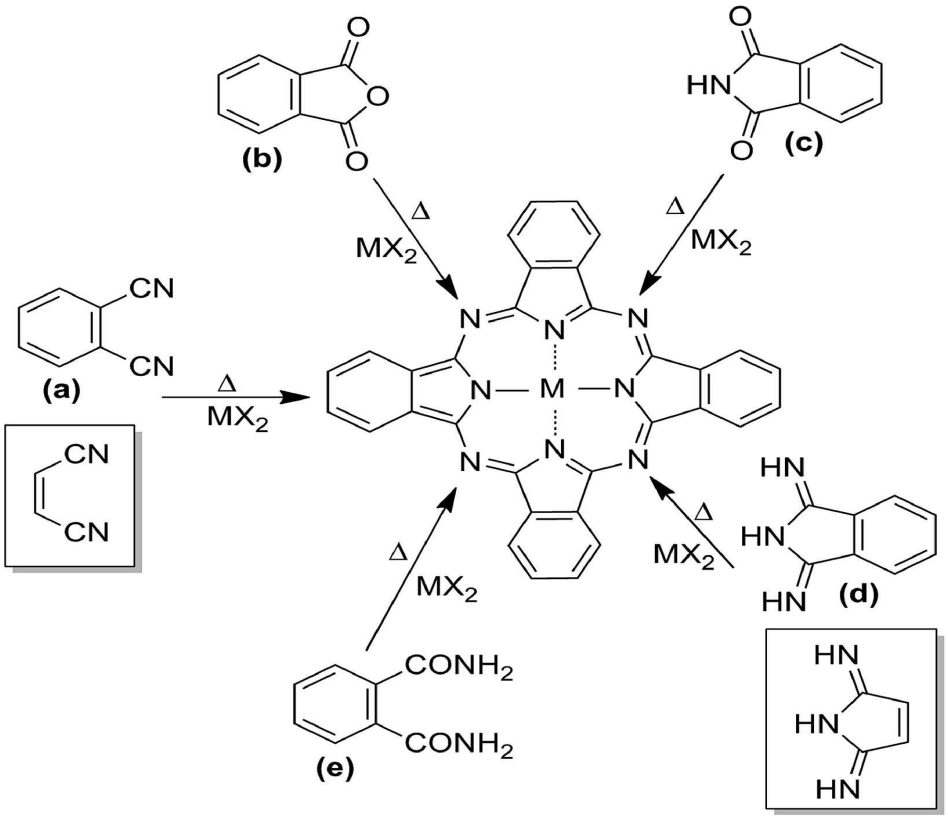


Figure 1.27 Phthalocyanine precursors include (a) phthalonitriles, (b) phthalic anhydrides, (c) phthalimides, (d) 1,3-diiminoisoindolines, and (e) phthalamides. The equivalents for (a) and (d) in porphyrazine synthesis (INSET) are maleonitriles and 2,5-diiminopyrrolines, respectively.

containing two *n*-BuS- or –NMe_2 substituents. A side product had earlier been noticed during the formation of star porphyrazines, which contain eight metal ligating S-substituents. When this was investigated in depth, it was found to only occur when the reaction was carried out under aerobic conditions. The presence of strongly electron donating substituents such as -NMe_2 results in electron rich double bonds on the ligand periphery, which can readily react with singlet oxygen (Fig. 1.28).

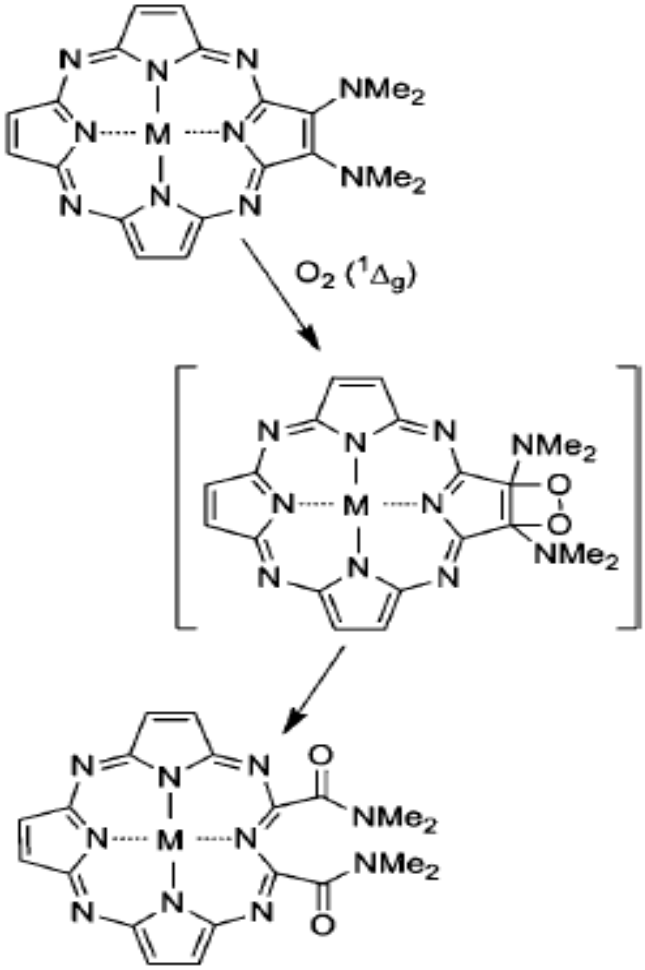


Figure 1.28 Mechanism for *seco*-ZnPz formation.

Further studies demonstrated that metal complexes can be prepared and that AAAB, ABAB, and AABC *seco*Pz structures can also be formed (where A, C, and B denote substitution of pyrroles with alkyl and -NMe_2 groups and the pyrrole moieties which are disrupted, respectively) based on oxidation of the products from mixed condensations. More recently, Gonca and co-workers have reported the synthesis of *seco*Pz's based on the presence of eight-4-biphenyl, 1-naphthyl, and *t*-Bu-phenyl substituents (Gonca et al., 2008)

1.3 PHTHALOCYANINE

Phthalocyanins (Pcs) can not be found in nature but was discovered accidentally in1907 during preparation of o-cyanobenzamide from phthalimide and acetic acid at the South Metropolitan Gas Company in London, (Fig. 1.29a) (Braun and Tcherniac, 1907).

Further discoveries of metallated derivatives of Pcs were made starting with de Diesbach and von der Weid in 1927 (Dandridge et al., 1929). The structure of Pc remained unknown till (Linstead et al., 1955),who used the technique of elemental analysis, molecular mass determination, and oxidative degredation which gave phtalimide to indicate that Pc is a symmetrical macrocycle having four isoindoline units and Robertson (Robertson and Woodward, 1940) in 1934, (Fig. 1.29) The word “phthalocyanine” (Pc) originated from the combination of Greek terms for naphtha (rock oil) and for cyanine (dark blue) was used for the first time by Linstead of the Imperial College of Science and Technology in 1933 to describe a symmetrical macrocycle composed of four iminoisoindoline units where the pyrrole groups are conjugated to benzene rings and bridged by aza nitrogens ($C_{32}H_{16}N_8$) , (Fig. 1.29)

Figure 1.29 H_2Pc (**a**) and MPc (**b**).

Pc is a general name for benzannulated derivative of tetraazaporphyrin or porphyrazine. There are mainly two types of Pcs, metal-free phthalocyanine (H_2Pc) and metallated phthalocyanine (MPc) as described in (Fig. 1.29) The specific Pc compound, H_2Pc, whose structure is seen in (Fig. 1.29), is the simplest Pc possible where the macrocycle contains no metal and there are no special substituents on the periphery of the Pc ring. Other members of the Pc family can differ from H_2Pc in either or both of these respects. Pc can be formed complex with a metal at the center of the molecule called metallo-phthalocyanine (MPc), (Fig. 1.29b). Metallated Pcs are formed by substituting the hydrogen atoms in the center of the compound with metal ions, mostly in the +2 oxidation state. When a metal cation is introduced to the Pc molecule, the macrocycle exists as dianion (Pc^{2-}) and can be oxidized or reduced to different oxidation states (Leznoff and Lever, 1996).

A Pc molecule consists of a central cavity that can accommodate different metal ions. Introduction of metal cations (e.g. Fe^{2+}, Zn^{2+}, Co^{2+} etc.) into the central cavity of Pc molecule influences its physical properties greatly. The photophysical properties of Pcs are also strongly influenced by the central metal ion. Complexation of Pcs with an open shell or paramagnetic metal ion such as Cu^{2+} ,Co^{2+}, Fe^{2+}, Ni^{2+}, Cr^{3+} or Pd^{2+} results in shortening the excited state lifetimes due to the effects of the unpaired electron(s), which in turn makes the compounds photo inactive. Pcs containing a closed *d* shell or diamagnetic metal ion, such as Zn^{2+}, Al^{3+} and Ga^{3+} have high triplet state quantum yields ($\varphi_T > 0.4$) with longer life-times ($\tau_T > 200$ μs) .

Many metal atoms can fit exactly into the central cavity without destruction of the planar structure of the Pc; however, some metal ions are too large to be accommodated in the central cavity of the Pc, causing distortion of the planar (Ziolo, 1981). Like the porphyrins as in (Fig. 1.30), Pcs are a class of tetrapyrrolic (TP) macrocyclic compounds, have bivalent, tetradentade, planar, 18 π-conjugated electron aromatic ring systems. Porphyrins, have four methine bridges (—CH=) linking the individual four pyrrole units. In contrast, Pcs are composed of four pyrrole units, linked by four aza (—N=C—) groups at the α-carbon of pyrrole unit and they have four aza bridges and four phenylene rings (Leznoff and Lever, 1996, Ziolo, 1981). The periphery of the macrocycle is also extended by fused benzene rings, which enhance the absorption at longer wavelengths compared to porphyrins very strong, absorption peak in the far red region of the visible spectra.

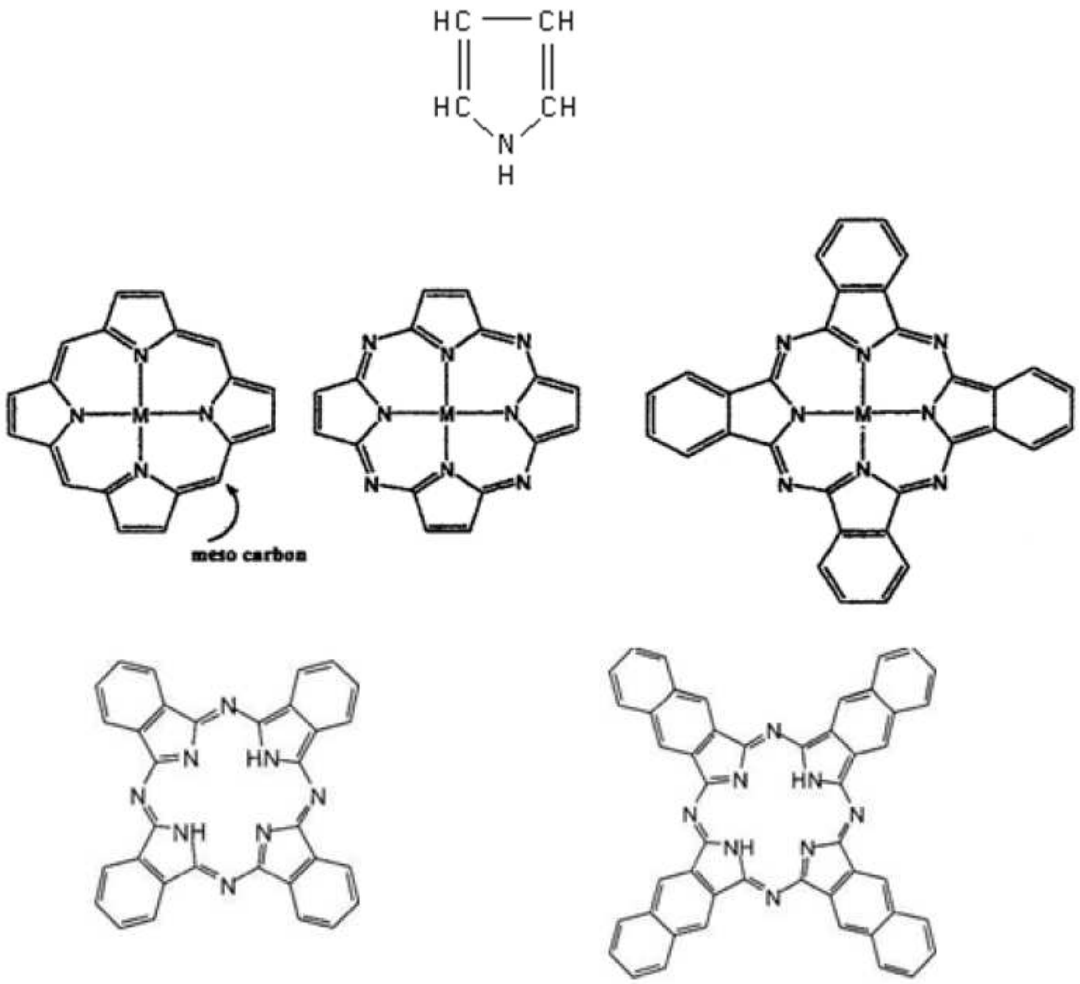


Figure 1.30 TP macrocycles; pyrrole unit, unsubstituted porphyrine, porphyrazine, MPc, H_2Pc, and NPc.

Between the time frame of the years 1930-1950, the full elucidation of the Pc chemical structure was determined and its X-ray spectra, absorption spectra oxidation and reduction, catalytic properties, magnetic properties, photoconductivity, and many more physical properties were investigated. As a result of these studies, it was concluded that Pcs are highly colored, planar 18 π-electron aromatic ring systems similar to porphyrins into the central cavity of which more than 70 different metal ions have been incorporated (Leznoff and Lever, 1996) as in (Fig. 1.30).

Since the discovery of the phthalocyanines, the main focus of the chemists has been on tailoring of their properties to produce molecular materials for previously targeted medical or technological applications. Thus many efforts are geared towards

the synthetic strategies in order to increase the range of possible molecules. The intense blue-green color of phthalocyanines is due to the electronic delocalization of their 18 π electrons. This made them to be initially utilized industrially as dyes and pigments in various fields.

Since then, their outstanding and tailorable properties such as liquid crystallinity (**24**–**26**), generation of singlet oxygen (**27**–**30**) and redox properties (**31**,**32**) have enhanced their use as efficient agents in several high technology applications including: photodynamic therapy, a technique for which phthalocyanines are currently the most promising class of compounds (**33**–**43**), for photodynamic antimicrobial chemotherapy (**44**–**47**), as sensors (**48**–**51**) including biosensors (**52**,**53**), for non-linear optical applications (**54**–**59**), dye sensitized photovoltaic production (**60**–**63**), semiconductor materials (**64**,**65**), oxidation or reduction catalysts and photocatalysts (**66**–**68**) among others. Their combination with nano-materials (quantum dots, nano-tubes, liposomes, dendrimers) (**69**–**74**) may efficiently enhance the desired properties.

The intrinsic structure of these compounds makes them, when unsubstituted, insoluble in nearly all the solvents. However appropriate substitution pattern helps to overcome this problem. Indeed, the flexible points for a chemist aiming at synthesizing soluble phthalocyanines are the substitution pattern (macrocyclic and/or axial) as well as the choice of the metal (Fig. 1.31). The introduction of one or two nitrogen atoms on the isoindole sub-units (the corresponding tetrapyridinoporphyrazine and pyrazinoporphyrazine derivatives being commonly designated as azaphthalocyanines (**75)**) is another point allowing for the tailoring of properties. Water solubility is a quest for many chemists in various fields, as several of the current applications of phthalocyanines are of biological interest and/or require environment friendliness, necessitating water solubility in various concentration, pH, etc. ranges. This is the case of biological and medical applications such as photodynamic therapy. Another very important application of water-soluble phthalocyanines is the catalysis of reactions in aqueous media, the main one being the degradation of pollutants. Catalysis of reactions in aqueous media is currently becoming of major interest **76**. Thus, when designing a phthalocyanine on demand for a specific application, or to get a precisely targeted property, its water solubility may be a requirement.

A first historical approach for using phthalocyanine in aqueous media was to formulate insoluble phthalocyanines mainly with the preparation of emulsion **77** or incorporation in water soluble polymers, covalently **78**, by weaker interactions **79** or by dialysis procedure (**70**,**80**). Conferring intrinsic water-solubility to phthalocyanines is based on two main strategies: ionic substituents or strongly hydrophilic ones, commonly carbohydrates or polyethylene glycol. Water-soluble phthalocyanines are not systematically used in aqueous solutions. Some phthalocyanines that are not water-soluble may become so after bonding to some polymers (**81**,**82**). In order to limit the scope of this review, and as the water-solubility is not an intrinsic property of the phthalocyanines, they will not be mentioned here. In this review, we will overview the synthesis of the reported water-soluble phthalocyanines: anionic, cationic or non-charged.

It is important at this point to define the water-solubility we are speaking about. Many of the applications said to require water soluble phthalocyanines will in fact occur in aqueous medium, for example buffered solutions. Such media are considered to belong to our topic. The phthalocyanine macrocycle is a hydrophobic system: to make it water-soluble, hydrophilic moieties must be added, and the resulting system will be more or less amphiphilic. Its water solubility depends on its overall amphiphilic balance, and as well on other parameters such as aggregation, the "nature" of the aqueous medium in terms of pH **83**, ionic strength, and presence of a co-solvent **84** among others.

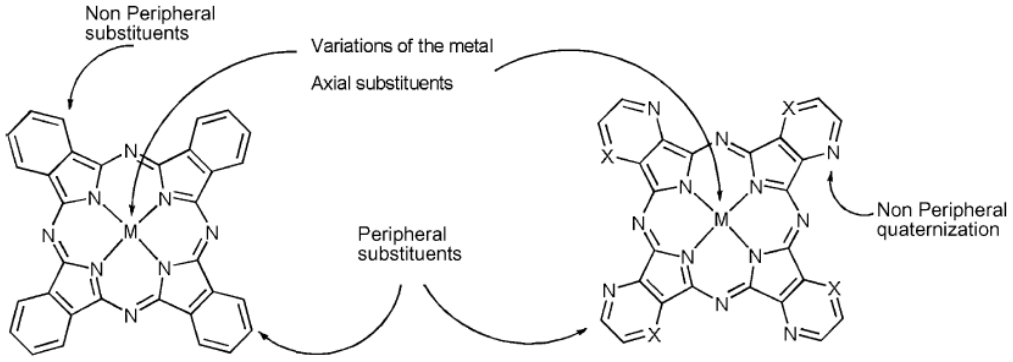
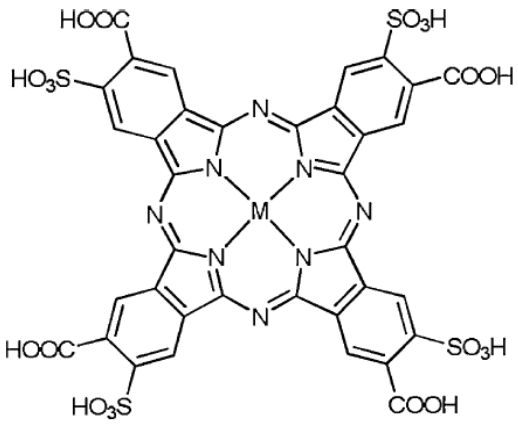


Figure 1.31 Modulable points of phthalocyanines.

1.3.1 Anionic Water-Soluble Phthalocyanines

Anionic substituents commonly utilized to confer water solubility to phthalocyanines are sulfonate, carboxylate, phosphorus-based functions, attached directly on the macrocycle or borne by various spacers. Their water-solubility is strongly pH-dependent, the conjugated acid forms of these groups being not necessarily water-soluble. The reported phthalocyanines bear usually only one type of these functions, with the notable exception of **1** (Fig. 1.32) which bears concomitantly two of the most common functions: sulfonic and carboxylic acids.

Some metallated unsubstituted phthalocyanines can axially complex cyanide ions (**86–88**). This allows the solubilization of these unsubstituted phthalocyanines (when metallated by metals such as Fe, Ru and Os) in aqueous KCN or NaCN solutions, as a result of the formation of water-soluble complexes bearing axial cyanide (**89**–**91**).



1

M: Cu, Co, Zn, Fe(OH)

Figure 1.32 Phthalocyanine **1** substituted by carboxylic and sulfonic acids.

1.3.2 Cationic Water-Soluble Phthalocyanines

Cationic groups are obtained by the quaternization of aliphatic or aromatic nitrogen atom. The quaternization occurs at the end of the synthetic pathway, on the

formed phthalocyanine. The nitrogen atom which will be quaternized is present during the phthalocyanine formation in the form of an amine or pyridine derivative, or can be part of the macrocycle itself (case of the tetrapyridinoporphyrazines). A few examples describe its introduction on a previously formed functionalized phthalocyanine. As far as we could find out, both types of cationic quaternized phthalocyanines: alkyl or aromatic, were described concomitantly for the first time in 1989, slightly preceded by quaternized tetrapyridinoporphyrazines. A special chapter will be devoted to the quaternization of the nitrogen atom belonging to the macrocycle of azaphthalocyanines (tetrapyridino and tetrapyrazinoporphyrazines).

1.3.3 Non-ionic water-soluble phthalocyanines

Several types of non-ionic substituents are also able to confer water-solubility to phthalocyanines. They can be divided into three main types: polyethyleneglycol, carbohydrate substituted phthalocyanines and other polyhydroxylated substituted derivatives.

1.3.4 Ultraviolet and Visible Spectra of Pcs

Pcs contain a highly conjugated aromatic p system (Leznoff and Lever, 1996). H_2Pcs and MPcs possess intense color arises from the unique property of having a single band located in the far end of the visible spectrum near 670-730 nm, termed the Q-band, with an average molar absorptivity (ε) of 10^5 L $mol^{-1}cm^{-1}$ (van Lier, 1988) is shown in Fig.1.33. In addition to that, there is another absorption in the Ultra Violet (UV) region between 320 and 370 nm, denoted the Soret band (B-band). These bands are formed because of the transitions between the following orbitals during the transitions. The Q-band absorption pattern was assigned to the p-p* transition from highest occupied (p) molecular orbital (HOMO), of a_{1u} symmetry, to the lowest unoccupied (p*) molecular orbital (LUMO) of e_g symmetry. The left side of the region

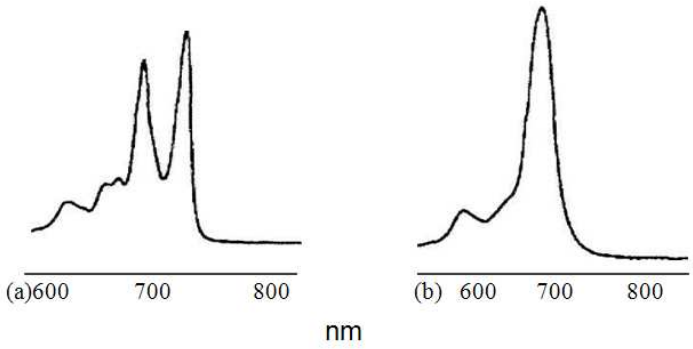


Figure 1.33 Typical absorption spectra of (a) H_2Pc and (b) MPc in the Q-band.

Figure 1.33 represents the ground state of a typical MTP macrocycles showing the two top most filled bonding p-orbitals (a_{1u} and a_{2u}) and the empty $e_g(p^*)$ orbital. The transition $a_{1u} \rightarrow e_g$ and $a_{2u} \rightarrow e_g$ are responsible for the intense Q and B (Soret) bands of the UV-visible spectrum (Leznoff and Lever, 1996). Their absorption spectra are characterized by one to two very strong absorptions between 670 and 730 nm as stated in Fig. 1.33 shows typical absorption spectra of H_2Pc and MPcs in the Q-band region. The characteristic intense blue (or blue-green) color of Pcs results from the Q-band absorption, which is quite sensitive to the environment of the Pc macrocycle and substitution pattern on the Pc ring. For example, unsubstituted H_2Pc possesses D_{2h} symmetry whereas MPc belongs to D_{4h} symmetry. The reduced symmetry of H_2Pcs is responsible for the split Q-band obtained from the absorption spectrum in Fig. 1.33a (Leznoff and Lever, 1996).

1.3.5 Solubility of Pcs and Aggregation Phenomenon

Pcs possess high thermal and chemical stability (Leznoff and Lever, 1996, Ziolo and Extine, 1981); however, their applications are limited due to poor solubility in polar and non-polar solvents. That is why, there are many different types of modifications that can be applied to the macrocycle by either adding functional groups at the peripheral or non-peripheral sites of the benzo ring or by introduction of different central ions. Some of these modifications can distort the planar structure of Pcs, which may greatly improve solubility (Ziolo and Extine, 1981).

Pcs containing alkali metals in the central cavity, the ions protrude from the plane of the Pc ring, resulting in a disruption of the p stacking (Leznoff and Hail, 1982) between the macrocyles. Therefore, enhanced solubility in polar organic solvents is observed with alkali metal derivatives such as Li_2Pc or Na_2Pc. In addition to this, as stated above adding substituents to the periphery of the Pc increases their solubility since these substituents contribute to an increase in the distance between the stacked macrocyles and enable their solvation (Leznoff and Hail, 1982), (Fig. 1.34) As has been previously mentioned, unsubstituted Pcs are extremely insoluble in most common solvents. In order to increase the solubility and to improve the physical, chemical and electronic properties of the Pc macrocycle, a seemingly endless number of functional groups and substitutions have been added to the Pc framework via covalent attachment to benzene rings on the periphery of the macrocyde.

A careful consideration of the functional groups added to the Pc can be used to fine-tune the properties of the macrocycle, leading to compounds with heightened characteristics for a certain application. Simple functional groups such as alkyl chains, higher order aromatics, ethers, amines, thiols, halides and various acidic groups have been used to improve pure solubility and pure characteristics of Pcs. More exotic substituents including crown ethers, dendrimers, ferrocenes and tetrathiafulvalenes lend other properties to the macrocyle that may enhance their activity and utility in various applications. Polynuclear Pc systems have also been prepared in order to synthesize novel organic materials, new chemical catalysts and high temperature polymers. Although a maximum of sixteen substituents can be added to the periphery of the Pc macrocycle, the most commonly synthesized Pcs contain only four or eight substituents. Symmetrically octasubsituted Pcs are usually less soluble than their tetrasubstituted analogues, since the latter are synthesized as a mixture of four isomers, which results in a lower degree of order in the solid state and hence increased solubility. Metal cations with an oxidation state of (+1) can also be incorporated into the central cavity. The bonding between the central metal atom with a (+1) oxidation state (Li^+ , K^+, Na^+ etc.) and the four nitrogen atoms of the macrocycle is considered to be electrovalent in nature, characterized by its ionic character and relative weakness. The central nitrogen atoms can ligate two M^+ atoms, (as in Fig. 1.34). However, in this case, the central nitrogen atoms ligate two ions. Since both of these cations cannot be accommodated in the central cavity, the metal ions protrude from the plane of the Pc ring. Pc and other

alkali metal derivatives possess high solubility in polar organic solvents. Due to the strong covalent and coordinate covalent bonding, Fig. 1.34, between the Pc and the metal ion, the metal cations cannot be removed without destruction of the macrocycle.

There are two types of possible bonding: electrovalent and covalent. According to X-ray analysis, the central metal atom with a (+2) oxidation state is bonded to two nitrogen atoms by covalent bonds and to the other two nitrogen atoms by coordinate covalent bonds, (Fig.1.34)

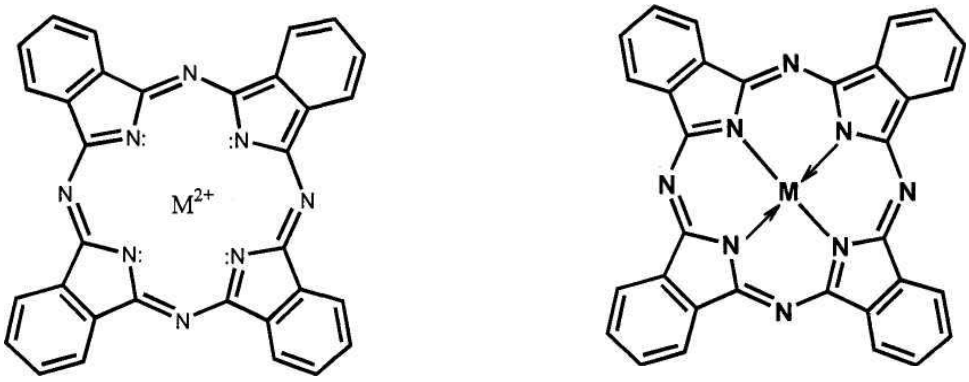


Figure 1.34 Central metal atom (M)-ligand bonding in Pc.

Enhanced solubility of the Pc ring is also seen with higher oxidation-state metal ions (larger than +2). These metal ions can accommodate an axial ligand that distorts the planarity of the Pc macrocycle, enhancing the solubility of the Pc (Ziolo and Extine, 1981). The strong bonding between the central metal ion and the Pc ring results in the formation of a highly stable adduct that can be prepared from various synthetic routes as indicated in Fig. 1.34. Pcs solubility can be greatly improved by placing substituents on the Pc ring either peripheral or non-peripheral sites and introducing metal ion to the central cavity (Leznoff and Lever, 1996, Leznoff and Hail, 1982). These modifications on Pc ring cause the absorption spectra to shift longer wavelengths in UV-Vis region, as shown in Figure 1.33. Pcs possess an extended p-conjugated electron system which permits p-stacking (aggregation) between planar macrocycles, provided the distance between the macrocycles is small. It is this intermolecular interaction between the macrocyles that causes Pcs to be virtually insoluble in common organic solvents and thus limits their applications (Leznoff and Lever, 1996).

The poor solubility of Pcs may arise, in large part, from the strong molecular association due to the p-p* interactions among the macrocyclic rings.

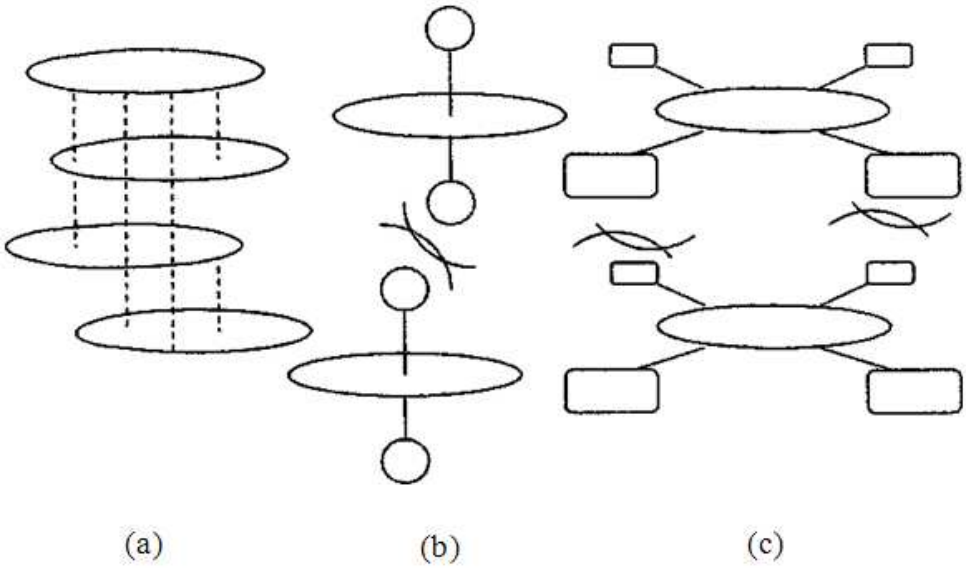


Figure 1.35 (a) Pcs are stacked together by the π- π* interactions. The π - π* stacking tendency is reduced by the attachment of (b) axial ligands or (c) bulky substituents onto the periphery of the macrocyclic core.

As expected the macrocycle possesses a poor solubility in common organic solvent and is highly aggregated. This aggregation phenomenon hinders both the purification and characterization processes. This aggregation phenomenon has a substantial influence on the spectral properties of Pcs. For example, aggregation usually induces a blue-shift of the Q band of Pcs from ca. 670 to 620 nm and a broadening of a signal. The introduction of naphthoxy substituents not only enhances the lipophilic character of the molecule, but also prevents its molecular aggregation in solution for steric reason, potentially resulting in superior photophysical characteristic enhanced PDT properties. Naphthoxy substituents molecule has synthesized recently. Characterization by proton nuclear magnetic resonance ^{1}H NMR spectroscopy is also difficult for aggregated Pcs. The concentration for ^{1}H NMR (usually at least 10^{-4} M) studies is too high to prevent aggregation and this will lead to a broadening of the ring proton's signals. To overcome these undesirable effects, appropriate substituents (Leznoff and Lever, 1996, Leznoff and Hail, 1982) are introduced to the macrocycle to increase the separation of Pc molecules, thereby reducing the aggregation tendency and increase the solubility of Pcs in water and most organic solvents. The most common

approach used to overcome this problem is to functionalize the peripheral benzo units with various substitutents which can interact with the solvent (Leznoff and Lever, 1996, Leznoff and Hail, 1982). Depending on the nature of these substitutents, the Pc can become either water soluble (ie: SO_3H groups) or soluble in organic solvents (i.e.: neopentoxy groups).

In general, substituents can be introduced to the axial positions or the periphery of the macrocycle. In order to prevent these undesirable effects, the attachment of axial ligands to the central metal ion of MPcs or peripheral bulky substituents can enhance the solubility and weaken to face-to-face intermolecular interactions. Bulky substituents can be introduced either at the 3- or 4-position of phthalonitriles, (Fig. 1.35). t*ert*-Butyl group is one of the most commonly used bulky fragments to prevent aggregation (Mikhalenko et al., 1971). The other commonly used group is tetra-substituted Pcs which were first prepared by Luk'yanets et al. Tetra-substituted Pcs since being as a mixture of four positional isomers, of C_s, C_{2v}, C_{4h}, and D_{2h} symmetries, in a statistical ratio of 4:2:1:1, which results in a lower degree of order in the crystal lattice and enhances solubility of the Pcs. HPLC technique is used to differentiate isomers from each other.

1.3.6 Photosensitizers for PDT

In contrast to porphyrins, they have stronger absorptions in the red visible region which allows a deeper light penetration into tissues. These applications for Pcs as a photosensitizer in PDT are generally related to their high stability and efficient light absorption ability in the visible and near-infrared region of the optical spectrum. They also possess favorable photophysical and chemical properties which can be altered through the incorporation of appropriate substituents either on the periphery of the macrocycle or at the axial positions linked to the metal centre. However, Pcs tend to aggregate which will shorten the excited state lifetimes and decrease the singlet oxygen quantum yield by dissipating the energy through internal conversion is shown in (Fig. 1.36).

This problem can be overcome by incorporating large and bulky substituents. PDT is a treatment utilizing a photosensitizer, visible or near-infrared radiation and O_2

to destroy unwanted cells. PDT is a modern therapeutic method for the treatment of cancer, macular degeneration and infectious diseases. It relies on the fact that certain dyes, after being injected into body, can accumulate and cause localized cellular damage upon excitation by visible light of suitable wavelength and power. Thus, photosensitizers which can preferentially bind to tumors, viruses, bacteria, fungi, and parasites are able to destroy these biological contaminants that infect body tissues as a result of light activation. Illumination on photosensitizers may induce a photochemical reaction that results in tissue destruction.

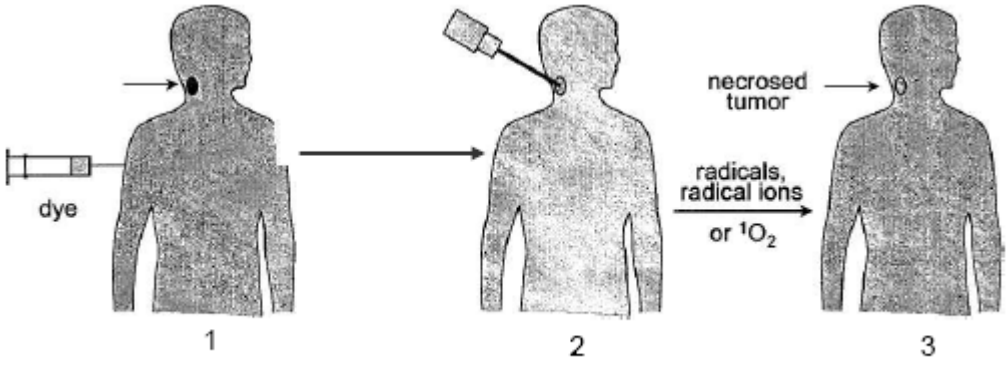


Figure 1.36 Essential steps in PDT.

A figure showing different stages and the essential steps in photodynamic therapy is given in Figure 1.36 and in Fig. 1.37. The basic steps in PDT are to (1) introduce into the patient a photosensitizer which shows selectivity for the unwanted cells, (2) wait a period of time (several hours to several days depending on the properties of the photosensitizer and the type of cells to be killed), and (3) irradiate the unwanted cells with light whose wavelength is matched to the absorption of the photosensitizer. Step 2 allows the photosensitizer to distribute between the various biological compartments and to accumulate in the unwanted cells. Step 3 leads, with the engagement of O_2, to cytotoxic oxygenated products through various photophysical pathways, and these lead to cell damage and death as stated in Fig. 1.36. The processes which can be described by the Jablonski diagram in photodynamic therapy are illustrated schematically in detail in (Fig. 1.37).

Upon excitation by light, the sensitizer is transformed from its singlet ground state S_0 to an electronically excited singlet state [S_1, (τs) = 10^{-6} s)], which can undergo

either a fluorescence emission or a non-radiative decay. It can also undergo an ISC to the excited triplet state [T_1, (τ_T)= 10^{-2} s)], which is important for the photodynamic action.

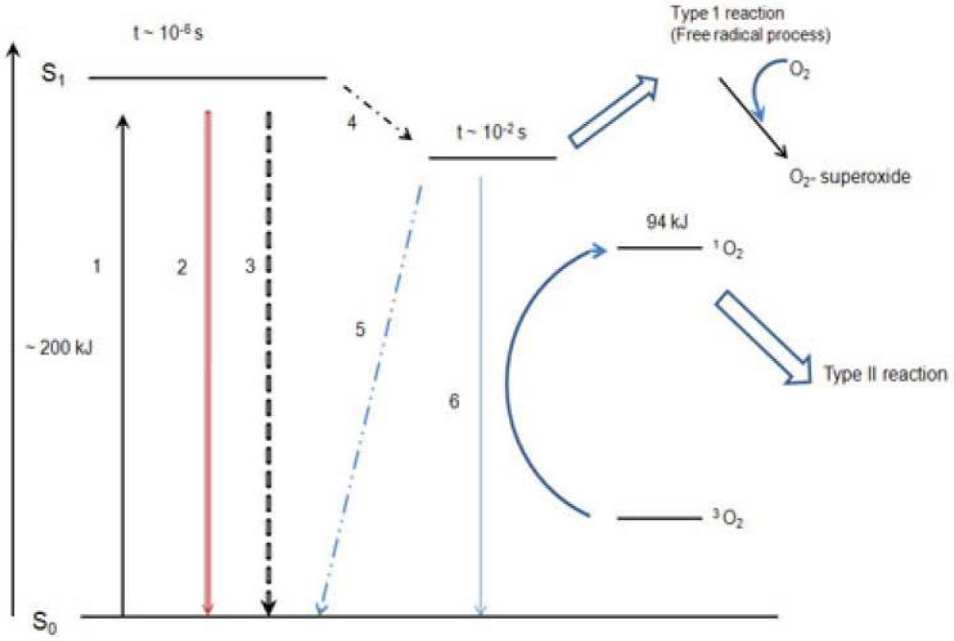


Figure 1.37 Modified Jablonski diagram showing the generation of reactive dioxygen species 1. Absorbtion, 2. Non-radiative Decay, 3. Fluorescence, 4. Intersystem Crossing, 5. Phosphorescence, 6. Energy Transfer.

High singlet oxygen quantum yield is one of the requirements for achieving an effective destruction of tumor cells. It is well-known that the efficiency of generating singlet oxygen can be greatly enhanced by using heavy atom substituents or coordination with certain close-shell transition metal ions. Zinc and aluminum Pcs for example, usually exhibit a relatively high singlet oxygen quantum yield. The excited triplet state can be relaxed to the ground state by interaction with oxygen in two pathways. First it can participate in an electron-transfer process to form oxygenated species such as superoxide ion O^{-2}. This is so-called Type 1 mechanism.

In Type 2 mechanism, the triplet state undergoes an energy-transfer process resulting in the formation of the short-lived but highly reactive singlet oxygen ($^1O_2$), which is a powerful, fairly indiscriminate oxidant that reacts with a variety of biological molecules. It is generally agreed that singlet oxygen is the main cytotoxic agent for cellular damage and the photodynamic therapy proceeds mainly by the Type 2

mechanism. It is explained in detail in the following section. It is shown in Figure 1.37 and Figure 1.38.

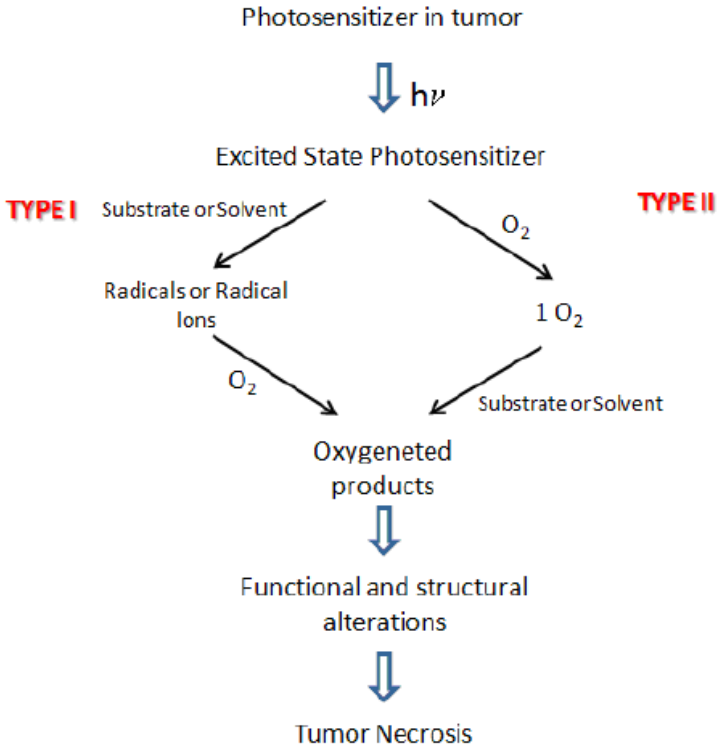


Figure 1.38 Mechanisms prospect for PDT.

1.3.7 Electrochemistry

Since the first electrochemical studies of porphyrins, an interest in Pcs, their sister compounds, has been expressed. However, the number of studies about the redox properties of porphyrins grew much faster. The closeness of these macrocycles to some enzyme sites had implications for the interest in their electrochemical properties, but another factor has also played a big part in the difference of activity between the fields, and that is the much lower solubility of Pcs; the more sulfonated compounds were the first to be studied by electrochemistry. The lack of Pc solubility also influenced other physicochemical studies, of course, but was also of a great importance for the purification and the characterization of the compounds. The influence of the pure solubility and purity of Pcs on their physicochemical studies is still apparent in the published works, but is less important now because the synthetic chemistry of Pcs has developed in recent years, so that modified and more soluble macrocycles are now

available. These substituted Pcs have different properties, and particularly modified redox behavior, which justifies their electrochemical study.

Although the chemistry of porphyrins is much richer, potentialities of the Pcs in the field of applications, as precursors of materials, are more promising, because of their robustness, their chemical, thermal and photochemical stability, which made them successful as dyes (Leznoff and Lever, 1996). Electrochemistry is appropriate technique to look at the molecular orbital energy levels of the molecules which are at the origin of their spectral properties, and of their capacity to accept or give electrons.

CHAPTER 2

FLUORINATED TETRAPYRROLE COMPLEXES

2.1 FLUORINATED PORPHYRINE DERIVATIVES

The one of the bestelectron-donating materials for photovoltaics seems to be porphyrins and phthalo-cyanines because their photovoltaic properties can be designed by suitable structural modification. Thus a lot of attention is put on the basic photo physical properties of these dyes. Such investigations are needed in searching for good organic dyes that could beused in a new generation dye-sensitized photo- device based on covalent electron-donor–acceptor systems. This was investigated phthalocyanines substituted with fluorine or chlorine atoms and was showed the occurrence of resonance effects which influence the dye's electronic and photocurrent properties (Siejak and Wrobel et al., 2006).

2.1.1 A Convenient Preparation of 2,3,5,6-tetrafluoro-4-iodo-benzaldehyde and Its Application in Porphyrin Synthesis

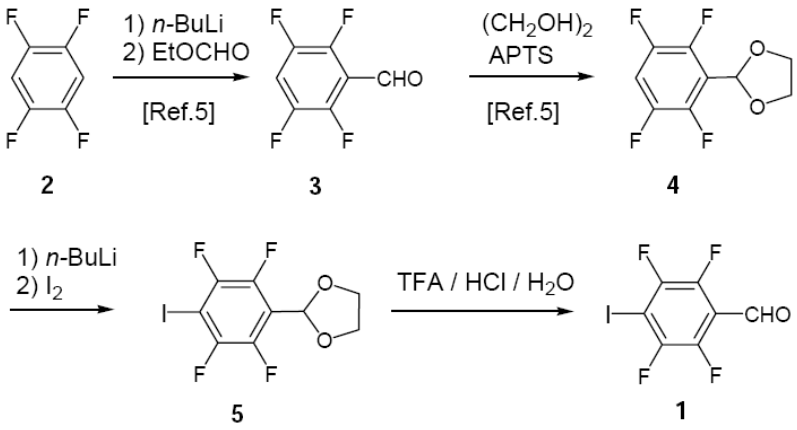


Figure 2.1 The synthesis of 2,3,5,6-tetrafluoro-4-iodo-benzaldehyde.

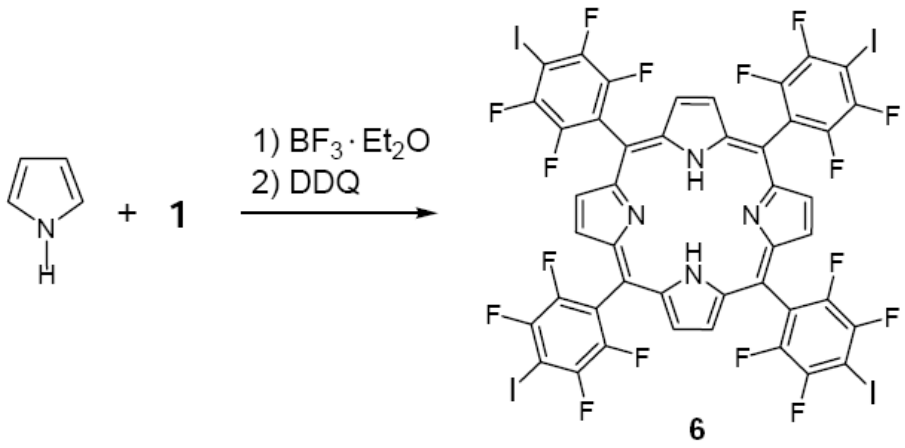


Figure 2.2 The synthesis of the porphyrin **6**.

The crystal structure of **1** consists of linear polymeric chains, seemingly suggesting the O…I intermolecular bonding as the directing interaction (Fig. 2.3).

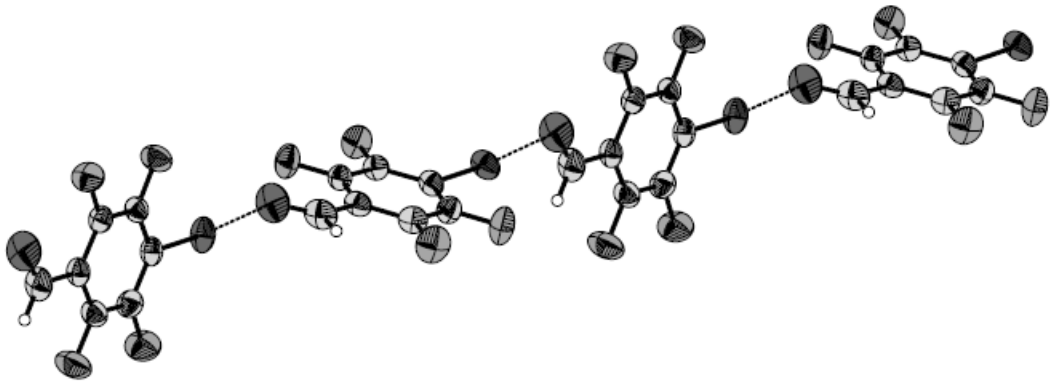


Figure 2.3 One-dimensional chain fragment of aldehyde **1** with non-covalent O… I bonds as the directing interaction.

To our knowledge, it is the first time that such a interaction between an aldehyde function and a iodoperfluorocarbon has been reported. Both the carbonyl oxygen and the iodine are involved in the halogen bonding as terminal lone pair donor and the most exposed electron acceptor site, respectively.

This conclusion can be drawn from the O…I distance (2.95 Å) which is significantly shorter (by ca. 17%) than the sum of the van der Waals radii of oxygen and

iodine (Bondi, 1964). The nearly linear arrangement of O…I–C (O–I–C angle = 175.9°) is consistent with the n → σ^* character of the halogen bonding (Foster, 1969). The observed values are within the range of the values reported in the literature for noncovalent O…I–C bonds. 4-Iodobenzaldehyde, the hydrogen analogue of **5**, shows also non-covalent halogen bonding with only a slightly longer O …I distance (3.07 Å).

2.1.2 Photovoltaic and spectroscopic studies of selected halogenated porphyrins for their application in organic solar cells

Molecular photovoltaic and optoelectronic devices basedon organic materials are much cheaper and easier to fabricate than the existing inorganic systems. In photovoltaics the organic devices exhibit much less efficiency when compared to conventional inorganic ones, however, a new generation of the organics is stil a subject of wide investigations. The perfect agents for molecular photovoltaics should be organic dyes with the π-electron systems as electron donors that could generate photocurrent. The one of the bestelectron-donating materials for photovoltaics seems to be porphyrins and phthalo-cyanines because their photovoltaic properties can be designed by suitable structural modification. Thus a lot of attention is put on the basic photo physical properties of these dyes. Such investigations are needed in searching for good organic dyes that could beused in a new generation dye-sensitized photo- device based on covalent electron-donor–acceptor systems. In our previous papers we investigated phthalocyanines substituted with fluorine or chlorine atoms and we showed the occurrence of resonance effects which influence the dye's electronic and photocurrent properties. Therefore in this paper we focus our attention on the studies of selected porphyrins i.e., dyes with the p-electron systems. It was previously shown that the p-electron systems are responsible for generation of light-induced current. In this paper we investigate three porphyrin dyes: free base tetraphenylporphyrin (TPP) and two porphyrin dyes substituted with fluorine atoms or chlorineones by the use of spectroscopic examinations to follow all radiative and non-radiative transitions occurring in the dye molecules after photon excitation, which could compete with photocurrent processes generated in a photoelectrochemical cell (PEC) sensitized by the dyes. The photoelectric investigations are correlated with spectroscopic studies and the results were discussed in terms of mesomeric and steric effects occurring in the substituted dyes. Thus, in the paper we

present absorption, fluorescence, photoacoustics and photothermal relaxation of excitation to follow singlet and triplet state behavior. As far as we know, in this contribution the photothermal studies have been done for the first time for fluorinated and chlorinated porphyrins and we have evidently showed that the dyes under investigations could be good agents for the new generation donor–acceptor systems for an organic solar cell.

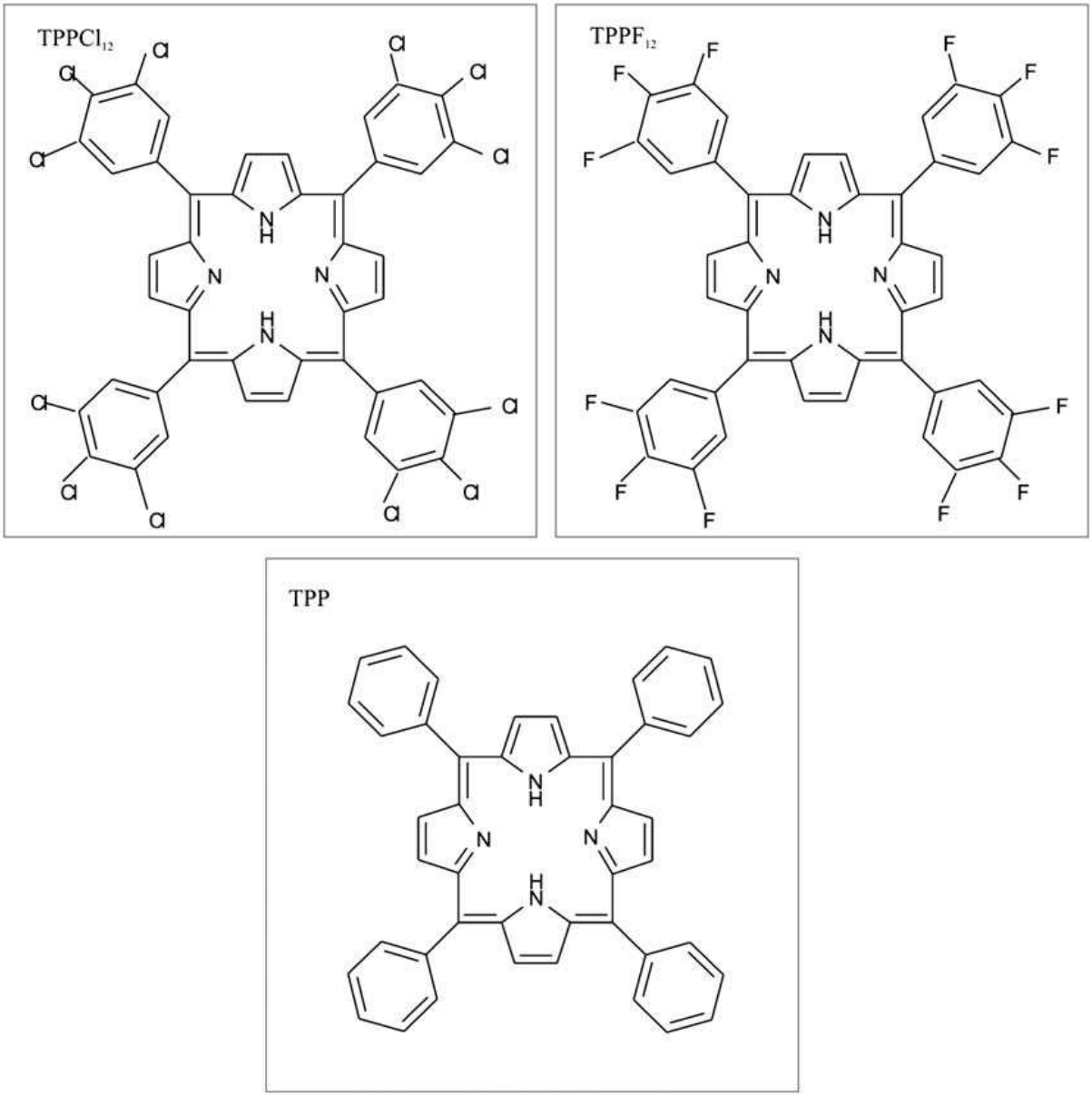


Figure 2.4 Molecular structures of the investigated dyes: TPP, $TPPCl_{12}$ and $TPPF_{12}$.

2.2 FLUORINATED PHTHALOCYANINE DERIVATIVES

For many years, phthalocyanine compounds (Pcs) have been widely used in the area of organic pigments and dyestuffs. Besides the application in traditional area, Pcs have recently been used as optical storage media in compact discs and as photoconducting medium in photocopying machines (Kobayashi, 1999). Their exceptionally high thermal and chemical stability have provoked research in other fields, including photocatalysis, electrocatalysis and as chemical sensors, semiconductors, nonlinear optical (NLO) devices, photodynamic therapy (PDT) (Iliev and Alexiev et al., 1999). The solubility of Pcs becomes very important for these applications, since many Pcs are poorly soluble in organic solvents and water, because Pcs are both large and flat, which make the molecules stack easily.

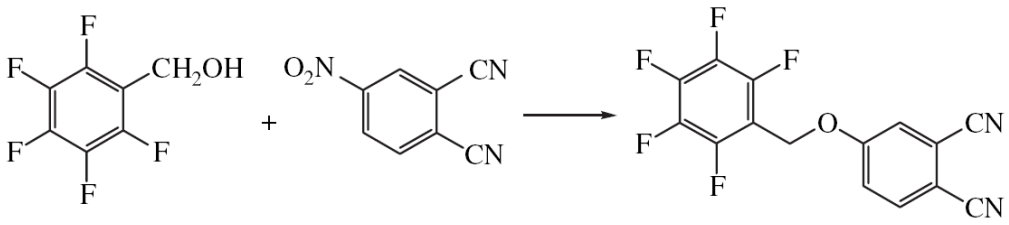
2.2.1 Novel Phthalocyanines with Pentafluorobenzyloxy-Substituents

Phthalocyanines are well known colorants; besides their intense colour and efficient energy absorption, more remarkable properties have been discovered due to their 18 π-electron conjugated system. On the other hand, phthalocyanines (Pcs) are also interesting compounds with increasing diverse industrial and biomedical applications including semiconductors, catalysts, chemical sensors, liquid crystals, nonlinear optics and electrochromic displays (Tabata and Fukushima et al., 2000). The exceptional chemical and physical properties of these compounds can be due to various substituents on the benzo rings. The range of solubility in phthalocyanines becomes very important for these applications, since many Pcs are poorly soluble in organic solvents and water. The solubility of Pcs can be enhanced by adding different kinds of substituents such as bulky or long chain alkyl, alkylthio or alkoxy groups at the periphery and axial positions of the phthalocyanine ring (Wie and Huang et al., 2003). The most extensively investigated soluble substituted phthalocyanines are the tetra- and octasubstituted derivatives and tetrasubstituted ones exhibit usually a higher solubility. The formation of constitutional isomers and the higher dipole moment of the tetrasubstituted phthalocyanines resulting from the unsymmetrical arrangement of the substituents in the periphery leads to a higher solubility of these systems.

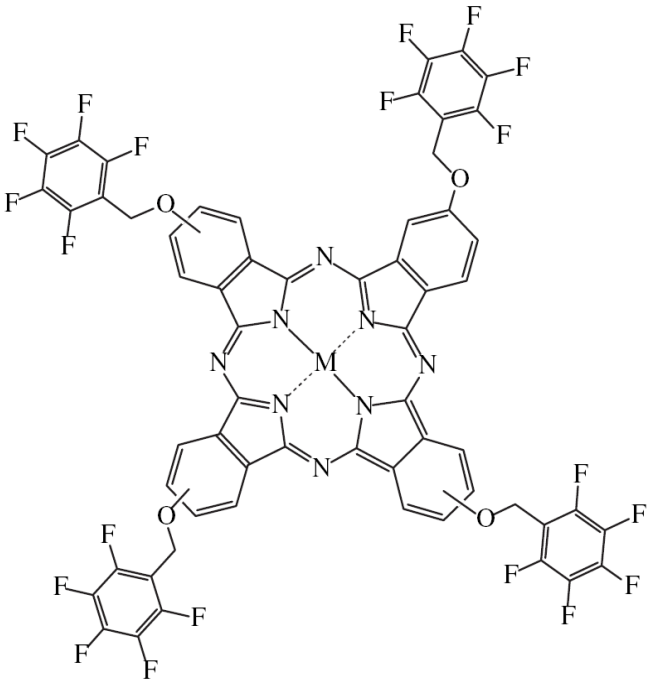
Although phthalocyanines carrying electron-donating substituents have frequently been described, those with electronwithdrawing groups especially containing fluorine atoms have not been extensively studied (Li and Zhang et al., 2006). Compared to unsubstituted parent metal phthalocyanines (Pcs), some of the metal complexes with multiple electron-withdrawing peripheral substituents are more stable and more active catalysts for a variety of hydrocarbon oxygenation reactions. The high stability of the substituted metal complexes may be attributed to the electron-withdrawing substituents at the periphery of the macrocycle that cause a large increase in the ionization potential of the system and thus protect the catalyst from oxidative destruction.

Fluorinated metal phthalocyanines are currently receiving a great deal of attention due to their interesting electron-transporting characteristics (Koca and Şener et al., 2005).

While unsubstituted phthalocyanines exhibit p-type behaviour due to the doping with electron-accepting molecules, thin films of some metal hexadecafluoro-phthalocyanines the electrical properties of Pcs, which are known as semiconducting organic materials, can also be changed by introducing substituent groups effective on Pc p-electron ring. Among these introduction of electron donor and acceptor groups into the Pc ring can be exhibit n-type behaviour. These properties resulted in a number of studies aiming at different applications like photovoltaic cells, rectifying junction and gas sensors. Generally, fluorosubstituted phthalocyanines are known for their high solubility even in polar, aprotic solvents and become good electron donor for use as chemical sensors. The increased solubility may be due to fluorine, which has the highest electronegativity of all elements. In the case of crown ethers as substituents, the molecules possess the capability of forming ion channels allowing the migration of alkali and alkaline-earth cations. A consequence of incorporating a sulfanyl function on the periphery has been a shift of the Q band absorption to longer wave-lengths in the electronic spectra (Yılmaz and Koçak et al., 2004) and it is preferred for a number of applications such as far-IR absorbers and photosensitizers.



2,3,4,5,6-Pentafluorobenzyl alcohol + 4-nitrophthalonitrile → 4-(2',3',4',5',6'-pentafluorobenzyloxy) phthalonitrile



M= 2H, Zn^{+2}, Ni^{+2}, Co^{+2}

Figure 2.5 Synthesis rote of novel phthalocyanines with pentafluorobenzyloxy-substituents.

2.2.2 Functionalized Polyfluorinated Phthalocyanines

Fluorinated metal phthalocyanines form a class of coordination compounds which are currently receiving a great deal of attention due to their interesting electron transporting characteristics (Kol'tsov and Basova et al., 2004). Also, fluorocarbons exhibit increased thermal stability, hydrophobicity, lipophobicity, chemical resistance and decreased intermolecular attractive forces in comparison to their hydrocarbon analogues.

Reaction of various nucleophiles with meso-tetra(pentafluorophenyl) porphyrine led to the selective replacement of the para-fluorine substituents of the starting porphyrin in high yields. The para-fluoro group is known to be reactive toward nucleophilic substitution reactions. The substitution regioselectivity was always quite high only at the para-fluorine of the pentafluorophenyl groups (Keown and Hanif et al., 2002). We have recently described the synthesis of metal phthalocyanines which contain tetra-pentafluorobenzyloxy moieties on the periphery. Various functionalized polyhalogeno compounds are prepared by regioselective substitution of the para-fluorine atoms by several nucleophiles such as primary and secondary amines, alkoxides and thiols (Suziki and Shimiza et al., 2003). The present paper reports the synthesis and characterization of some new metal phthalocyanines containing four covalently attached hexylthio-groups on the periphery of the tetrakis(pentafluorophenyl) moieties by regioselective substitution reactions. These new compounds have been characterized by elemental analysis, FT-IR, ^{1}H NMR, ^{19}F NMR, UV-vis and mass spectral data.

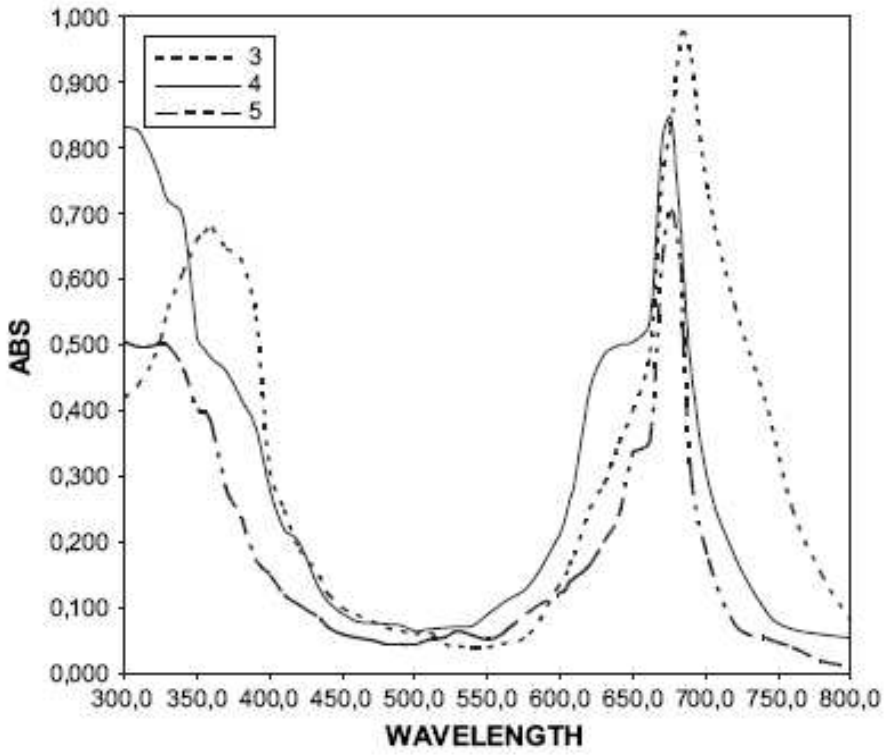


Figure 2.6 UV-Vis spectra for the phthalocyanines in chloroform (2.5×10^{-5} mol dm^{-3}).

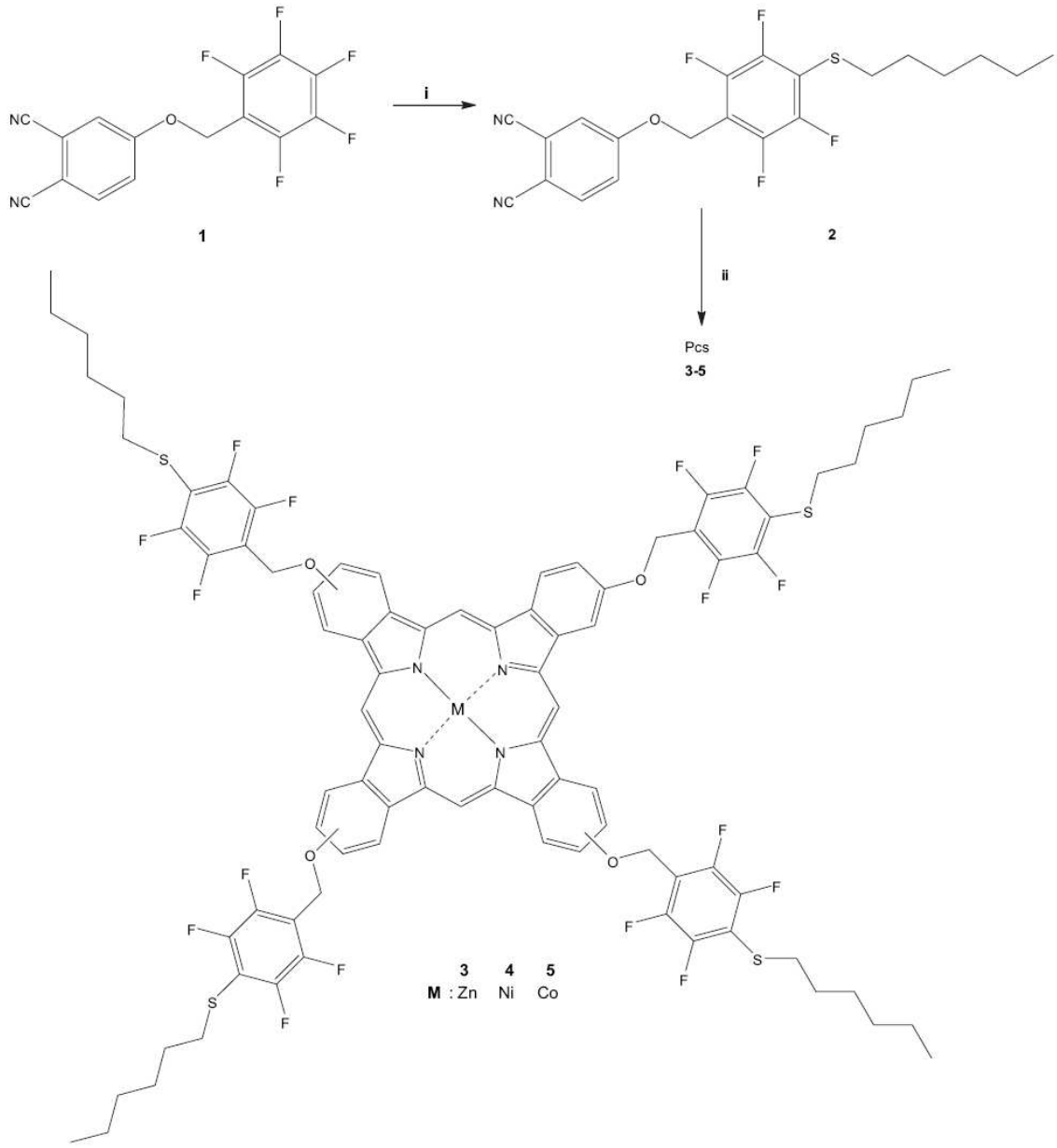


Figure 2.7 Synthesis route of the phthalonitrile derivative **2** and the phthalocyanines (**3**-**5**); (i) hexanethiol, DMF and K_2CO_3; (ii) metal salts and DMF.

New metallophthalocyanines substituted with four para-hexylthio-tetrafluoro-phenoxy groups were described. These compounds show high solubility in solvents of differing polarity from ethanol to acetone, chloroform, hexane. Hexylthio-substitution resulted with a red shift of Q band maxima in these phthalocyanines. These materials deserve further research on their catalytic and photoelectric properties.

2.2.3 Water-Soluble Fluorinated Zinc Phthalocyanine

Zinc hexadecafluorophthalocyanine ($ZnF_{16}Pc$) is a hydrophobic compound and it selectively accumulates in tumors (Boyle and Lier, 1996). However, its photodynamic effect is quite low (Boyle and Lier, 1996). Although the reason for its low photodynamic effect is not clarified yet, it is known that aggregated compounds decrease photodynamic activities suggesting that the phthalocyanines may be aggregated in cells. With the aim of developing a compound that has the beneficial characteristics of phthalocyanines as well as adequate photodynamic effect, zinc tetracarboxyoctafluorophthalocyanine (ZnC_4F_8Pc, see Fig. 2.9) was synthesized in this study. To prevent the potential aggregation condition, the number of fluoro groups is limited, and to increase hydrophilicity carboxyl groups are bonded. Uptake of the compound in tumor cells was measured and the relationship of its photodynamic efficiency and hydrophobicity are discussed.

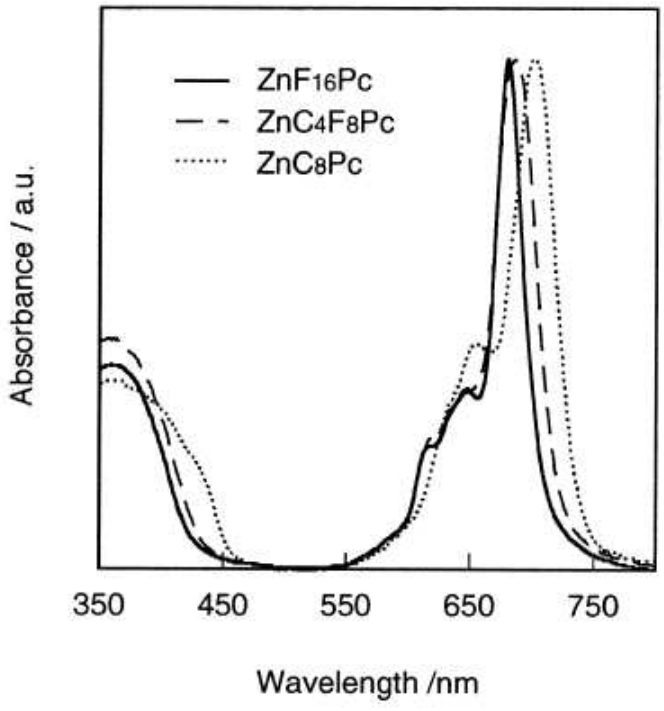


Figure 2.8 Absorption spectra of $ZnF_{16}Pc$, ZnC_4F_8Pc and ZnC_8Pc in pyridine. The concentration of zinc phthalocyanine was $2.3x10^{-6}$ mol/ l.

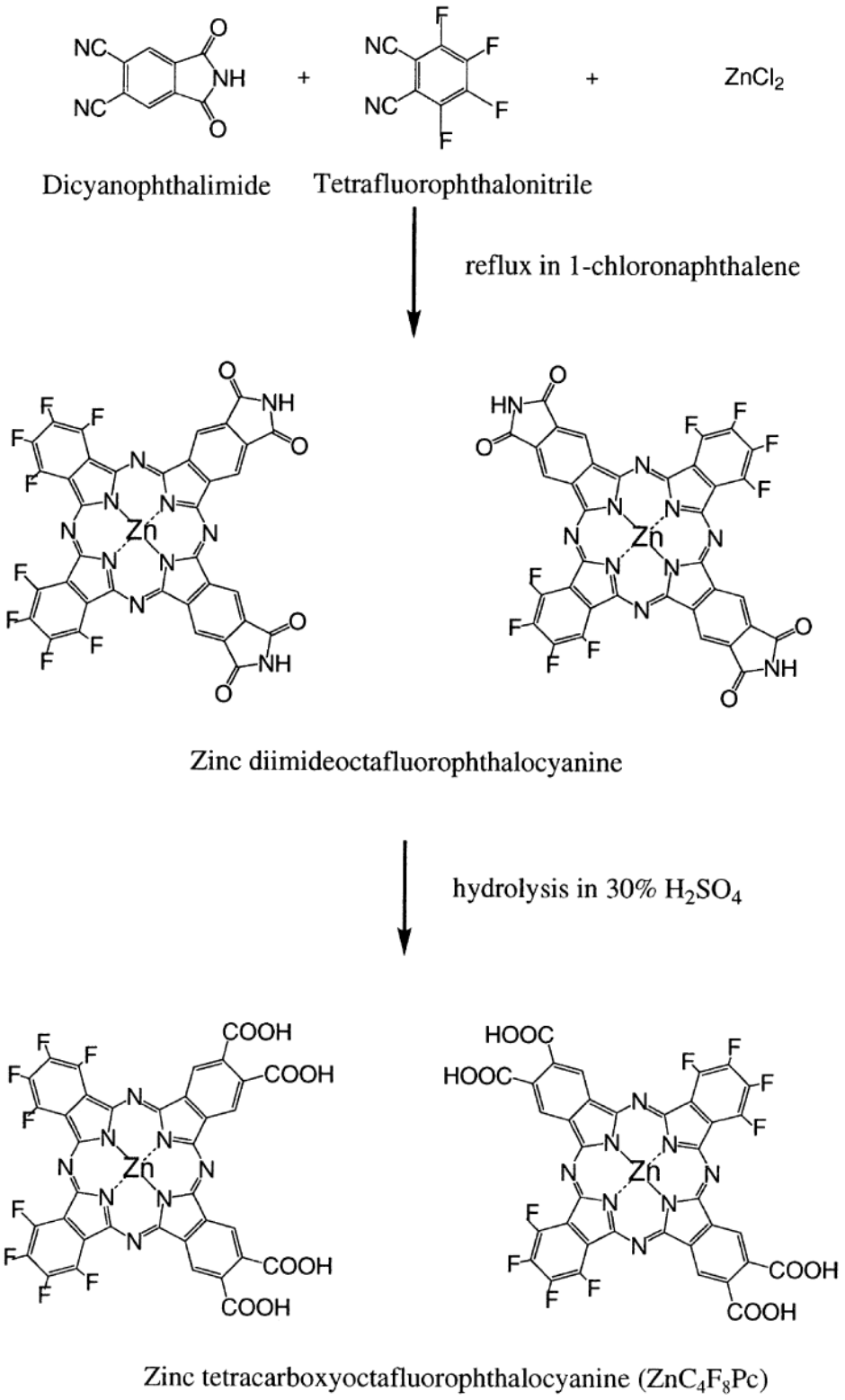


Figure 2.9 Synthesis route of zinc tetracarboxyoctafluorophthalocyanine (ZnC_4F_8Pc).

2.2.4 Tetrakis-Phthalocyanines Bearing Electron-Withdrawing Fluoro Functionality

Tetra- and octa-substituted metallophthalocyanines (MPcs) have higher chemical stability as compared to unsubstituted ones. Electron-withdrawing substituents at the periphery of the macrocycle cause a large increase in the ionization potential of the system, protect the MPc from oxidative destruction (Bench and Brennessel et al., 2002), and thus enhance its catalytic activity. From the viewpoint of organic semiconductors, it is known that substitution of electron donor and acceptor groups leads to *p*-type and *n*-type characteristics of the Pc ring, respectively.

The main problem limiting applications of phthalocyanines (Pcs) in many fields is still their limited solubility. Their solubility can be increased, however, by introducing electron-withdrawing (F, Cl, Br) and electron-donating (NH_2, ArS, RO, RS) bulky or long chain alkyl groups into the peripheral sites (Cook, 1996). The formation of constitutional isomers and the higher dipole moment of the tetrasubstituted Pcs resulting from the unsymmetrical arrangement of the substituents on the periphery leads to higher solubility of Pcs in many organic solvents.

Redox processes of Pcs can be shifted by electron-withdrawing and/or electron-repelling groups. Thus, fluorinated MPcs are currently receiving a great deal of attention due to electronwithdrawing nature of fluorine atoms (Bench and Brennessel et al., 2002). Althoughmany studies on the chemistry of MPcs in solution, which have been limited to Pc with electrondonating substituents, have been carried out, those with electron-attracting groups, especially containing fluorine atoms, have not been extensively studied (Bench and Brennessel et al., 2002; Goldberg and Michel et al., 1998).

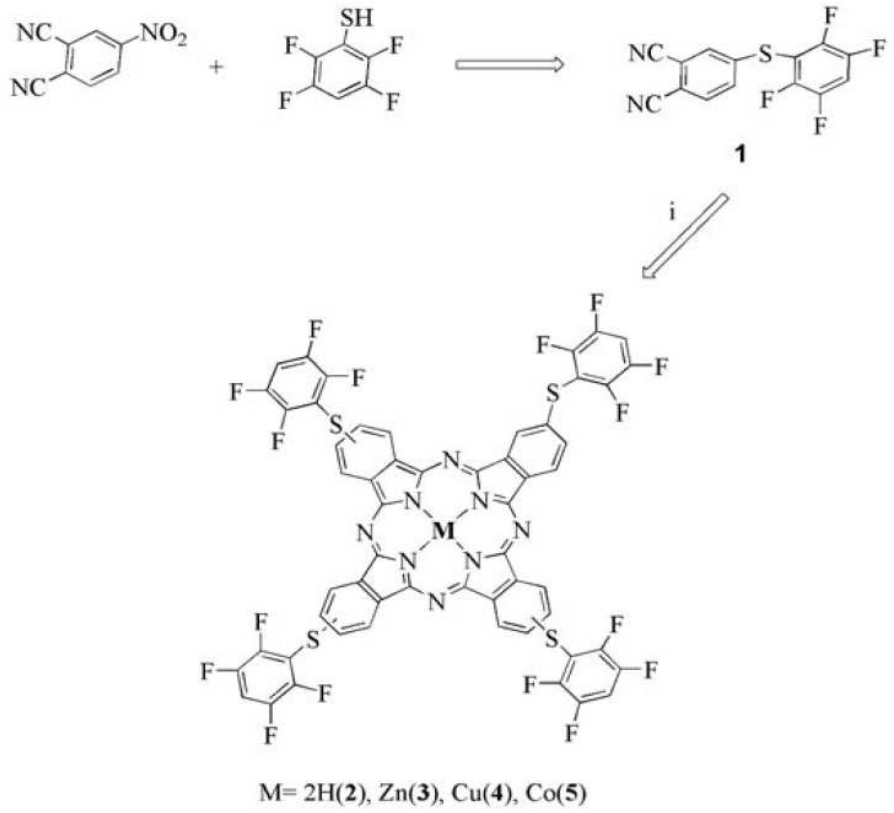


Figure 2.10 Synthesis route of 4'-(2,3,5,6-Tetrafluorophenylthio)phthalonitrile (1) and its free and metal complexes (M = 2H, Zn(II), Cu(II), Co(II). (i) 2,3,5,6-Tetrafluorothiophenol and 4-nitrophthalonitrile and K_2CO_3 in DMF at 40°C for 24 h. (ii) anhydrous $Zn(acac)_2$, $CuCl_2$, and $CoCl_2$, DBU, quinoline.

Here, it is reported the synthesis and characterization of a new ligand, 4'-(2,3,5,6-fluorophenylthio)-phthalonitrile, obtained through 2,3,5,6-fluorolthiophenol and 4-nitrophthalonitrile in the presence of K_2CO_3 in dimethylformamide (DMF) and its complexes. It's also investigated their redox properties by cyclic and differential pulse voltammetry and spectroelectrochemistry.

CHAPTER 3

CHEMICALS AND EQUIPMENTS

3.1 CHEMICALS

3,5-bis(trifluoromethyl)benzyl chloride, Sodium Cyanide (NaCN), Dimethylformamide (DMF), Carbon Disulfide (CS_2), Isobutanol, Methanol (CH_3OH), Ethanol (C_2H_5OH), Iodine (I_2), Magnesium turnings (Mg), Sodium Sulfate (Na_2SO_4), Chloroform ($CHCl_3$), Dichloromethane (CH_2Cl_2), Conc.Ammonia (NH_3), Trifluoroacetic acid (CF_3COOH), *n*-Butanol (C_4H_9OH), Diethylether ($C_4H_{10}O$), Toluene, Acetone (C_3H_6O), Paraffin Oil, *n*-hexane, Cobalt Acetate [$Co(OAc)_2$], Copper Acetate [$Cu(OAc)_2$] , Zinc Acetate [$Zn(OAc)_2$], Silica Gel 60 (0.063-0.200 mm), TLC Aluminum Sheets, Parafilm, Distilled water (H_2O).

3.2 EQUIPMENTS

IR Spectrophotometer	Perkin Elmer Spectrum One FT-IR (ATR sampling accessory)
UV/ VIS Spectrophotometer	UNICAM UV2-100
Magnetic Stirrer and Heater	IKA
Elemental Analyses	Thermo Finnigan Flash EA 1112
^{1}H-NMR Spectrophotometer	Bruker Ultra Shield Plus 400 MHz
^{13}C-NMR Spectrophotometer	Bruker Ultra Shield Plus 400 MHz
^{19}F-NMR Spectrophotometer	Bruker Ultra Shield Plus 400 MHz
Mass Spectrophotometer	Bruker Daltonics Micro-TOF and MALDI-TOF

CHAPTER 4

EXPERIMENTAL PART

4.1 SYNTHESIS OF DITHIOMALEONITRILE DISODIUM SALT (1)

Dry and powder NaCN (10 g, 0.213 mol) was stirred in DMF (70 mL) around 10 minutes. 12.84 mL (0.213 mol) CS_2 was added into that solution drop wise with stirring in ice bath for 10 minutes. Dark brown solution was stirred for extra 10 minutes and diluted to 200 mL with isobutanol and heated until all of the contents were dissolved in solvent. The solution was filtered with vacuum filtration to remove unreacted NaCN while solution was hot. Then solution was left to cool and crystallize. Needle type brown crystals was formed and filtered by vacuum filtration. The crystals were washed with diethyl ether and dried in hood.

The obtained needle type brown crystals were dissolved in 100 mL of chloroform and the dark brown solution was filtered. The solution was left to stand for 4-5 days and precipitation occurred. The precipitate having the product and sulphur was filtered and dried. Then it was dissolved in minimum methanol that can only dissolve the product and diethyl ether was added for crystallization of the product. Yellowish crystals were filtered and washed with ether and left to dry. The product (**1**) was soluble in methanol, ethanol and water and insoluble in diethyl ether, chloroform and benzene (Davison and Holm, 1967).

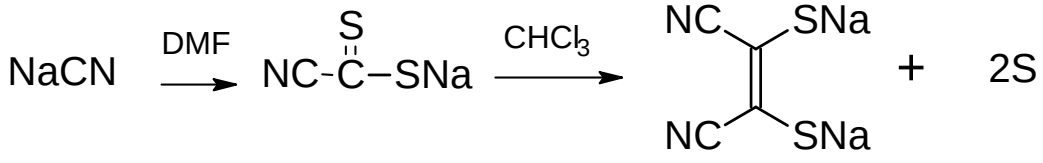


Figure 4.1 Synthesis of dithiomaleonitrile disodium salt.

4.2 SYNTHESIS OF 2,3-BIS[3,5-BIS(TRIFLUOROMETHYL)BENZYLTHIO] MALEONITRILE (2)

Disodium salt of dithiomaleonitrile (**1**) (1.12 g, 6.00 mmol) was mixed with 3,5-bis(trifluoromethyl)benzyl chloride (3.94 g, 15.0 mmol) in methanol (50.0 mL) and refluxed under nitrogen for about 18 h. When MeOH was evaporated, the remaining product was treated with $CHCl_3$ to remove insoluble salts by filtration. The $CHCl_3$ solution was extracted several times with 15% Na_2SO_4 solution and then dried over anhydrous Na_2SO_4 overnight. After evaporation of the solvent the colored product was extracted with refluxing n-hexane to remove any excess 3,5-bis(trifluoromethyl)benzyl chloride.

The product (**2**) was an orange colored and was very soluble in chloroform, dichloromethane and acetone, but insoluble in n-hexane. Yield: 2.07 g (58%). FT-IR, $\nu_{max}/(cm^{-1})$: 3085-3040 (CH, aromatic), 2935-2865 (CH, aliphatic), 2227 (C≡N), 1667, 1619 (C=C, aromatic), 1590, 1510, 1412, 1350, 1303, 1276, 1180, 1118, 1059, 901, 845, 705, 681, 585. ^{1}H NMR (δ, ppm): 7.58 (s, 2H, Ar-H), 7.32 (s, 4H, Ar-H), 4.68 (s, 4H, S-CH_2) (Appendix A). ^{13}C NMR (δ, ppm): 40.2, 113.7, 115.8, 121.8, 124.5, 129.2, 131.0, 140.4 (Appendix B). ^{19}F NMR (δ, ppm): -63.40 (Appendix C). MS (ESI): (m/z): 594.9 $[M]^+$ (Appendix D). Anal. calcd. for $C_{22}H_{10}N_2S_2F_{12}$: C, 44.45; H, 1.70; N, 4.71%. Found: C, 44.57; H, 1.82; N, 4.60%.

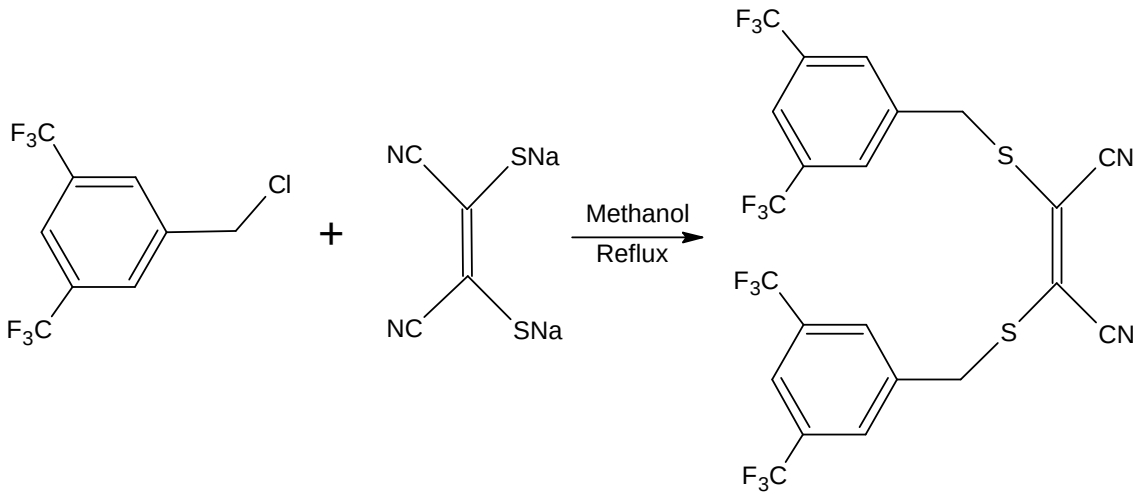


Figure 4.2 Synthesis of 2,3-bis[3,5-bis(trifluoromethyl)benzylthio]maleonitrile.

4.3 {2,3,7,8,12,13,17,18-OCTAKIS[3,5-BIS(TRIFLUOROMETHYL) BENZYLTHIO]PORPHYRAZINATO} Mg(II) (3a)

Mg turnings (6 mg, 0.25 mmol) and a small I_2 crystal were refluxed in n-BuOH (20.0 mL) for about 8 h to obtain $Mg(BuO)_2$. 2,3-bis[3,5-bis(trifluoromethyl)benzylthio]maleonitrile (**2**) (297 mg, 0.50 mmol) was added to this solution and the mixture was refluxed for about 12 h. The dark green product was filtered, washed with ethanol and water and dried in a vacuum. The crude product was dissolved in $CHCl_3$ and filtered. The $CHCl_3$ solution was dried over anhydrous Na_2SO_4. When the solvent was evaporated, a colored product was obtained. Finally, pure porphyrazine was obtained by column chromatography (SiO_2, CH_3OH: $CHCl_3$, 1:50 v/v). The blue-green colored product (**3a**) was soluble in chloroform, dichloromethane, acetone and toluene, but insoluble in n-hexane. Yield: 219 mg (73%). FT-IR, ν_{max}/(cm^{-1}): 3075 (CH, aromatic), 2925-2855 (CH, aliphatic), 1665, 1608 (C=C, aromatic), 1505, 1442, 1262, 1184, 1110, 1022, 890, 732 (Appendix E). UV-Vis ($CHCl_3$), λ/nm (log ε / $dm^3mol^{-1}cm^{-1}$): 378 (4.71), 668 (4.70) (Appendix F). ^{1}H NMR (δ, ppm): 7.64 (s, 8H, Ar-H), 7.35 (s, 16H, Ar-H), 4.65 (s, 16H, CH_2-S) (Appendix G). ^{13}C NMR (δ, ppm): 40.0, 113.4, 115.6, 121.6, 124.6, 129.1, 131.2, 140.2 (Appendix H). ^{19}F NMR (δ, ppm): -63.44 (Appendix I). MS (ESI): (m/z): 2402.5 $[M]^+$ (Appendix J). Anal. calcd. for $C_{88}H_{40}N_8S_8F_{48}Mg$: C, 44.00; H, 1.68; N, 4.66%. Found: C, 44.15; H, 1.80; N, 4.53%.

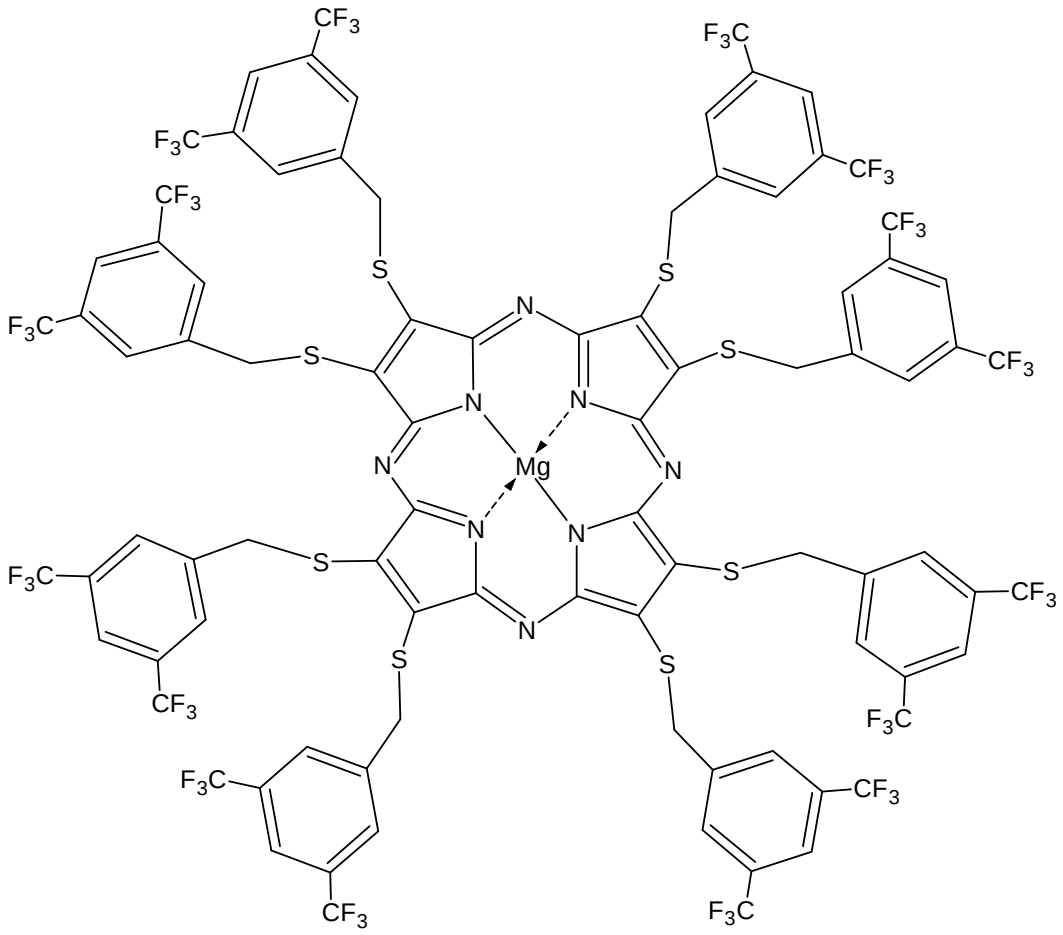


Figure 4.3 Synthesis of [2,3,7,8,12,13,17,18-octakis(3,5-bis-trifluoromethyl-benzylthio) porphyrazinato] Mg(II).

4.4 {2,3,7,8,12,13,17,18-OCTAKIS[3,5-BIS(TRIFLUOROMETHYL) BENZYLTHIO] H^{21}, H^{23} PORPHYRAZINE} (3b)

3a (120 mg, 0.05 mmol) was dissolved in the minimum amount of trifluoroaceticacid (~4.00 mL) and stirred for 3 h at room temperature. When the reaction mixture was added to ice drop by drop and neutralized with 25% ammonia solution, precipitation occurred and it was filtered. The precipitate was extracted into the chloroform and the chloroform solution was extracted with water twice. After drying over anhydrous Na_2SO_4, the solvent was evaporated to obtain a violet colored metal-free porphyrazine. **3b** was obtained by column chromatography (SiO_2, CH_3OH: $CHCl_3$, 1:30 v/v). Yield: 76 mg (64%). FT-IR, $\nu_{max}/(cm^{-1})$: 3320 (N-H), 3058 (CH, aromatic), 2922-2851 (CH, aliphatic), 1655 (C=C, aromatic), 1555, 1445, 1257, 1113,

1044, 891, 735 (Appendix K). UV-Vis ($CHCl_3$), λ/nm (log ε / $dm^3mol^{-1}cm^{-1}$): 336 (4.65), 652 (4.45), 715 (4.48) (Appendix L). ^1H NMR (δ, ppm): 7.66 (s, 8H, Ar-H), 7.33 (s, 16H, Ar-H), 5.12 (s, 16H, CH_2-S), -0.95 (br s, 2H, NH) (Appendix M). ^{13}C NMR (δ, ppm): 40.2, 113.2, 115.4, 121.7, 124.5, 129.0, 131.3, 140.4. ^{19}F NMR (δ, ppm): -63.42 (Appendix N). MS (ESI): (m/z): 2379.1 $[M]^+$ (Appendix O). Anal. calcd. for $C_{88}H_{42}N_8S_8F_{48}$: C, 44.41; H, 1.78; N, 4.71%. Found: C, 44.55; H, 1.91; N, 4.61%.

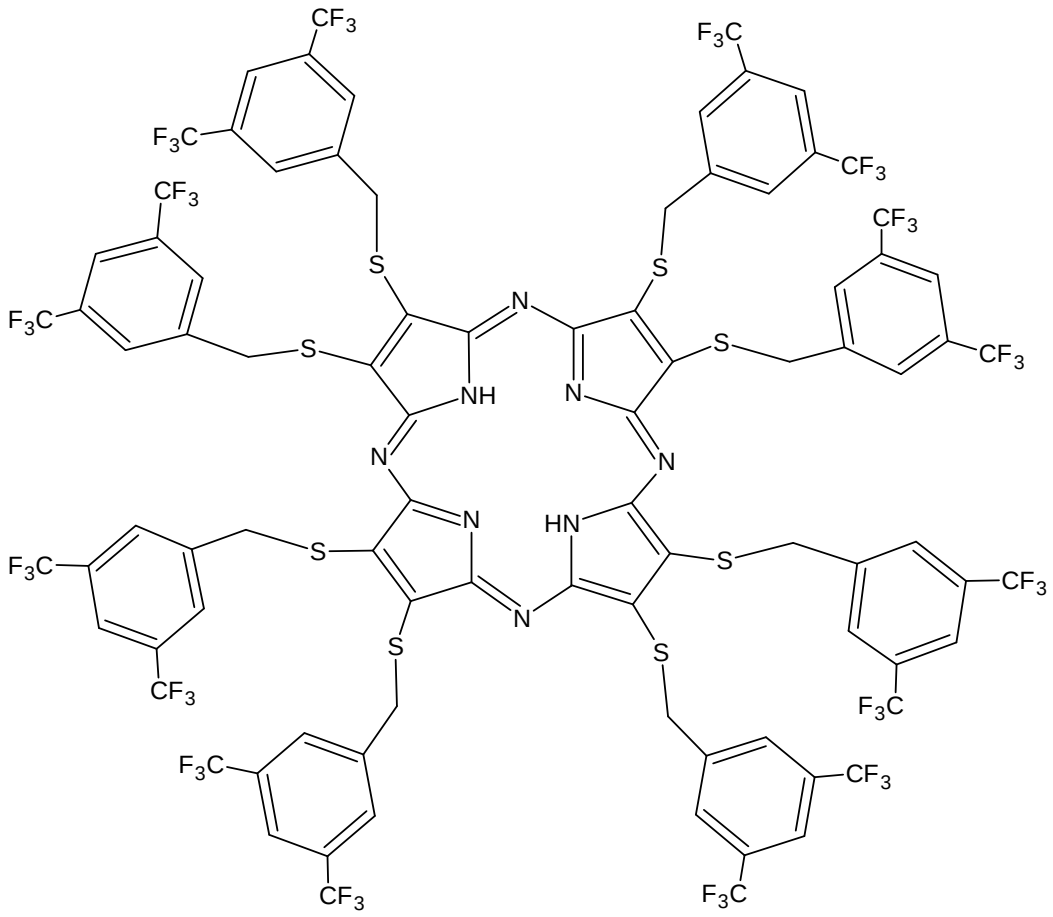


Figure 4.4 {2,3,7,8,12,13,17,18-octakis[3,5-bis(trifluoromethyl)benzylthio] H^{21}, H^{23} porphyrazine}

4.5 GENERAL PROCEDURE FOR METALLO-PORPHYRAZINES (3c-3e)

3b (119 mg, 0.05 mmol) in $CHCl_3$ (10.0 mL) was stirred with the metal salt [$Cu(OAc)_2$ (91 mg, 0.5 mmol), $Zn(OAc)_2$ (92 mg, 0.5 mmol) or $Co(OAc)_2$ (89 mg, 0.5 mmol)] in ethanol (15.0 mL) and refluxed under nitrogen for about 4 h. Then, the precipitate composed of the crude product and the excess metal salt was filtered. The

precipitate was treated with $CHCl_3$ and the insoluble metal salts were removed by filtration. The filtrate was reduced to minimum volume under reduced pressure and then added into n-hexane (150 mL) drop by drop to realize the precipitation. Finally, pure porphyrazine derivatives (**3c-3e**) were obtained by column chromatography (SiO_2, CH_3OH: $CHCl_3$, 1:50 v/v).

4.5.1 {2,3,7,8,12,13,17,18-octakis[3,5-bis(trifluoromethyl)benzylthio] porphyrazinato} Cu(II) (3c)

Yield: 51 mg (42%). FT-IR, $\nu_{max}/(cm^{-1})$: 3070-3030 (CH, aromatic), 2920-2850 (CH, aliphatic), 1660, 1605 (C=C, aromatic), 1584, 1508, 1408, 1346, 1302, 1275, 1184, 1122, 1066, 906, 846, 706, 682, 586. UV-Vis ($CHCl_3$), λ/nm (log ε / $dm^3mol^{-1}cm^{-1}$): 368 (4.60), 676 (4.52) (Appendix P). MS (ESI): (m/z): 2441.9 $[M]^+$. Anal. calcd. for $C_{88}H_{40}N_8S_8F_{48}Cu$: C, 43.29; H, 1.65; N, 4.59%. Found: C, 43.18; H, 1.74; N, 4.70%.

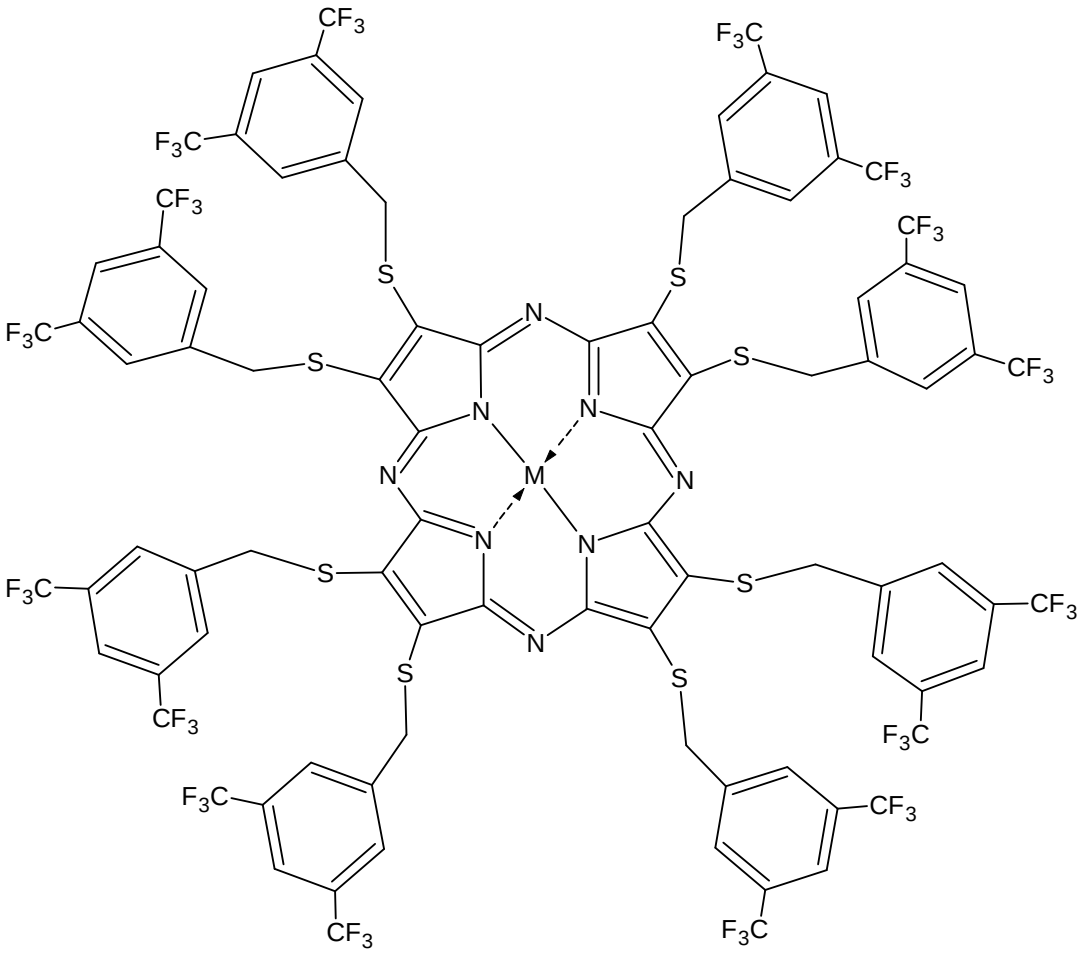
4.5.2 {2,3,7,8,12,13,17,18-octakis[3,5-bis(trifluoromethyl)benzylthio] porphyrazinato} Zn(II) (3d)

Yield: 46 mg (38%). FT-IR, $\nu_{max}/(cm^{-1})$: 3058 (CH, aromatic), 2928-2870 (CH, aliphatic), 1662, 1606 (C=C, aromatic), 1502, 1440, 1249, 1108, 1042, 892, 732 (Appendix Q). UV-Vis ($CHCl_3$), λ/nm (log ε / $dm^3mol^{-1}cm^{-1}$): 360 (4.68), 676 (4.48) (Appendix R). ^1H NMR (δ, ppm): 7.65 (s, 8H, Ar-H), 7.36 (s, 16H, Ar-H), 4.86 (s, 16H, CH_2-S) (Appendix S). ^{13}C NMR (δ, ppm): 40.0, 113.3, 115.8, 121.4, 124.6, 129.0, 131.1, 140.1 (Appendix T). ^{19}F NMR (δ, ppm): -63.40. MS (ESI): (m/z): 2443.6 $[M]^+$ (Appendix U). Anal. calcd. for $C_{88}H_{40}N_8S_8F_{48}Zn$: C, 43.26; H, 1.65; N, 4.59%. Found: C, 43.38; H, 1.76; N, 4.47%.

4.5.3 {2,3,7,8,12,13,17,18-octakis[3,5-bis(trifluoromethyl)benzylthio] porphyrazinato} Co(II) (3e)

Yield: 55 mg (45%). FT-IR, $\nu_{max}/(cm^{-1})$: 3072-3032 (CH, aromatic), 2928-2857 (CH, aliphatic), 1664, 1608 (C=C, aromatic), 1582, 1503, 1408, 1344, 1300, 1275, 1184, 1122, 1066, 903, 846, 708, 682, 584. UV-Vis. ($CHCl_3$), λ/nm (log ε / $dm^3mol^{-1}cm^{-}$

[1]): 344 (4.38), 678 (4.33) (Appendix V). MS (ESI): (m/z): 2436.1 $[M]^+$. Anal. calcd. for $C_{88}H_{40}N_8S_8F_{48}Co$: C, 43.38; H, 1.65; N, 4.60%. Found: C, 43.50; H, 1.54; N, 4.71%.



M^{2+} = Cu^{2+} (**3c**); Zn^{2+} (**3d**); Co^{2+} (**3e**)

Figure 4.5 Metallo-porphyrazines.

CHAPTER 5

RESULTS & DISCUSSIONS

The starting material for these novel porphyrazine structures with eight 3,5-bis(trifluoromethyl)benzylthio units bound to the periphery through flexible methylthio chains is 2,3-bis[3,5-bis(trifluoromethyl)benzylthio]maleonitrile (**2**) which was obtained from the disodium salt of dithiomaleonitrile (**1**) and 3,5-bis(trifluoromethyl)benzyl chloride (Fig. 5.1). The orange colored product (**2**) was obtained in 58% yield. The presence of electron-donating S-groups is expected to give porphyrazines absorbing electromagnetic radiation just in the same range as phthalocyanines (Polat and Gül, 2000; Vagin and Barthel et al., 2003; Hasanov and Gül, 2001). The conversion of 2,3-bis[3,5-bis(trifluoromethyl)benzylthio]maleonitrile into porphyrazine was achieved by the template effect of magnesium butanolate. The cyclotetramerization gave the blue-green octakis[3,5-bis(trifluoromethyl)benzylthio] porphyrazinato magnesium (**3a**) (Fig. 5.2). It is soluble in chloroform, dichloromethane, toluene and acetone, but insoluble in apolar hydrocarbon solvents such as n-hexane. The conversion of **3a** into **3b** was achieved by the treatment with relatively strong acids (e.g. trifluoroacetic acid). The mass spectral results have clearly indicated the change of the structure from magnesium porphyrazinate (**3a**) to the demetallated porphyrazine (**3b**). Further reaction of this product with copper(II) acetate, zinc(II) acetate and cobalt(II) acetate has led to the metal porphyrazinates (M = Cu, Zn, Co) (**3c-e**) (Fig. 5.1).

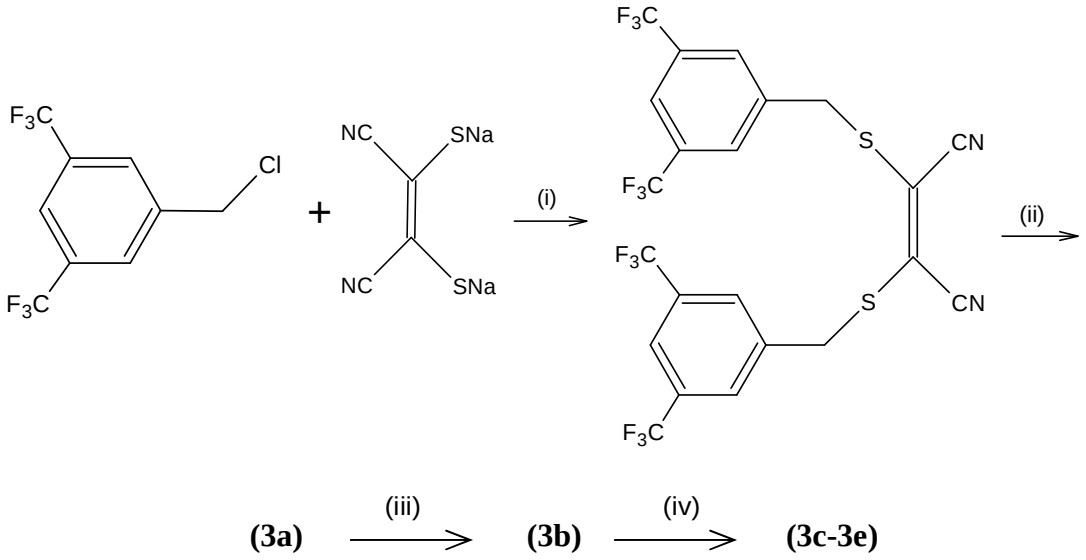
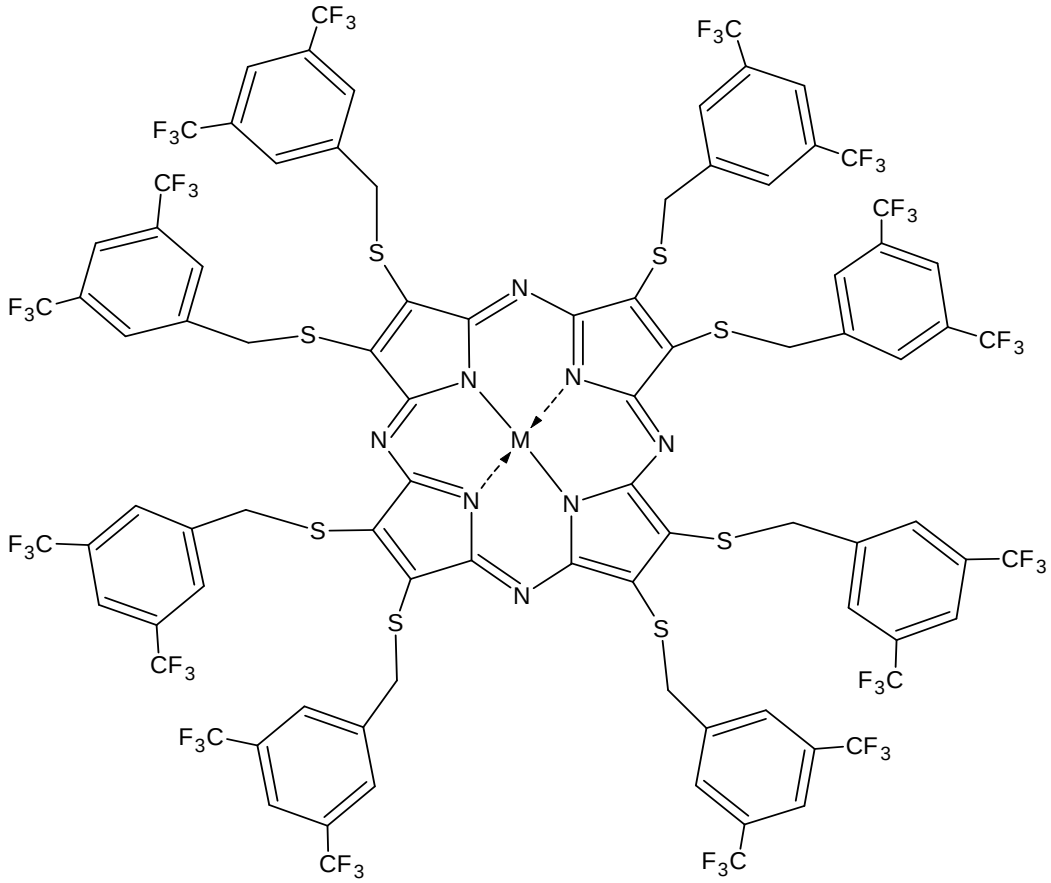


Figure 5.1 (**i**) Methanol; (**ii**) Mg turnings, I_2, n-BuOH; (**iii**) CF_3CO_2H; (**iv**) EtOH and $Cu(OAc)_2$, $Zn(OAc)_2$, or $Co(OAc)_2$.



M^{2+} = Mg^{2+} (**3a**); $2H^+$ (**3b**); Cu^{2+} (**3c**); Zn^{2+} (**3d**); Co^{2+} (**3e**).

Figure 5.2 Octakis[3,5-bis(trifluoromethyl)benzylthio] porphyrazinato magnesium (**3a-3e**).

All new compounds were identified through several spectroscopic techniques such as FT-IR, ^{1}H NMR, ^{19}F NMR, ^{13}C NMR, UV-Vis, mass and elemental analysis. The spectroscopic data of desired products were in accordance with the assigned structures.

The mass spectra of **2** and (**3a-3e**) correspond closely with the real values. Elemental analyses correspond closely with the values calculated for **(2, 3a-e)** (Table 5.1).

Table 5.1 Elemental analyses results of **2** and **3a-3e***.

Compound	C	H	N
2	44.57 (44.45)	1.82 (1.70)	4.60 (4.71)
3a	44.15 (44.00)	1.80 (1.68)	4.53 (4.66)
3b	44.55 (44.41)	1.91 (1.78)	4.61 (4.71)
3c	43.18 (43.29)	1.74 (1.65)	4.70 (4.59)
3d	43.38 (43.26)	1.76 (1.65)	4.47 (4.59)
3e	43.50 (43.38)	1.54 (1.65)	4.71 (4.60)

* Required values are given in parentheses

In the FT-IR spectrum of 2,3-bis[3,5-bis(trifluoromethyl)benzylthio]maleonitrile (**2**) stretching vibration of C≡N is observed at 2227 cm^{-1}, the aromatic and aliphatic C-H peaks are around 2865-3085 cm^{-1} and the aromatic C=C peak is at 1619 cm^{-1}. These values comply with those reported in the literature for similar compounds (Gonca and Köseoğlu et al., 2004). After the conversion of dinitrile derivative (**2**) to porphyrazine (**3a**), the sharp C≡N vibration around 2227 cm^{-1} disappeared. The N-H stretching absorption of the inner core of the metal-free porphyrazine (**3b**) was observed around 3330 cm^{-1}. FT-IR spectra of all porphyrazines derivatives (**3a-e**) showed the aromatic and aliphatic C-H peaks are in the range 2850-3085 cm^{-1} and the aromatic C=C peak is at 1605-1667 cm^{-1} (Gonca and Köseoğlu et al., 2004).

The N-H protons of the metal-free porphyrazine (**3b**) were also identified in the ^{1}H NMR spectrum with a broad peak at δ = -0.95 ppm, presenting the typical shielding of inner core protons, which is a common feature of the ^{1}H NMR spectra of metal-free porphyrazines (Pullen and Faulmann et al., 1999; Polat and Gül, 2001; Sağlam and Gül, 2001; Akkuş and Gül, 2001; Uslu and Gül, 2000; Gonca and Köseoğlu et al., 2004). In

the ^{1}H NMR spectra of diamagnetic porphyrazines **3a**, **3b** and **3d,** three different types of protons are clearly seen: Two singlets around 7-8 ppm corresponding to aromatic protons and a singlet at 4.65 ppm (**3a**)**,** 5.12 ppm (**3b**) or 4.86 ppm (**3d**) for methylene protons. The ratio of the integral values 3:2 also confirms the proposed structure. In the ^{13}C NMR spectra of diamagnetic porphyrazines **3a**, **3b** and **3d,** eight different single chemical shifts for carbon atoms are clearly seen. ^{19}F NMR spectra of diamagnetic porphyrazines **3a**, **3b** and **3d** show a single chemical shift for trifluoromethyl groups at -63.44, -63.42 and -63.40 ppm, respectively.

Electronic spectra were very useful to establish the structure of the porphyrazines (**3a-e**). UV-Vis spectra of porphyrazine core are dominated by two intense bands, the Q band around 670 nm and the B band in the near UV region around 350 nm, both correlated to $\pi \rightarrow \pi^{*}$ transitions (Van Nostrum and Nolte, 1996; Sağlam and Gül, 2001). The presence of an electron donating group on the periphery causes a bathochromic shift on Q bands. UV-Vis spectra of metallo-porphyrazines (**3a, 3c-e** in $CHCl_3$) prepared in the present work exhibited intense single Q band absorptions around 668-680 nm and B bands in the near UV region around 344-378 nm (Table 5.2). For metal-free derivative (**3b**), Q band is split into two peaks at 652 and 715 nm as a consequence of the change in the symmetry of porphyrazine core from D_{4h} (in the case of metallo derivatives) to D_{2h}. UV-Vis spectra of **3a** and **3b** in chloroform are shown in Fig. 5.2 An absorbance *vs.* concentration study indicated that due to (3,5-bis-trifluoromethyl-benzylthio) units, the aspect of the UV-Vis spectrum of the free ligand in Fig. 5.2, with broad and low intensity Q-bands does not exclude the presence of aggregation. UV-Vis spectra of **3c** in solvents of different polarity (dichloromethane, ethanol, chloroform and pyridine) are given in Fig. 5.4. There is almost no difference with respect to the changes in the nature of the solvent.

Table 5.2 UV-Vis Data for (**3a-3e**) in $CHCl_3$.

Compound	**λ/nm (log ε / dm^3 mol^{-1} cm^{-1})**		
3a	378 (4.71)	668 (4.70)	
3b	336 (4.65)	652 (4.45)	715 (4.48)
3c	364 (4.64)	664 (4.49)	
3d	348 (4.40)	680 (4.36)	
3e	344 (4.33)	678 (4.38)	

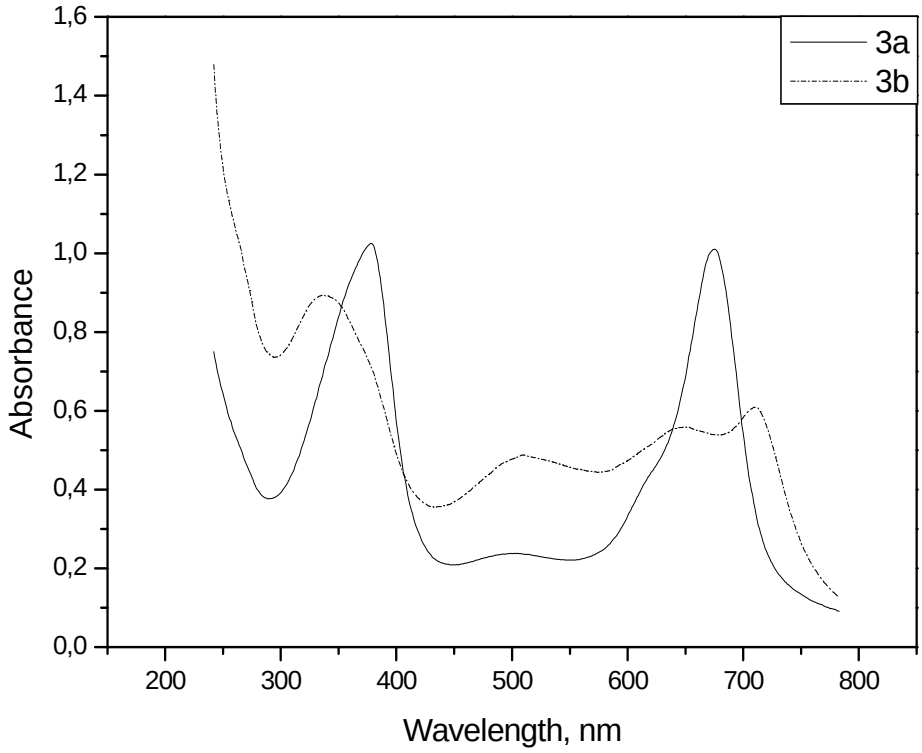


Figure 5.3 UV-Vis Spectra of **3a** and **3b** in $CHCl_3$.

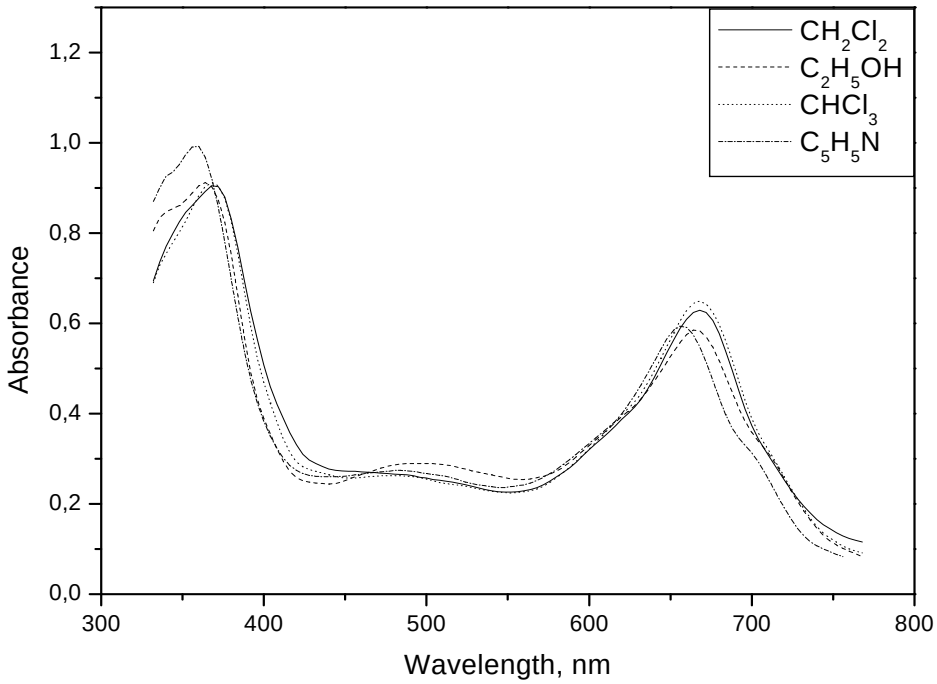


Figure 5.4 UV-Vis Spectra of **3c** in Various Solvents.

REFERENCES

Adachi, C., M.A. Baldo, M.E. Thompson, S.R. Forrest, J. Appl. Phys. Vol. 90, pp. 5048, 2001.

Akkuş, H., A. Gül, Transition Met. Chem., Vol. 26, pp. 689-694, 2001.

Akkuş, H., A. Gül, Transition Met. Chem. Vol.26, pp. 689-694, 2001.

Al'yanov, M. A.; Smirnov, R. P.; Boretskii, E. S.; Federov, L. M. Tr. IVanoV. Khim. Chem. Abstr, Vol. 79, pp. 139, 1973.

Ali, H., and van Lier, J. E. Metal complexes as photoand radiosensitizers. Chem. Rev. Vol. 99, pp. 2379-2450, 1999.

Bench, B. A.; Brennessel, W. W.; Lie, H-J.; Gorun, S. M. Angew Chem, Int Ed, Vol. 41, pp. 750,2002.

Bohrer, F.I., C.N. Colesniuc, J. Park, M.E. Ruidiaz, I.K. Schuller, A.C. Kummel, W.C. Trogler, Comparative gas sensing in cobalt, nickel, copper, zinc, and metal-free phthalocyanine chemiresistors, J. Am. Chem. Soc. 131 (2), pp. 478–485,2009.

Bondi, A., J. Phys. Chem. 68 pp. 441–451, 1964.

Bonnett, R., Photosensitizers of porphyrin and phthalocyanines series for photodynamic therapy, Chem. Soc. Rev. 24 , pp. 19–33,1995.

Boronat, M.; Viruela, R.; Ortı´, E. Synth. Met., Vol. 71, pp. 2291, 1995.

Boyle, R.W., J.E.V. Lier, Hexadecafluorinated zinc phthalocyanine: photodynamic properties against the EMT-6 tumour in mice and pharmacokinetics using ^{65}Zn as a radiotracer, Br. J. Cancer Vol.73, pp. 49–53, 1996.

Braun, A. and Tcherniac, J., Uberdie Producte der Einwirkung Von Acetanhydrid auf Phtalamid, Chemische Berichte Chemical Ges., Vol. 40, pp. 2709-2714, 1907.

Campbell, J. B. U.S. Patent 2,765,308; 1956; Chem. Abstr., Vol. 51,pp. 8143, 1956.

Cho, L H.; Lim, Y. S., Chemistry Letters, pp. 2107, 1987.

Cook, M. J. J Mater Chem Vol. 6, pp. 677, 1996.

Dandridge, A.G., Drescher, H.A.E. and Thomas, J., Dyes British Patent, No:322169, 1929.

De la Torre, G.; Torres, T.; Agullo-Lo´pez, F. AdV. Mater. Vol. 9, pp. 265, 1997.

Decreau, R., Richard, M.-J., and Juillard, M. Photodynamic therapy against achromic M6 melanocytes: phototoxicity of lipophilic axially substituted aluminum phthalocyanines and hexadecahalogenated zinc phthalocyanines. J. Porphyrins Phthalocyanines Vol. 5, pp. 390-396, 2001.

Dogo, S., Germain, J. P., Maleysson, C and Pauly, A. Interaction of NO_2 with Copper Phthalocyanine Thin-Films .2. Applicatıon to Gas Sensing, Thin Solid Films, Vol. 219, pp. 251-256, 1992.

Eisner, U.; Lichtarowicz, A.; Linstead, R. P. J. Chem. Soc., pp. 733–739, 1957.

Elvidge, J. A. and Linstead R. P. Conjugated macrocycles. Part XXVII. The formation of tetrazaporphins from imidines. Tribenzotetrazaporphin, Journal of the Chemical Society, pp. 3536-3544, 1955.

Elvidge, J. A.; Golden, J. H. J. Chem. Soc., pp. 700, 1957.

Elvidge, J. A.; Linstead, R. P. J. Chem. Soc., pp. 5008, 1952.

Fedoroff, O.Y.; Salazar, M.; Han, H.; Chemeris, V.V.; Kerwin, S.M.; Hurley, L.H. Biochemistry, Vol. 37, pp. 12365, 1998.

Fietzek, C., H.-G. Mack, Influence of different transition metals in phthalocyanines on their interaction energies with volatile organic compounds: an experimental and computational study, J. Mol. Model. Vol. 13, pp. 11–17, 2007.

Fietzek, C., K. Bodenhöfer, P. Haisch, M. Hees, M. Hanack, S. Steinbrecher, F. Zhou, E. Plies, W. Göpel, Soluble phthalocyanines as coatings for quartzmicrobalances: specific and unspecific sorption of volatile organic compounds, Sens. Actuators B Vol. 57, pp. 88–98, 1999.

Fischer, H.; Nenitzescu, C. Liebigs Ann. Chem. Vol. 433, pp. 113–129, 1925.

Fischer, H.; Orth, H. Die Chemie des Pyrrols, Akademische Verlag., Vol. 2, pp. 193, 1937.

Forsyth, T. P.; Williams, D. B. G.; Montalban, A. G.; Stern, C. L.; Barrett, A. G. M.; Hoffman, B. M. J. Org. Chem.,Vol. 63, pp. 331- 336, 1998 .

Foster, R., Organic Charge-Transfer Complexes, Academic Press, London, 1969.

Freeman, B. A.; Smith, K. M. Synth. Commun., Vol. 29,pp. 1843–1855, 1999.

Fuchter, M. J.; Zhong, C.; Zong, H.; Hoffman, B. M.; Barrett, A. G. M. Aust. J. Chem. Vol. 61, pp. 235, 2008.

Gao, L.D., X.H. Qian, J. Fluorine Chem. Vol. 113, pp. 161, 2002.

Goldberg, D. P.; Michel, S. L. J.; White, A. J. P.; Williams, D. J.; Barrett, A. G. M.; Hoffman, B. M. Inorg Chem Vol. 37, pp. 2100, 1998.

Gonca, E., Baklacı,Ü . G., Dinçer, H. A. Polyhedron, Vol. 27, pp. 2431, 2008.

Gonca, E., Y. Köseoğlu, B. Aktaş, A. Gül, Polyhedron Vol. 23, pp. 1845-1849, 2004.

Gonca, E., Y. Köseoğlu, B. Aktaş, A. Gül, Polyhedron, Vol. 23, pp. 1845-1849, 2004.

Gregory, P. Industrial applications of phthalocyanines. J. Porphyrins Phthalocyanines Vol. 4, pp. 432-437, 2000.

Gross, T., F. Chevalier, J.S. Lindsey, Inorg. Chem. Vol. 40, pp. 4762, 2001.

Guillaud, G., Skoulios, A., Piechocki, C., Simon, J., and Weber, P. Molecular Crystals & Liquid Crystals, Vol. 275, pp. 100, 1983.

Guo, L., F.S. Meng, X.D. Gong, H.M. Xiao, K.C. Chen, H. Tian, Dyes Pigments 49.

Hasanov, B., A. Gül, Synth. React. Inorg. Met-Org. Chem. Vol. 31, pp. 673-680, 2001.

Holmes, R.J., B.W. D'Andrade, S.R. Forrest, J.L.X. Ren, M.E. Thompson, Appl. Phys. Lett. Vol. 83, pp. 3818, 2003.

Iliev V, Alexiev V, Bilyarska L. Journal of Molecular Catalysis A: Chemical, Vol. 137: pp. 15–22, 1999.

Inhoffen, H. H.; Fuhrhop, J.-H.; Voigt, H.; Brockmann, Jr., H. Liebigs Ann. Chem., Vol. 695, pp. 133–143, 1966.

Jackson, A. H.; Kenner, G. W.; Wass, J. J. Chem. Soc., Perkin Trans. 1, pp. 1475–1483, 1972.

Janda, P., Kobayashi, N. and Lever. A. B. P. Dioxygen Reduction at a Graphite Electrode Modified by Mononuclear Tetraneopentoxyphthalocyaninatocobalt(II) and Related Polynuclear Species, Canadian Journal Of Chemistry-Revue Canadienne De Chimie, Vol. 67, pp. 1109-1119, 1989.

Kandaz, M., I. Yılmaz, Ö. Bekaroğlu, Polyhedron, Vol. 19, pp. 115, 2000.

Kobayashi N. Phthalocyanines. Current Opinion in Solid State & Materials Science, Vol. 4, pp. 345, 1999.

Koca, A., M.K. S¸ ener, M.B. Koçak, A. Gül, Transit. Metal Chem., Vol. 30, pp. 399, 2005.

Kol'tsov E, Basova T, Semyannikov P, Iqumenov I. Mater Chem Phys, Vol. 86, pp.222-7, 2004.

Kol'tsov, E., I. Igumenov, T. Basova, P. Semyannikov, Mater. Chem. Phys., Vol. 86, pp. 222, 2004.

Kulikov, M. A.; Vorob'ev, Yu. G.; Berezina, G. R.; Stepanenko, V. A. Russ J. Gen. Chem. Zh. Obshch. Khim., Vol. 74, pp. 1031, 2004.

Leznoff, C.C. and Hail, T.W., The Synthesis of a Soluble Unsymmetrical Phthalocyanine on Solid Phases, Tetrahedron,Vol. 23, pp. 3023-3026, 1982.

Leznoff, C.C. and Lever, A.B.P., Phthalocyanines: Properties and Applications, , VCH, New York. Vol. 1-4, pp. 83, 1989, 1992, 1993, 1996.

Li, R., X. Zhang, I.P. Zhu, D.K.P. Ng, N. Kobayashi, J. Jiang, Inorg. Chem. Vol. 45, pp. 2327, 2006.

Liao, M.S., T. Kar, S.M. Gorun, S. Scheiner, Inorg. Chem. (Washington, DC, US), Vol. 43, pp. 7151–7161, 2004.

Lin, X.Q. and Kadish, K.M. Vacuum-Tight Thin-Layer Spectroelectrochemical Cell with a Doublet Platinum Gauze Working Electrode Analytical Chemistry, Vol. 57, pp. 1498-1501, 1985.

Lindsey J.S., I.C. Schreiman, H.C. Hsu, P.C. Kearney, A.M. Marguerettaz, J. Org. Chem., Vol. 52, pp. 827–836, 1987.

Lindsey, J. S. In The Porphyrin Handbook, Kadish, K. M.; Smith, K. M.; Guilard, R., Eds.; Academic Press: Boston; Vol. 1, Chapter 2, pp 45–118, 1999.

Mauzerall, D. J. Am. Chem. Soc., Vol. 82, pp. 2601–2605, 1960.

Mc Keown, N.B., Hanif, S., Msayib, K., Tattershall CE, Budd PM. Chem Commun pp. 2782-3, 2002.

Meller, A., and Ossko, A. Phthalocyaninartige KorKomplexe. Monatsch. Chem. Vol. 103, pp. 150-155, 1972.

Mikhalenko, S. A., Barknova, S. V., Lebedev, O. L. and Luk'yanets, E. A. Phthalocyanines And Related Compounds .9. Synthesis And Electron Absorption-Spectra of Tetra-4-Tert-Betyl-Phthalocyanines, Zhurnal Obshchei Khimi., Vol. 41, pp. 2735, 1971.

Montalban, A. G.; Meunier, H. G.; Ostler, R. B.; Barrett, A. G. M.; Hoffman, B. M.; Rumbles, G. J. Phys. Chem. A, Vol. 103, pp. 4352, 1999.

Moskalev, P.N., Kirin, I.S. Russian Journal of Physical Chemistry, Vol. 46, pp. 1019, 1972.

Natale, C.D., R. Paolesse, A. Macagnano, S. Nardis, E. Martinelli, E. Dalcanale, M. Costa, A. D'Amico, Sensitivity–selectivity balance in mass sensors: the case of metalloporphyrins, J. Mater. Chem., Vol. 14, pp. 1281–1287, 2004.

Nemykin, V. N.; Kobayashi, N.; Nonomura, T.; Luk'yanets, E. A. Chem. Lett., pp. 184, 2000.

Nicolau, M.; Rojo, G.; Torres, T.; Agullo-Lopez, F. J. Porphy. Phthalocya., Vol. 3, pp. 703–711, 1999.

Nie, H.; Stern, C. L.; Barrett, A. G. M.; Hoffman, B. M. Chem. Commun., pp. 703, 1999.

O'Regan, B., M.Gratzel, Photovoltaic and photochemical conversion of solar cell. Low cost and highly efficient solar cells based on the sensitization of colloidal titaniumdioxide, Vol. 335, pp. 7377–7385, 1991.

Oda, K., S.I. Ogura, I. Okura, J. Photochem. Photobiol. B: Biol. Vol. 59,pp. 20, 2000.

Ohno-Okumura, E., Sakamoto, K., Kato, T., Hatano, T., Fukui, K., Karatsu, T., Kitamura, A., and Urano, T. Synthesis of subphthalocyanine derivatives and their characterization. Dyes Pigments Vol. 53, pp. 57-65, 2002.

Ough, E.; Nyokong, T.; Creber, K. A. M.; Stillman, M. J. Inorg. Chem., Vol. 27, pp. 2724, 1988.

Özer, M., A. Altındal, A.R. Özkaya, M. Bulut, Ö. Bekaroğlu, Synth. Met., Vol. 155 pp. 222, 2005.

Özer, M., A. Altindal, A.R. Özkaya, M. Bulut, Ö. Bekaro˘glu, Polyhedron, Vol. 25 pp. 3593, 2006.

Polat, M., A. Gül, Dyes and Pigments, Vol. 45, pp. 195-199, 2000.

Polat, M., A. Gül, Dyes and Pigments, Vol. 45, pp. 195-199, 2000.

Poon, K.W., W. Liu, P.K. Chan, Q. Yang, T.W.D. Chan, T.C.W. Mak, D.K.P. Ng, J. Org. Chem., Vol. 66, pp. 1553, 2001.

Pullen, A.E., C. Faulmann, P. Cassoux, Eur. J. Inorg. Chem., pp. 269-276, 1999.

Pullen, A.E., C. Faulmann, P. Cassoux, Eur. J. Inorg. Chem., pp. 269-276, 1999.

Robertson J. M. and Woodward J. Journal of the Chemical Society, pp. 36-48, 1940.

Rusanova, J., M. Pilkington, S. Decurtins, Chem. Commun., pp. 2236, 2002.

Sağlam, Ö., A. Gül, Polyhedron, Vol. 20,pp. 269-275, 2001.

Sawyer, D. T. and Roberts, J. L., Journal of Electroanalytical Chemistry, Vol. 12, pp. 90, 1966.

Schmid, G., Sommerauer, M., Geyer, M., and Hanack, M. Synthesis and chromatographic separation of tetrasubstituted and unsymmetrically substituted

phthalocyanines. In Phthalocyanines: Properties and Applications (Leznoff, C. C., and Lever, A. B. P., Eds.) Vol. 4, pp 1-18, 1996.

Schramm, C.J., B.M. Hoffman, Inorg. Chem., Vol. 19, pp. 383, 1980.

Sessler, J. L.; Mozaffari, A.; Johnson, M. R. Org. Synth., Vol. 70, pp. 68–78, 1991.

Shimizu, S.; Zhu, H.; Kobayashi, N. Chem.sEur. J., Vol. 16, pp. 11151, 2010.

Siejak, A., D.Wrobel, R.M.Ion, Study of resonance effects in copper phthalocyanines, J.Photochem.Photobiol.A:Chem., Vol. 181, pp. 180–187, 2006.

Simith, J.R.L., Reginato, G. Org Biomol Chem 1, pp. 2543-9, 2003.

Sorokin, A., Suzzoni-Dezard, S. D., Poullain, D., Noel, J. P. And Meunier, B., CO_2 as the ultimate degradation product in the H_2O_2oxidation of 2,4,6-trichlorophenol catalyzed by iron tetrasulfophthalocyanine, Journal of the American Chemical Society, 1996.

Sugimori, T., M. Handa, K. Kasuga, Inorg. Chim. Acta, Vol. 278, pp. 253, 1998.

Sugimori, T., S. Horike, M. Handa, K. Kasuga, Inorg. Chim. Acta, Vol. 278, pp. 253, 1998.

Suziki, M., Shimiza, S., Shin, J.Y., Osuka, A. Tetrahedron Lett., Vol. 44, pp. 4597-601, (2003).

Tabata, K., K. Fukushima, K. Oda, I. Okura, J. Porphyr. Phthalocyanin., Vol. 4, pp. 278, 2000.

Titov, A. I. Tetrahedron, Vol. 19, pp. 557-580, 1963.

Uslu, R.Z., A. Gül, C. R. Acad. Sci. Paris Ser. II C:Chim., Vol. 3, pp. 643-648, 2000.

Uslu, R.Z., A. Gül, C. R. Acad. Sci. Paris Ser. II C:Chim., Vol. 3, pp. 643-648, 2000.

Vagin, S., M. Barthel, D. Dini, M. Hanack, Inorg. Chem. Vol. 42,pp. 2683-2694, 2003. Hasanov, B., A. Gül, Synth. React. Inorg. Met-Org. Chem. Vol. 31,pp. 673-680, 2001.

Vagin, S., M. Barthel, D. Dini, M. Hanack, Inorg. Chem., Vol. 42, pp. 2683-2694, 2003.

Van Lier, J. E. New sensitizers for photodynamic therapy of cancer. In Light in Biology and Medicine, Vol. 1, pp. 133-140, 1988.

Van Nostrum, C.F., R.J.M. Nolte, Chem. Commun., pp. 2385-2392, 1996.

Van Nostrum, C.F., R.J.M. Nolte, Chem. Commun., pp. 2385-2392, 1996.

Vicente, M. G. H.; Smith, K. M. In Embryonic Encyclopedia of Life Sciences 1999.

Wan, S., J.A. Parrish, R.R. Anderson, M. Madden, Transmittance of nonionizing radiation in human tissues, Photochem. Photobiol., Vol. 34, pp. 679–681, 1981.

Wang, M., Chen, H. Z. and Yang, S. L. Photoconductivity of Phthalocyanine Composites .2. Double-Layered Photoreceptor of FEIIPC-PVK, Journal of Photochemistry and Photobiology A: Chemistry, Vol. 53, pp. 437-441, 1990.

Wheelhouse, R.T. J. Am. Chem. Soc., Vol. 120, pp. 3261–3262, 1998.

Whitlock, H. W.; Hanauer, R. J. Org. Chem., Vol. 33, pp. 2169–2171, 1968.

Wie, S., D. Huang, L. Li, Q. Meng, Dyes Pigments, Vol.56, pp. 1, 2003.

Williams, A.J.R., Analyst, Vol. 108, pp. 1067, 1983.

Wro´bel D., A. Siejak, P. Siejak, Institute of Physics, Vol. 94, pp. 492–500, 2010.

Yenilmez, H.Y., I. Özçeşmeci, A.I. Okur, A. Gül, Polyhedron, Vol. 23, pp. 787, 2004.

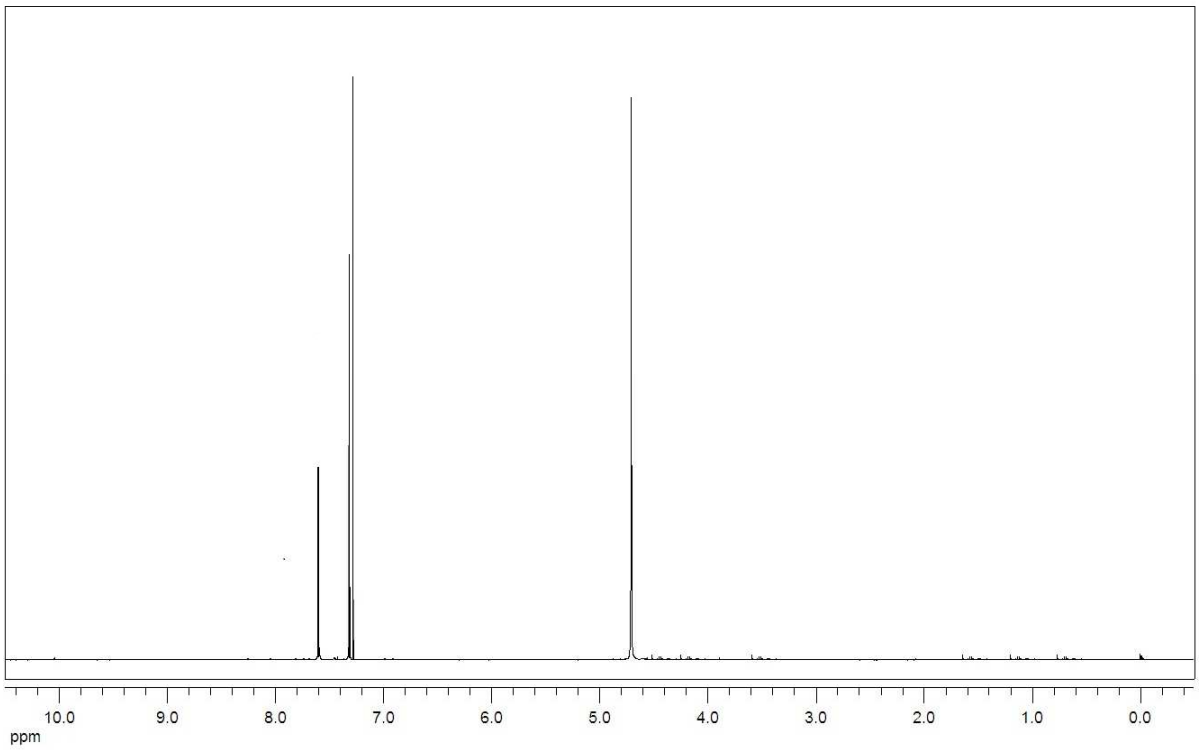
Yılmaz, I., M.B. Koçak, Polyhedron, Vol. 23, pp. 1279, 2004.

Yslas, E.I., E.N. Durantini, V. Rivarola, Bioorg. Medic. Chem., Vol. 15, pp. 4651, 2007.

Yslas, E.I., V. Rivarola, E.N. Durantini, Bioorg. Med. Chem., Vol. 15, pp. 39, 2005.

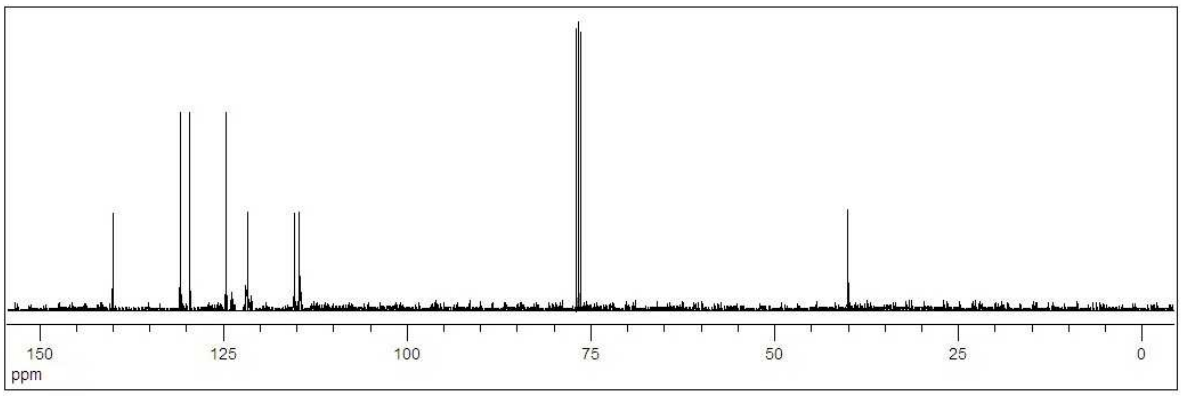
Ziolo, F. and Extine M. New alkali metal phthalocyanine (Pc) complexes. Structure of the quasi-multimacrocycle $K_2Pc(DMF)_4$ an the KPcK template, Inorganic Chemistry, Vol. 20, pp. 2709, 1981.

APPENDIX A



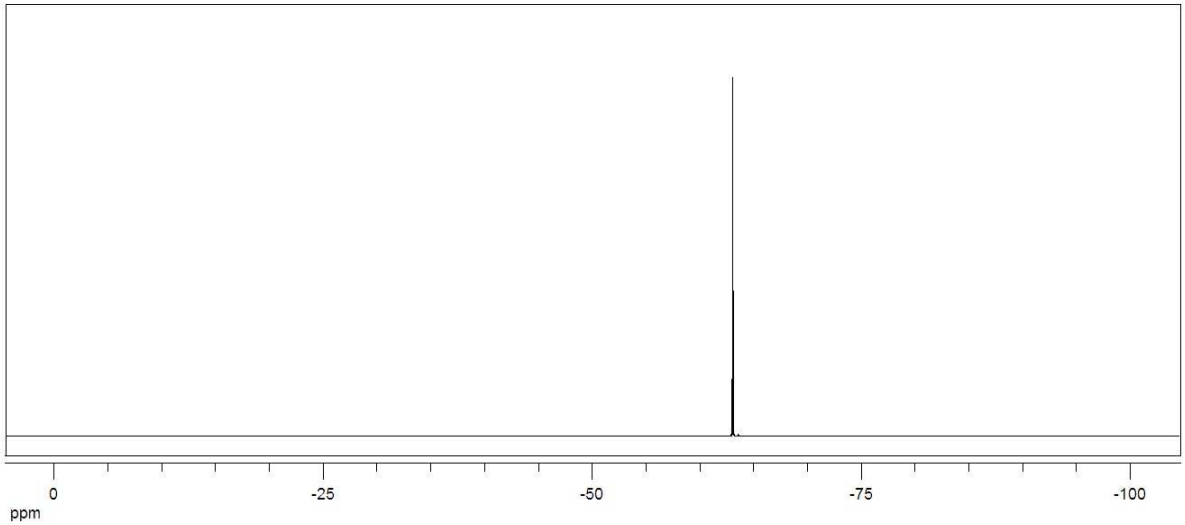
^{1}H NMR Spectrum of 2,3-bis[3,5-bis(trifluoromethyl)benzylthio]maleonitrile (**2**).

APPENDIX B



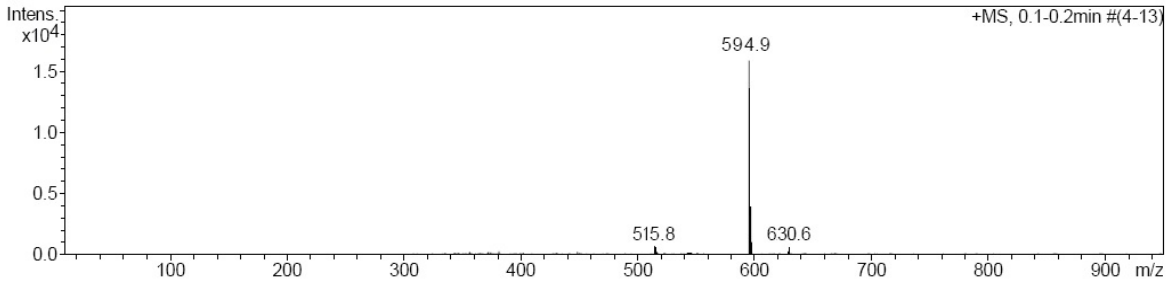
^{13}C NMR Spectrum of 2,3-bis[3,5-bis(trifluoromethyl)benzylthio]maleonitrile (**2**).

APPENDIX C



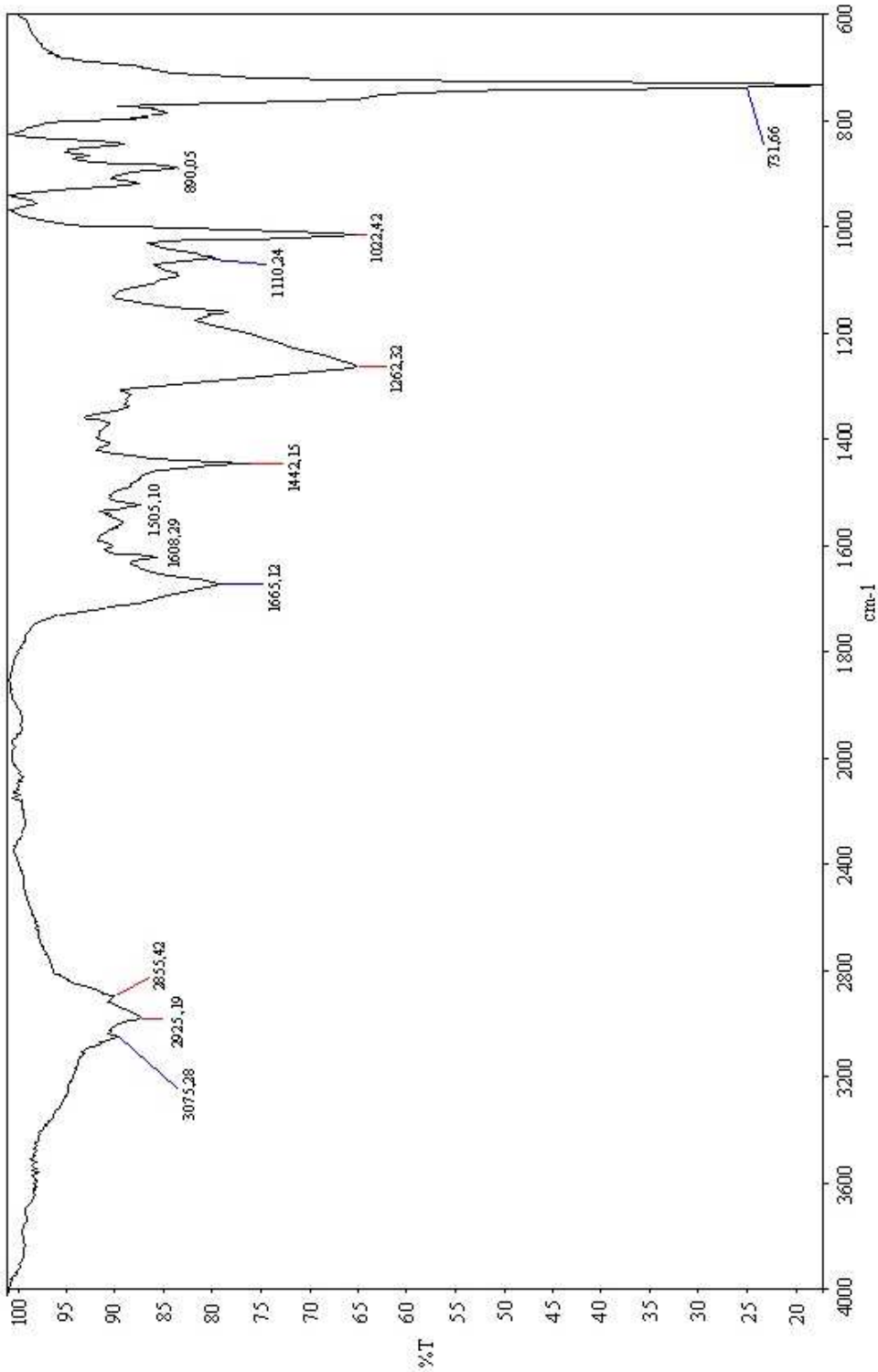
^{19}F NMR Spectrum of 2,3-bis[3,5-bis(trifluoromethyl)benzylthio]maleonitrile (**2**).

APPENDIX D



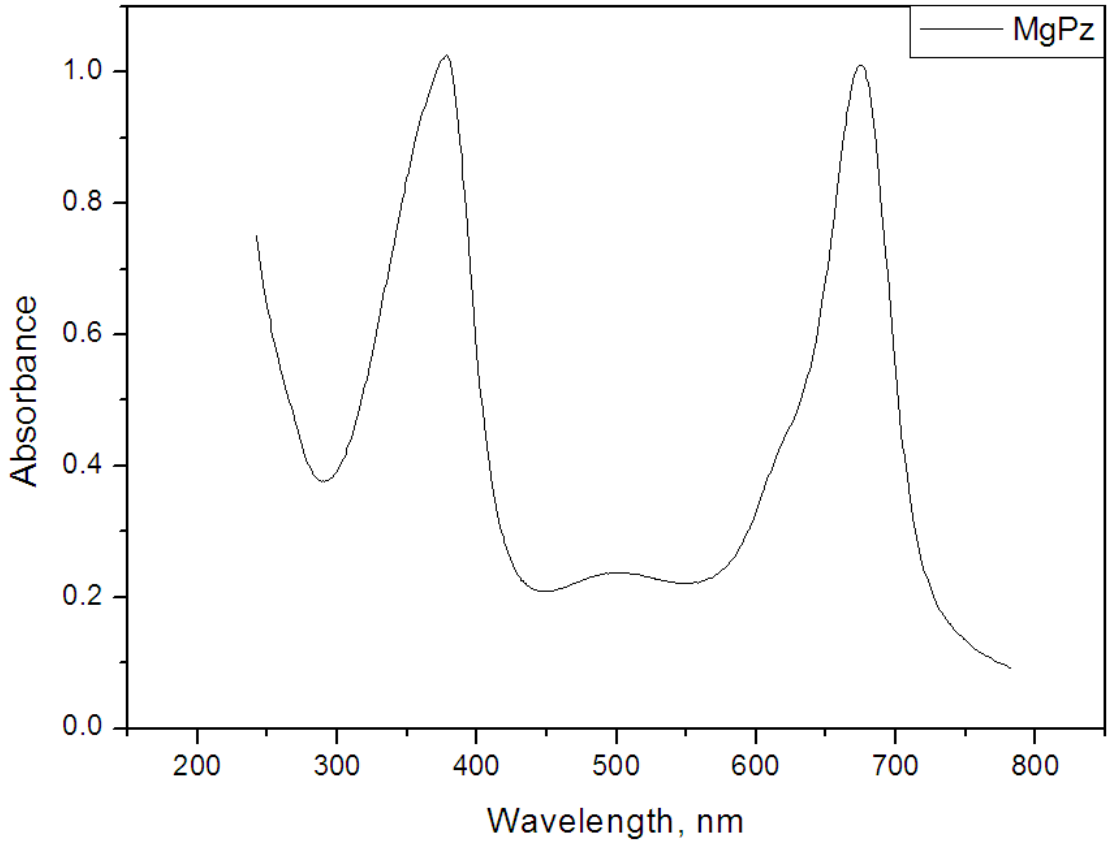
Mass Spectrum of 2,3-bis[3,5-bis(trifluoromethyl)benzylthio]maleonitrile (**2**).

APPENDIX E



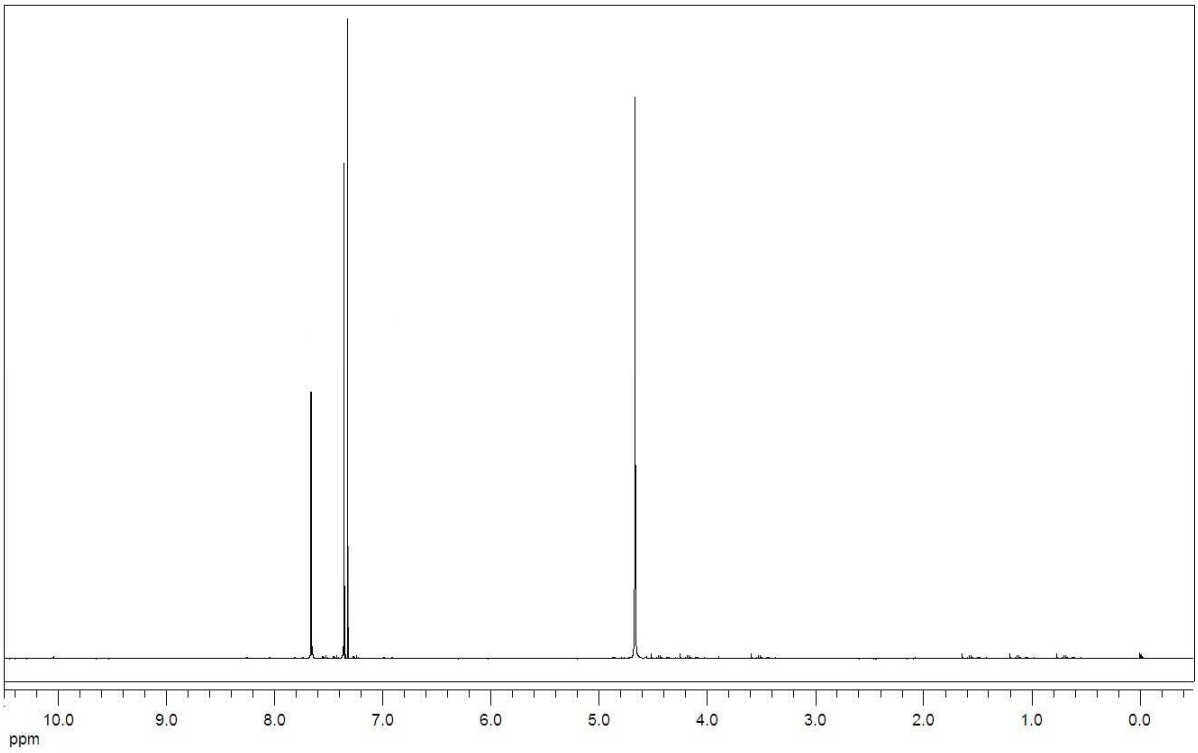
FT-IR Spectrum of MgPz (**3a**).

APPENDIX F



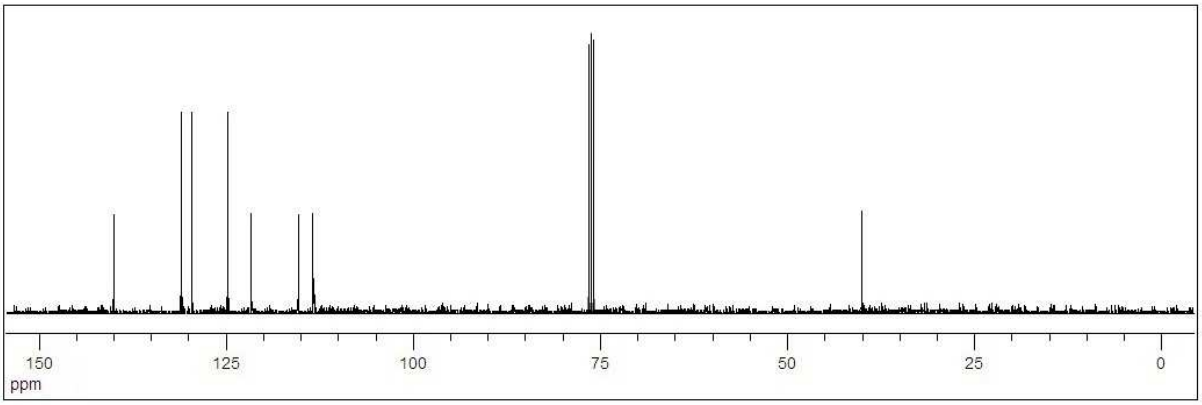
UV-Vis Spectrum of MgPz (**3a**) in $CHCl_3$.

APPENDIX G



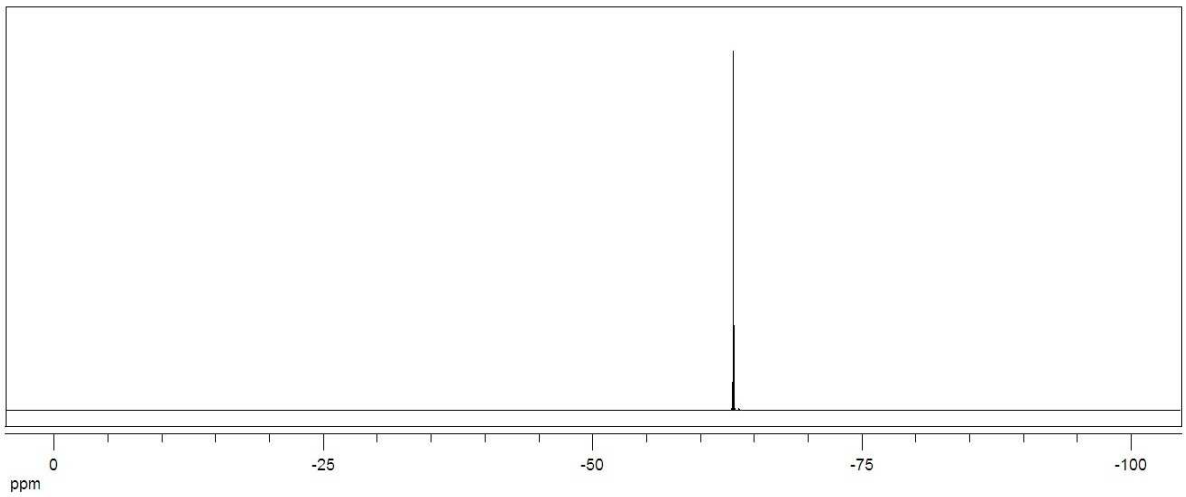
^{1}H NMR Spectrum of MgPz (**3a**).

APPENDIX H



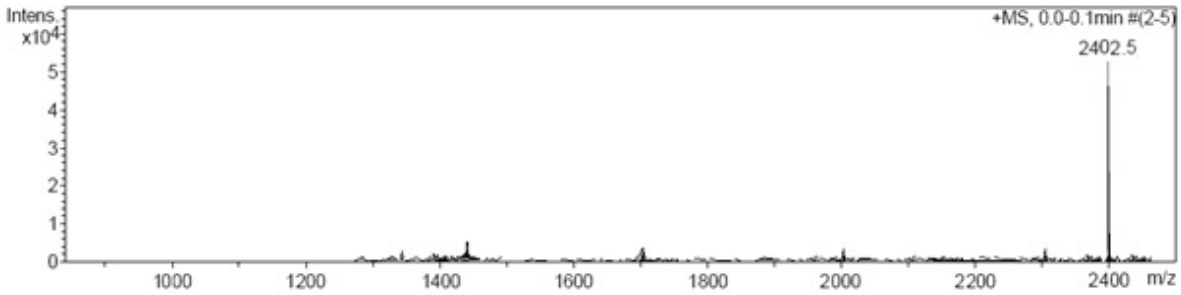
^{13}C NMR Spectrum of MgPz (**3a**).

APPENDIX I



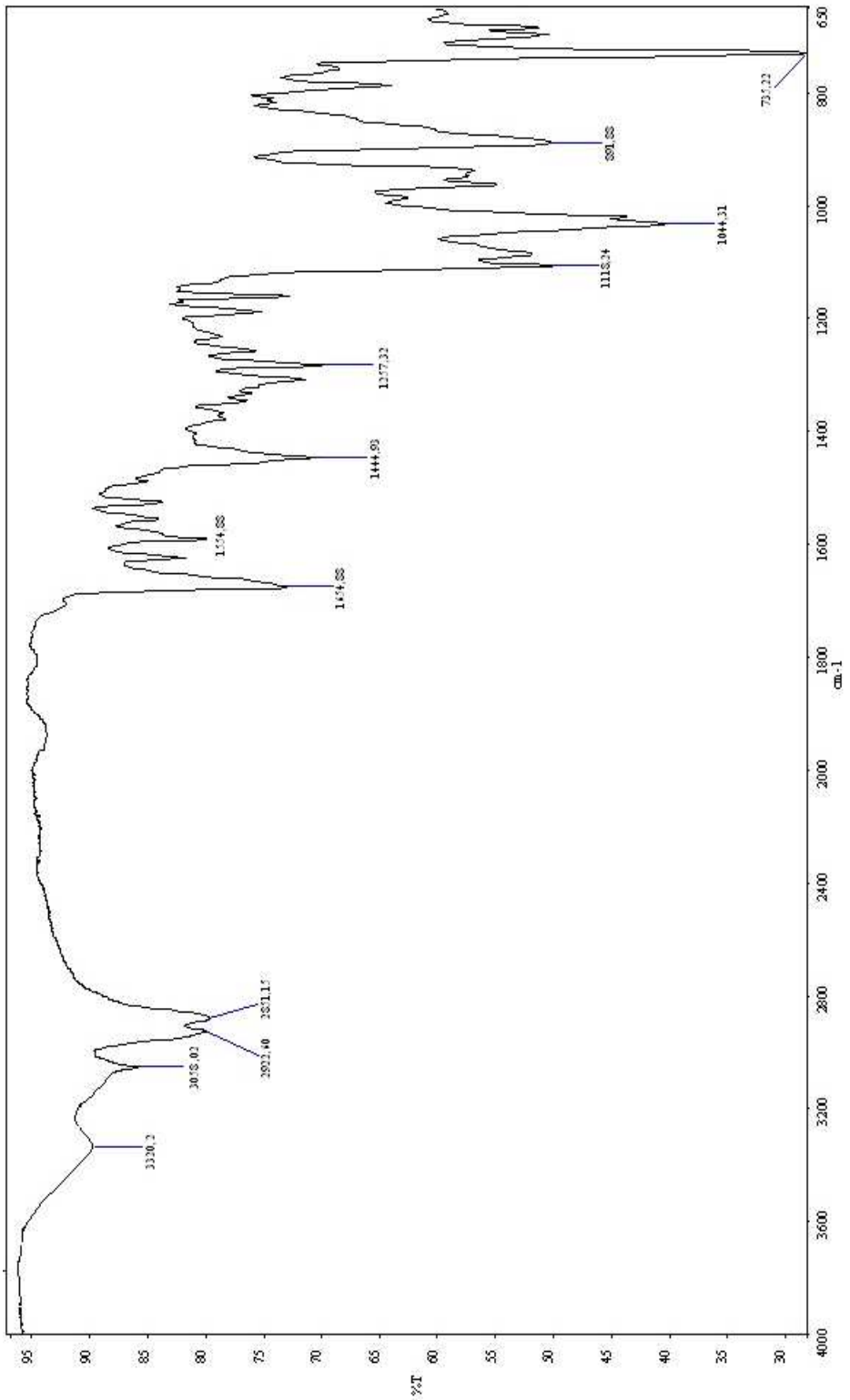
^{19}F NMR Spectrum of MgPz (**3a**).

APPENDIX J



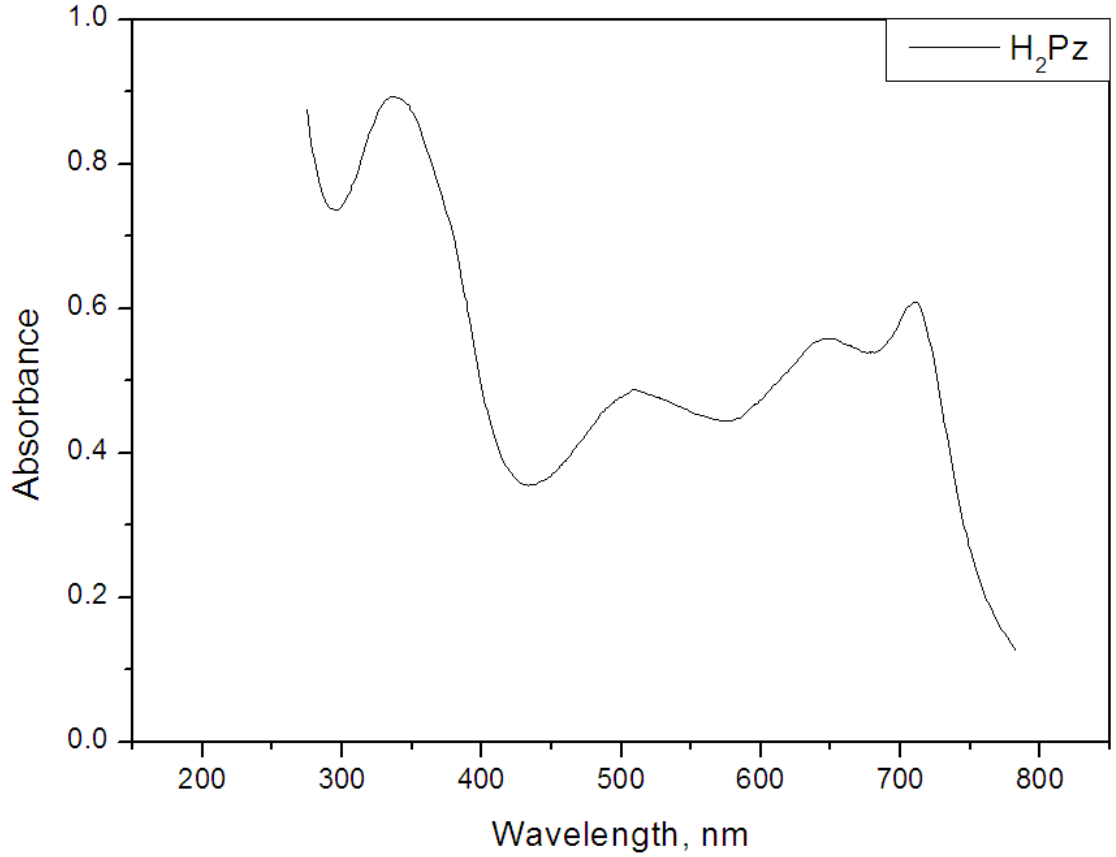
Mass Spectrum of MgPz (**3a**).

APPENDIX K



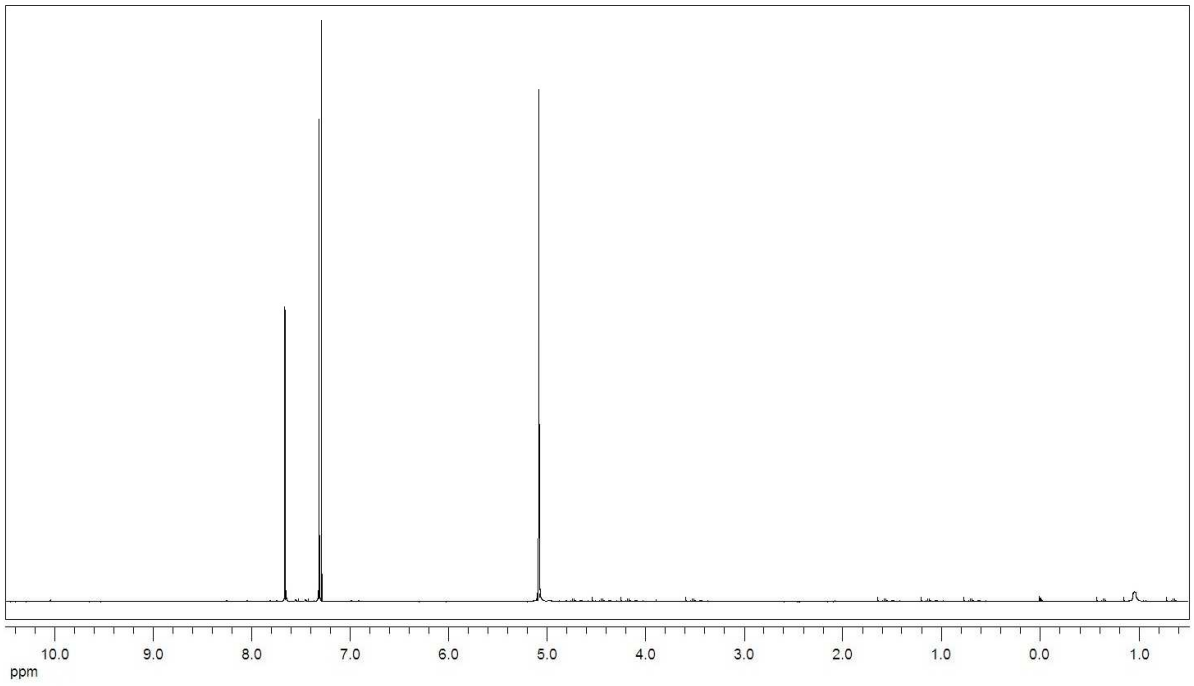
FT-IR Spectrum of H_2Pz (**3b**).

APPENDIX L



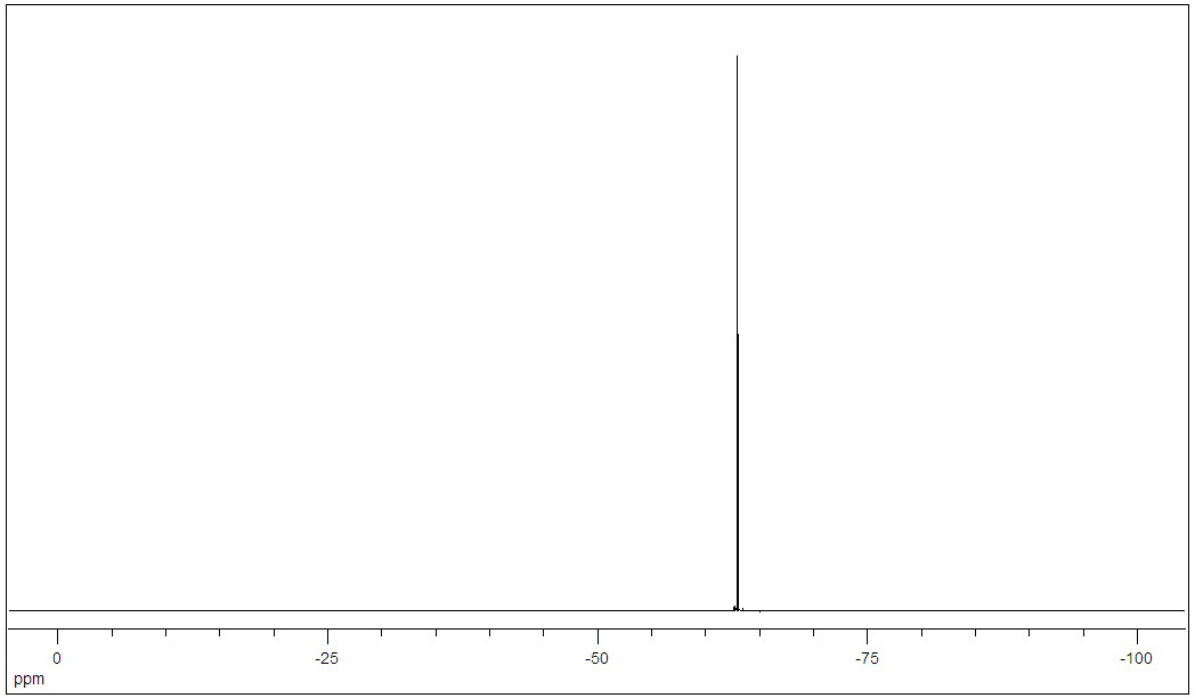
UV-Vis Spectrum of H_2Pz (**3b**) in $CHCl_3$.

APPENDIX M



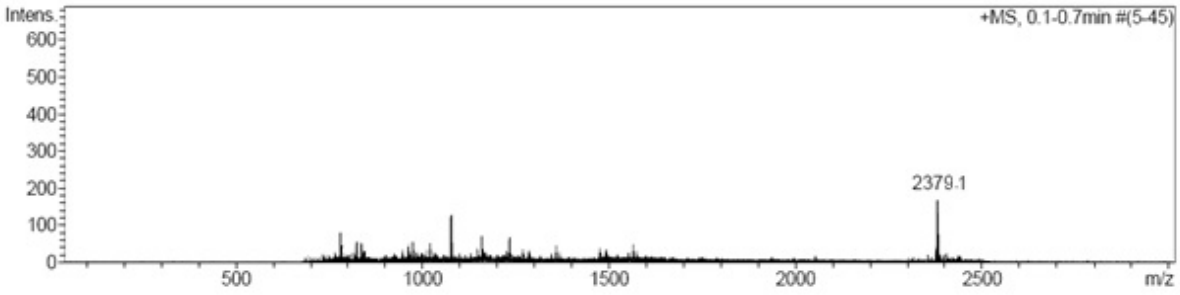
^{1}H NMR Spectrum of H_2Pz (**3b**).

APPENDIX N



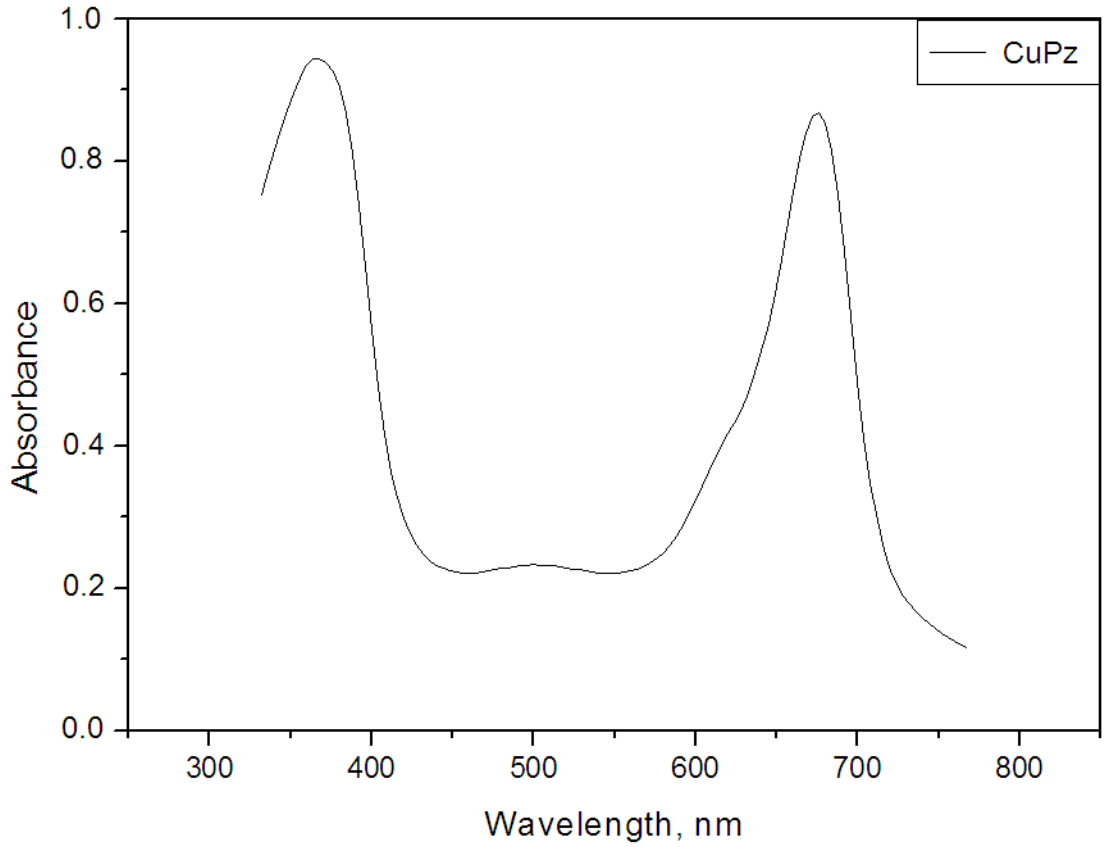
^{19}F NMR Spectrum of H_2Pz (**3b**).

APPENDIX O



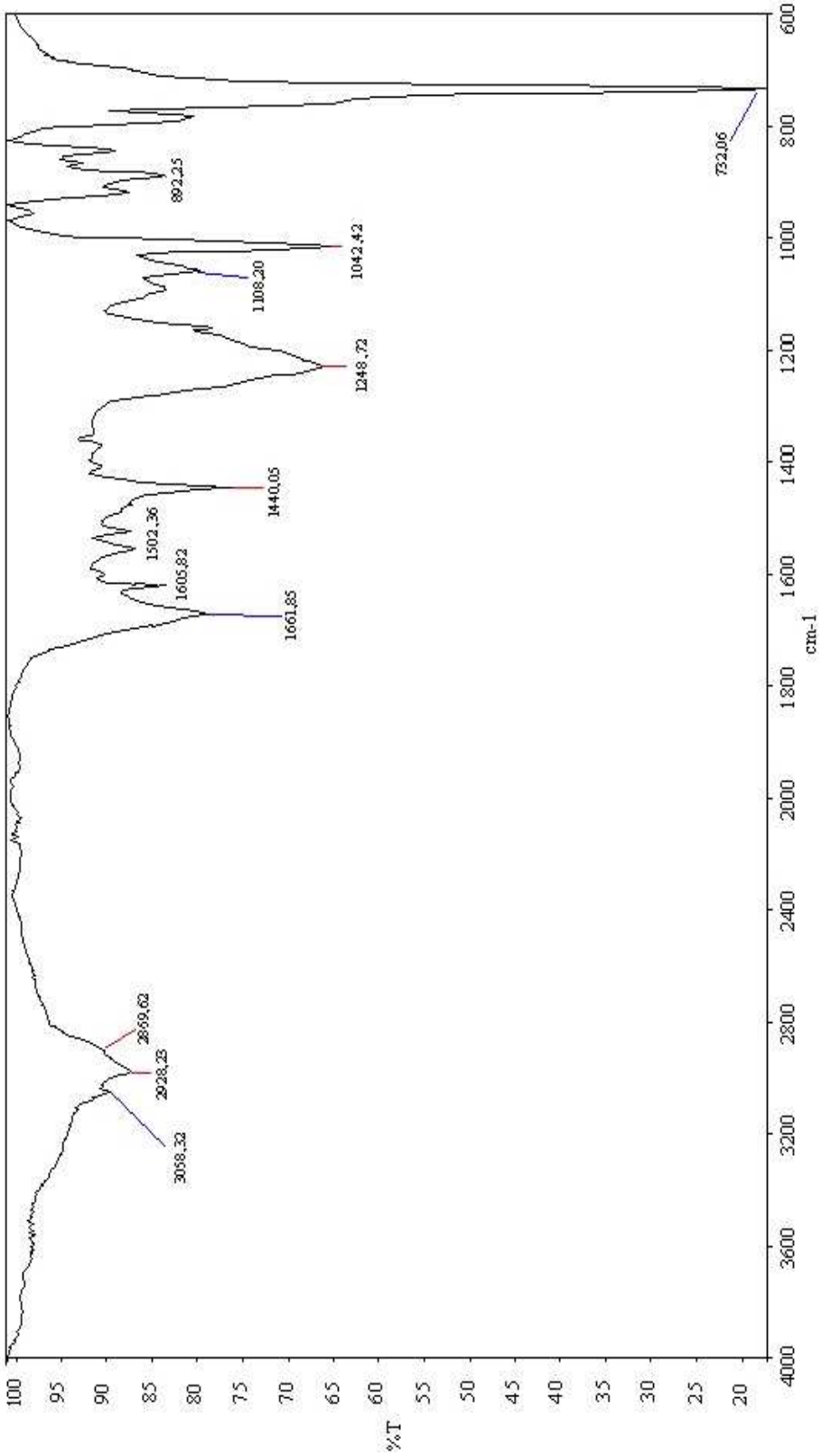
Mass Spectrum of H_2Pz (**3b**).

APPENDIX P



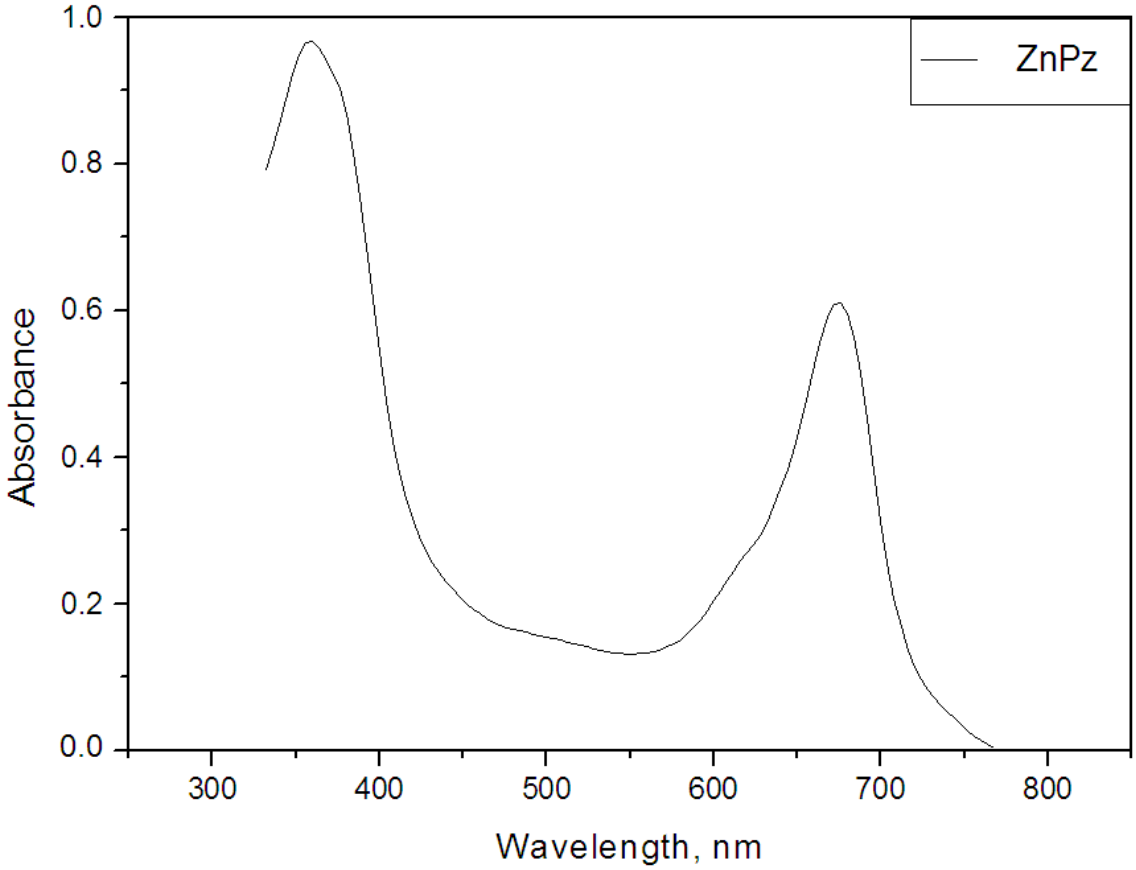
UV-Vis Spectrum of CuPz (**3c**) in $CHCl_3$.

APPENDIX Q



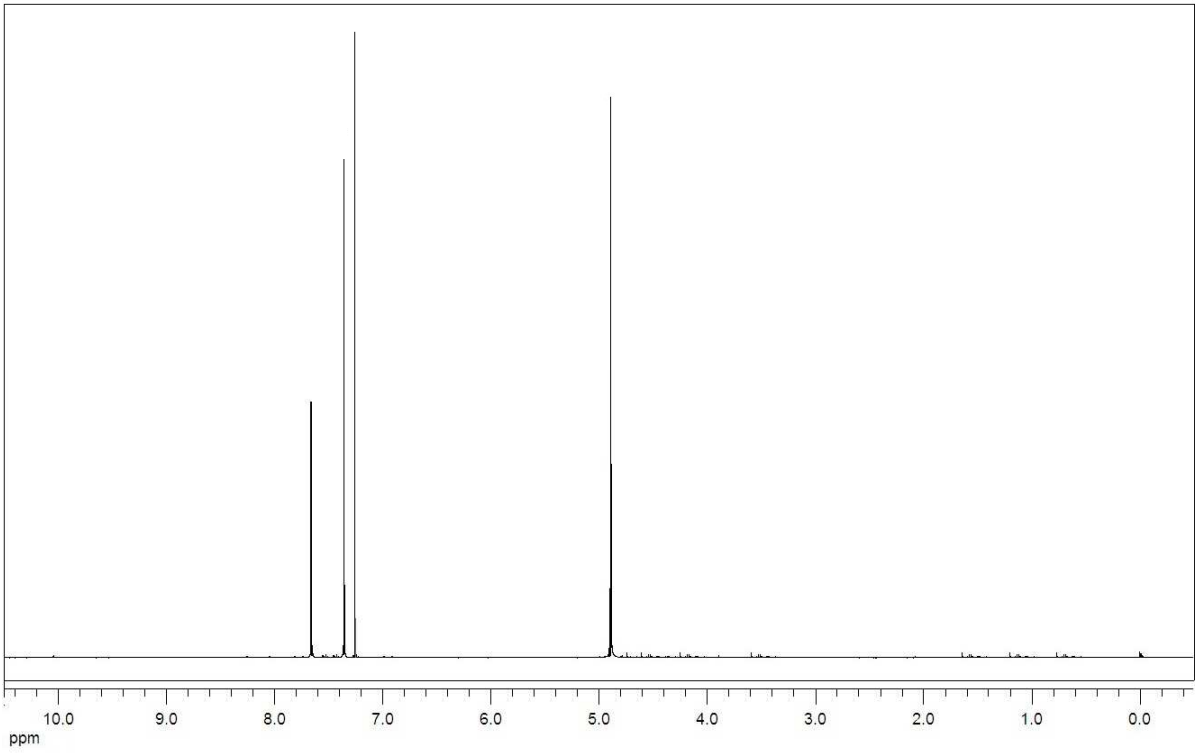
FT-IR Spectrum of ZnPz (**3d**).

APPENDIX R



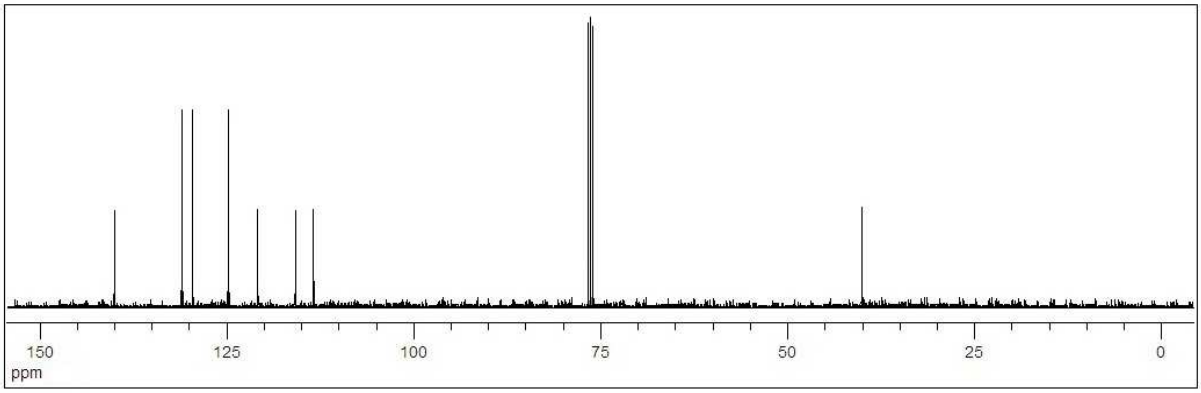
UV-Vis Spectrum of ZnPz (**3d**) in $CHCl_3$.

APPENDIX S



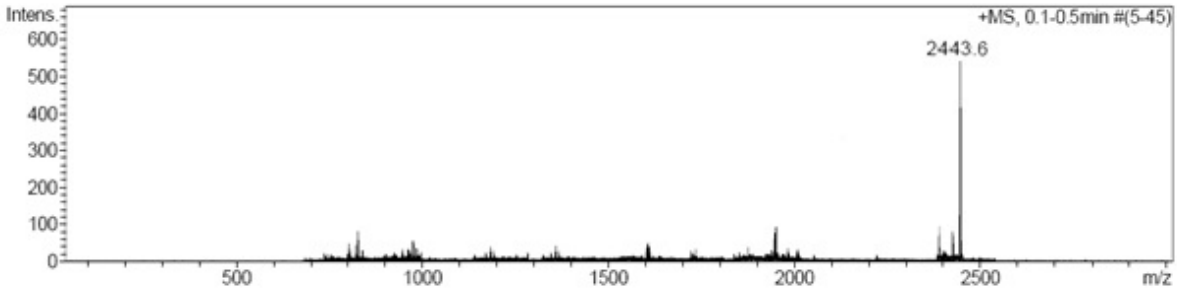
^{1}H NMR Spectrum of ZnPz (**3d**).

APPENDIX T



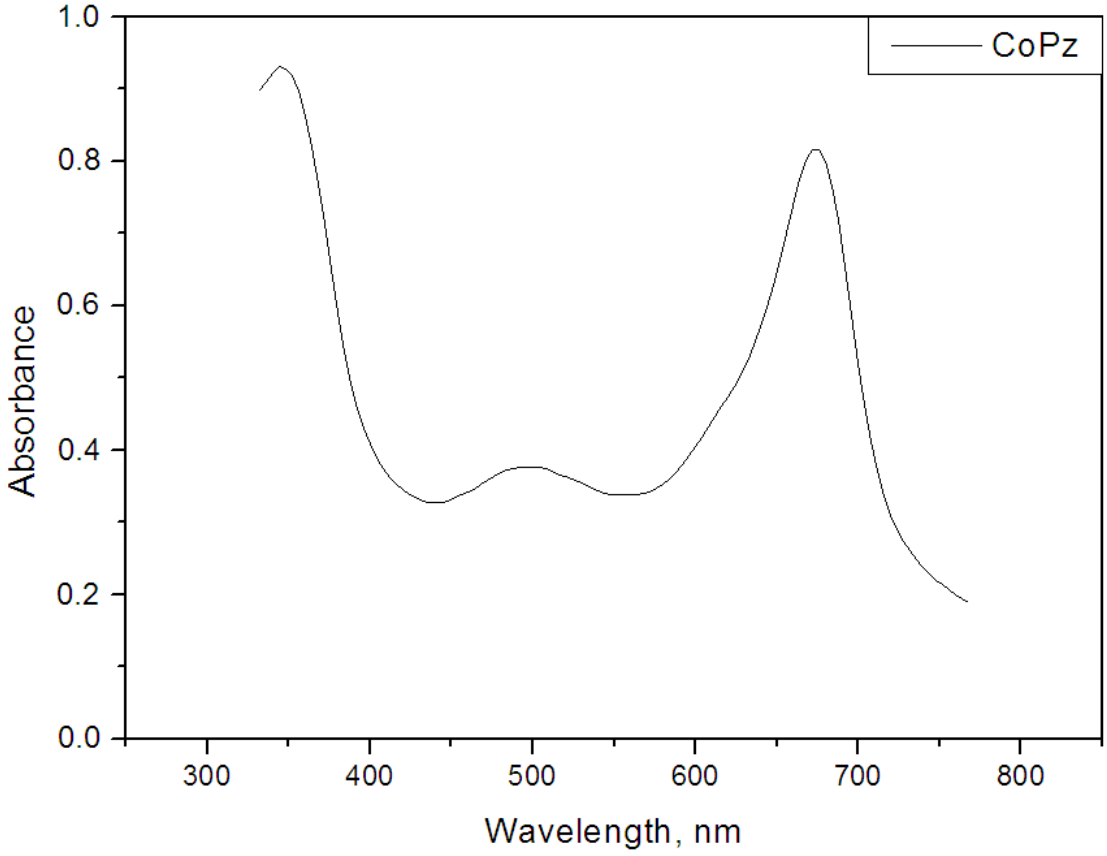
^{13}C NMR Spectrum of ZnPz (**3d**).

APPENDIX U



Mass Spectrum of ZnPz (**3d**).

APPENDIX V



UV-Vis Spectrum of CoPz (**3e**) in $CHCl_3$.