This is to certify that the

thesis entitled

Synthesis of the Tetrapyrrolic Macrocycle 3,4,8,9,17,18,22,-23-Octamethyl-30,31,33,34-Tetraazaheptacyclo[23.3.1.1^{2,5}.1^{7,10}.1^{11,15}.1^{16,19}.1^{21,24}]Tetratriaconta-1,3,5,7(33),8,-10,15(32),16,18,20,22,24(30),25(29-Tridecaene

Presented By

Robert Allan Berger

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Chemistry

Eugene LeGoff
Major professor

Date December 8, 1977

SYNTHESIS OF THE TETRAPYRROLIC MACROCYCLE 3,4,8,9,17,18,22,23-OCTAMETHYL-30,31,33,34-TETRAAZAHEPTACYCLO[23.3.1.1^{2,5}.1^{7,10}.1^{11,15}.1^{16,19}.1^{21,24}]TETRATRIACONTA-1,3,5,7(33),8,10,15(32),16,18,20,22,24(30),25(29)-TRIDECAENE

By

Robert Allan Berger

A DISSERTATION

Submitted to

Michigan State University

in partial fulfillment of the requirements

for the degree of

DOCTOR OF PHILOSOPHY

Department of Chemistry

1978

ABSTRACT

SYNTHESIS OF THE TETRAPYRROLIC MACROCYCLE 3,4,8,9,17,18,22,23-OCTAMETHYL-30,31,33,34-TETRAAZAHEPTACYCLO-[23.3.1.1^{2,5}.1^{7,10}.1^{11,15}.1^{16,19}.1^{21,24}]TETRATRIACONTA-1,3,5,7(33),8,10,15(32),16,18,20,22,24(30),25(29)-TRIDECAENE

By

Robert Allan Berger

The synthesis of the next higher member of a family of vinylogously ring expanded tetrapyrrolic macrocycle 25,26,27,28-tetraazapentacyclo[20.2.1.1^{3,6}.1^{10,13}.1^{15,18}]octacosa-1,3,5,-7,9,11,13(27),14,16,18,20,22(25),23-tridecaene, $\underset{\sim}{I}$, of which the porphyrins are the first members is described. The condensation of 1,3-bis(3,4-dimethylpyrrol-2-yl)cyclohex-1-ene with 1,3-bis(5-formyl-3,4-dimethylpyrrol-2-yl)cyclohex-1-ene followed by air oxidation gave 3,4,8,9,17,18,22,23-octamethyl-30,31,33,34-tetraazaheptacyclo[23.3,1.1^{2,5}.1^{7,10}.1^{11,15}.1^{16,19}-.1^{21,24}]tetratriaconta-1,3,5,7(33),8,10,15(32),16,18,20,22,24-(30),25(29)-tridecaene, $\underset{\sim\sim}{II}$. Both $\underset{\sim\sim}{II}$ and its diprotonated salt were deep green and exhibited an intense Soret-like absorption at 477 nm. The PMR spectrum indicated that $\underset{\sim\sim}{II}$ was diatropic as expected in a [22]annulene. Spectral data are presented for the structural proof of $\underset{\sim\sim}{II}$ and its precursors.

To my wife, Janet,

who gave constant

faith and encouragement;

To my parents,

Cleva and Calvin Berger,

who never stopped believing

and gave me so much.

ACKNOWLEDGMENTS

I would like to thank the Department of Chemistry at Michigan State University for providing financial support in the form of a teaching assistantship for the past four and one-half years. I would also like to express my appreciation to Professor Eugene LeGoff for his very patient guidance, his careful and constructive evaluation of my ideas, and for arranging financial support through the thin summers.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Since the early days of organic chemistry the aromatic compounds have been a source of considerable thought and constant argument as to their structure and chemical behavior. Work in the middle of the nineteenth century had shown only that aromatic compounds generally possessed a high percentage of carbon to hydrogen, but nothing was determined about their structures. The ability of aromatic compounds to undergo substitution reactions while staying inert to most addition reactions was baffling. In 1865, the first tentative approach to their structure was given by Kekule in his report that benzene's structure was satisfied by a six-membered cyclic molecule of alternating single and double bonds with the remaining valence used for substitution reactions.[1] However, his work required further clarification since the number of isomers in multi-substitution reactions was less than what was predicted by his structure.[2] (See 1 and 2). He proposed that the double and single bonds interchanged rapidly such

1

2

that it is possible to separate only the reported number of isomers. Many other structures proposed for benzene disappeared quickly since they failed to explain experimental data. That double and single bonds might be able to interchange was not considered a problem since 1,4-addition to conjugated systems was known. Although why they behaved so was a mystery.

Further clarification was presented by Thiele[3] when he proposed the concept of partial bonds existing when double bonds were in conjugation. He proposed that in benzene there were no discrete single or double bonds in the ring but six partial bonds that were equivalent. Conjugation would be a mixing of bond character. Benzene and aromatic compounds are the extreme case giving total equivalency, while 1,4-addition across butadiene gives partial mixing of bond character. This approach was not accepted since it predicted that all cyclic compounds containing alternating double bonds should be aromatic. The subsequent synthesis of cyclooctatetraene in 1913[4] showed that there must be something else in the definition of an aromatic compound. Since aromatic compounds containing a large number of carbon atoms were unknown, a gentle nudge was required from outside work before anything more could be accomplished. This nudge came with the discovery of the electron. Armit and Robinson[5] proposed that the electron was the particle most likely responsible for the concept of valency, and that electrons

in aromatic molecules somehow behaved similarly to those in closed shells of the noble gases. This brought back the older idea of bonding equivalency and was used to give a new structure for benzene; i.e., a hexagon enclosing a circle,

All the work to this time was useful, but nothing was proposed as to why the "aromatic sextet" was so unique. The mathematics of quantum mechanics became the next step. The valence bond theory by Heitler-London[6] and the molecular orbital theory by Hückel[7] tried to explain aromaticity on the basis of ground state energies versus transition state energies that occurred during reactions. These two theories were the first to explain why aromatic reactions were so different from alkene reactions. Hückel also predicted what new compounds could be expected to exhibit aromatic character. Both theories worked with varying degrees of success, yet this was considered reasonable since both were designed with different assumptions.

In valence bond theory, a molecule is regarded as a group of atoms being brought together while still retaining a large degree of their individual character. A specific

valence bond is considered to involve only two atoms, and each bond is based on the overlap of atomic orbitals. Then the symmetry of aromatic molecules requires explanation by the concept of "resonance". Whenever more than one molecular structure can be drawn for a molecule and the only difference is the location of the electrons, that molecule is said to possess resonance. Structures 1 and 2 are resonance pictures of benzene since six electrons in three bonds are shifted to give different structures of benzene. The difference between the theoretical energy of a particular resonance structure and the experimentally determined energy is called the resonance energy. For benzene, the resonance energy is determined by comparing its energy to that of three isolated olefinic bonds.

A major shortcoming of the valence bond theory is that it predicts a stabilizing resonance energy for cyclobutadiene and cyclooctatetraene.[8] Since this has not been observed, its use as a predicting theory has been tarnished. While not completely correct in its interpretation of aromaticity, the valence bond theory has been of major importance. Its approach uses structures that the chemist is more familiar with and hence, easily understandable.[9]

The molecular orbital (MO) theory, as developed by Hückel, treats bonding as bringing the orbitals of two or more atoms together to form a linear combination of atomic orbitals which produces an equal number of molecular orbitals of stable and unstable energies. The electrons are placed

in molecular orbitals filling the lowest energy orbitals first and each succeeding orbital, according to Hund's Rule and the Pauli Exclusion Principle, until all the electrons have been used. While not as easy to visualize as the commonly accepted two-electron bond, the predictive power of Hückel's MO theory led to his discovery of a general rule which is known as Hückel's Rule. It states that "amongst fully conjugated, planar monocyclic polyolefins only those possessing $(4n + 2)$ π-electrons, where n is an integer, will have special aromatic stability."[6] As a corollary, all similar systems containing $4n$ π-electrons will not possess any special aromatic stability and should be unstable if all bonds are equivalent. This rule has been found to work for many compounds.

Large, fully-conjugated, monocyclic ring systems have shown that Hückel's Rule and MO theory are not valid beyond a certain size. As n gets larger MO theory predicts that the resonance energy should constantly increase, while the energy difference between $(4n + 2)$ and $4n$ π-electron systems should approach zero (see Figure 1).[10] Only the latter has been shown to be true for the larger annulenes. Beyond a 22 π-electron macrocycle, some predicted aromatic annulenes have been shown to act as polyolefins,[11] while [22] annulene is still aromatic as indicated by PMR studies (see below).[12] Further, the delocalization energy of the annulenes does not increase with size. MO theory also predicts resonance stabilization for even the $4n$ series, which has not been

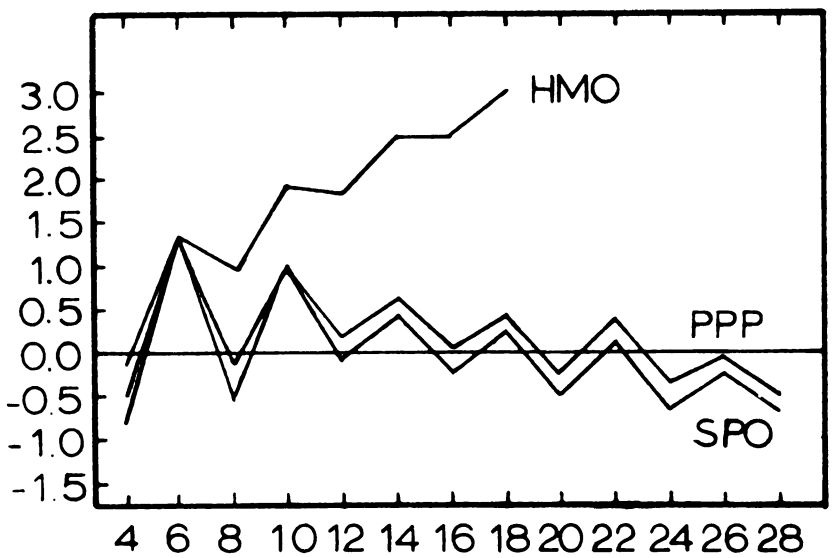


Figure 1. Graph of delocalization energy vs number of π-electrons as calculated by HMO, PPP, and SPO methods.

reported. The smaller members of the 4n series have been shown to be destabilized, when planar, which means a negative stabilization energy.[13] On this basis, MO theory gives good qualitative predictions for determining aromatic compounds, but is still a poor method for obtaining quantitative values for delocalization energies.

Since 1931 many other theories have been proposed which tried to remove inconsistencies such that better qualitative values could be obtained using fewer or more logical approximations in the calculations. In 1965, Dewar[10] published some results where he used three methods to determine the delocalization energies of the annulenes; i.e., the simplest of the conjugated ring systems. The three methods, as seen in Figure 1, are the Hückel MO theory; the PPP method, a

combination of Pople's method with Pariser and Parr values; and the SPO or split p-orbital method. The latter two methods compensate for some of the approximations used in the MO theory; i.e., the assumptions of a planar polygon geometry, equal carbon-carbon bond lengths, and no electron-electron repulsions. The MO results are useful, but the two new methods have shown more reasonable agreement with available experimental data. All three methods agree that relative stability energies approach a constant value as $\underset{\sim}{n}$ gets larger. However, the PPP and SPO methods are consistent with experimental data showing there is no stabilizing energy when $\underset{\sim}{n}$ becomes too large a number. The PPP and SPO methods do account for the negative delocalization energies of anti-aromaticity[14] of the 4n series and show at approximately what value of $\underset{\sim}{n}$ the (4n + 2) system becomes a non-aromatic polyolefin. Experimental observations of [22] annulene[12] show it is aromatic while a [26] annulene[11] is non-aromatic.

Based on his calculations Dewar proposed a definition for aromaticity that stated:[15] Cyclic conjugated systems are considered aromatic if cyclic delocalization of electrons makes a negative contribution to their heats of formation. Dewar's work has been confirmed by Figeys[16] even though there is still disagreement with experimental work on how rapidly the resonance energy decreases for the (4n + 2) systems as $\underset{\sim}{n}$ gets larger.

A major problem that existed with the Dewar and Hückel works was how to determine quickly if a compound was aromatic.

Their works used resonance energy for the definition of aromaticity. Two tedious experimental methods, heats of combustion and hydrogenation, were the only ways to verify aromaticity. Fortunately, a much simpler method exists through the diamagnetic anisotropy[17-19] of aromatic molecules. The major benefit of this property is that paramagnetic and diamagnetic effects may be observed through chemical shifts in the nuclear magnetic resonance of protons (PMR) on the exterior or interior of the ring.[20] Such an effect is observed when an aromatic molecule in the ground state is perturbed very slightly in the presence of a magnetic field.

The principle requires a closed conjugated path where the π-electrons would be free to circulate around the molecule. If an external magnetic field, H_o, was then added, a "ring current" would be induced due to the flow of π-electrons on the circular path. The "ring current" would in turn produce its own small magnetic field, H'. If the induced current is perpendicular to H_o, then H' would oppose H_o and create shifts that would be discernable by PMR. (See Figure 2).

As illustrated in Figure 2, a proton external to the ring feels a positive enhancement of the applied magnetic field by the induced magnetic field. The net effect on this proton is that it is shifted to a lower field than what is found for an isolated proton. Conversely, a proton inside the ring is shifted to a higher field since the induced magnetic

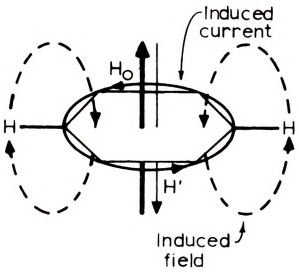


Figure 2. Illustration of diamagnetic ring current effect.

field is opposed to the applied field. Such a phenomenon is due to a diamagnetic ring current and molecules which exhibit this property are called diatropic.[21] The opposite effect, where external protons are shifted upfield and interior protons shifted downfield, is due to a paramagnetic ring current and molecules which exhibit this effect are called paratropic.[21] A third term, atropic, is used to describe molecules in which no ring current effects are seen. Earlier use of the term "non-aromatic" has been replaced by paratropic and atropic since the two effects are different and it is necessary to differentiate between the two forms. Currently, a molecule which possesses diamagnetic anisotropy cannot give a quantitative value to the degree of aromaticity through PMR, but as long as protons are available on the

ring this effect is an excellent qualitative determination of π-electron delocalization.

Sondheimer has made extensive use of this phenomenon for the determination of π-electron delocalization in the annulenes. Since these molecules contain a large number of internal and external protons in differing numbers, they are well suited to this technique. Sondheimer has determined the PMR spectra for a series of [4n] annulenes and [4n + 2] annulenes and found them to be paratropic and diatropic, respectively.[11,22] Some of the larger annulenes were also studied and these gave chemical shifts of isolated olefinic protons of atropic character. Since this technique can also be used to detect diatropism in hetero-aromatics, e.g., porphyrins, it is a simple method for determining if a molecule can possess a ring current and, therefore, be aromatic.

Another method for the determination of aromatic character is through study of the uv-visible spectra of aromatic molecules. In Hückel's MO theory, aromatic compounds have degenerate highest filled and lowest unfilled orbitals. The absorption of light in the visible and ultraviolet region corresponds to electronic transitions from lower to higher energy states. When the number of possible transitions between the highest filled and lowest unfilled orbitals is determined for an aromatic compound, its spectrum may be predicted as to wavelength and relative intensity of each band. An interesting development is that for a series of related aromatic

compounds the uv-visible spectra can possess the same general shape.[23] If the spectrum has been obtained for one aromatic compound, e.g., benzene, then a larger aromatic homolog, e.g., [18] annulene, may have a spectrum that only differs in its shift to a lower energy. Consequently, the spectrum of a new compound, when compared to a known aromatic compound's spectrum, can be used to determine whether the new compound is a homologous molecule, i.e., aromatic. The use of UV-Visible spectrophotometry to discover aromaticity is not as qualitative as PMR spectrometry, since substitution effects may be large. Together, the two methods can be useful techniques for the determination of aromaticity in new molecules.

From this brief history of aromatic compounds, the arguments for determining just what is meant by aromaticity have been presented:

(1) A high percentage of carbon to hydrogen led to alternating double bonds;

(2) Equivalent bonds were explained by rapid interchanging, then partial bonds, then a magical "aromatic sextet";

(3) Quantum mechanics gave valence bond theory, molecular orbital theory, Huckel's Rule, the PPP method, and SPO method.

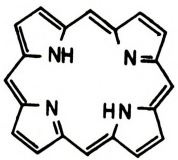
The expansion from benzene to benzenoid to non-benzenoid species has broadened the boundaries of the definition of aromaticity to what is now used. Also, the determination

of aromaticity has been simplified. Early use of heats of combustion or hydrogenation has changed to the use of PMR chemical shifts for proving the predicted diatropism or paratropism from calculations proposed earlier.

PURPOSE OF THIS INVESTIGATION

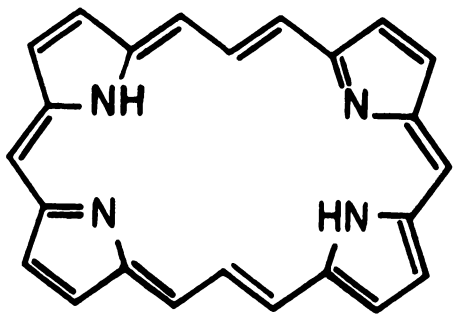
Sondheimer has determined that π-electron delocalization is detectable by PMR spectrometry for a large number of annulenes and dehydroannulenes. He also found a 22 π-electron system to be diatropic,[12] while a 24 π-electron system was paratropic.[24] There is some argument as to whether or not a 26 π-electron system is aromatic.[11,25,26] A major problem with many annulenes is that aromaticity can be temperature dependent, due to flexibility in their rings. It is possible that no diatropic effect was seen, since the molecules were in a conformation that was unfavorable to a ring current. This investigation was proposed to produce a system that would be rigid enough to show if the Sondheimer results were viable for all macrocyclic molecules.

Perhaps the best known aromatic macrocyclic system is that of the porphyrins, 4. Porphyrins are very stable 18 π-electron molecules, incorporating four pyrrole rings in



4

their structures. If the meso-bridges could be expanded from one carbon to three or five carbons, this system could prove ideal for the rigid structure required in the proposal. Several methods have been devised for extending the meso-bridges,[27-29] and this investigation tried to use them in the preparation of a new macrocyclic compound. Since new territory was being explored, it was decided to make the next larger homo-porphyrin that should prove to be di-atropic; i.e., a 22 π-electron system. This molecule would possess alternating trimethine and methene meso-bridges. We propose to call this the platyrin* system, 5.



5

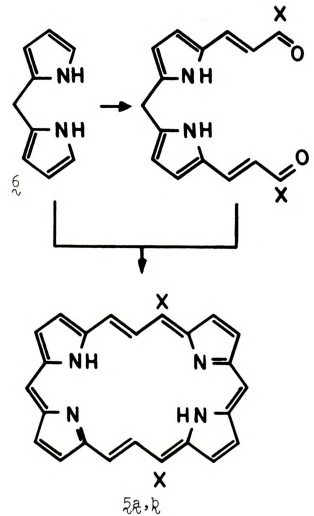
*From the Greek word "platys", (meaning broad or wide) and the -rin suffix (from porphyrin).

INITIAL ATTEMPTS TO SYNTHESIZE PLATYRIN

If classical porphyrin syntheses were to be followed, two main ways of building the platyrin system would be suggested:

(1) Build the 2,2'-dipyrrylmethane, 6, and place three-carbon handles on the free α-positions for use in a later condensation with another molecule of 6 to form 5 (5a, X = CH_3; 5b, X = H); (see Scheme 1)

Scheme 1



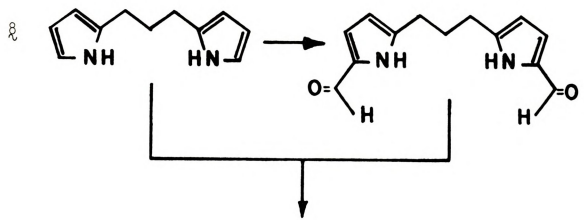
6

7a,b

5a,b

(2) Build the 2,2'-dipyrrylpropane, 8, place one-carbon handles on its free α-positions and condense with another molecule of 8 to form 5. (See Scheme 2)

Scheme 2

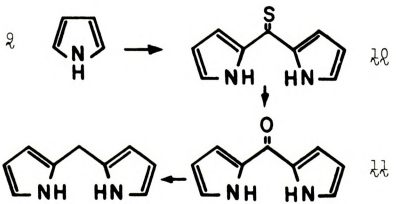


5

Each of these schemes required the oxidation of the newly-formed macrocycle to the platyrin. We decided to use air in each case, since many porphyrin syntheses were successful when air was used as the oxidizing agent.

We decided to attempt Scheme 1 first, since there existed an easy preparation of 6 from pyrrole, 9.[30,31] (See Scheme 3)

Scheme 3



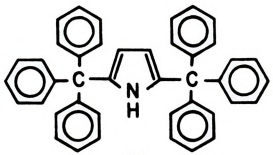
Pyrrole was nucleophilic enough to react with thiophosgene to give 2,2'-dipyrrylthione, 10. Thiones, when treated with basic peroxide, gave ketones. This method was used to make 2,2'-dipyrrylketone, 11. The reduction of 11 was achieved through sodium borohydride and morpholine treatment to give 6.

The three-carbon functional groups were also easily synthesized since pyrroles with free α-positions undergo a Michael reaction with α,β-unsaturated carbonyl compounds.[32] Two methanes were synthesized (7a, X = CH_3; 7b, X = H) using 3-butyn-2-one and propargyl aldehyde.[33]

It was at this point that Scheme 1 failed, since the final condensation to form the macrocycles, 5a and 5b, required an acid catalyst. It had been hoped that the condensation would occur more rapidly than any side reactions. Unfortunately, a mineral acid was required, and in all cases, the decomposition of the existing methane bridge was the first reaction. This was followed by rapid polymerization of the unprotected pyrroles. The characteristic chromophore of a dipyrryltrimethine at 580 nm could be observed, but no material could be isolated which could be identified.

A curious side reaction of this scheme occurred while searching for a strong acid that might be used for the condensation. We proposed to try a compound which is not generally used as an acid, triphenylmethyl tetrafluoroborate, 12. A model system was set up under anhydrous

conditions where 2-pyrrylaldehyde and pyrrole were treated with 12 in acetonitrile. A colorless crystalline precipitate was immediately formed as the only recoverable compound. It was identified through CMR spectrometry as 2,5-bis(triphenylmethyl)pyrrole, 13. Triphenylmethyl-2-pyrrole, 14, has been made in quantitative yields from triphenylcarbinol and pyrrole in refluxing acetic acid,[34] but this



13

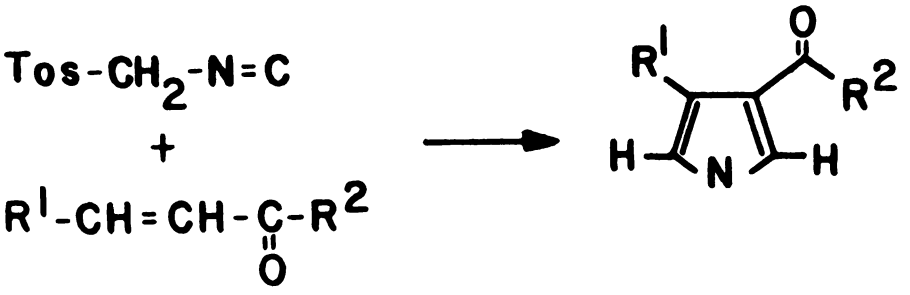
was the first reported synthesis of the bis-adduct. None of compound 14 was isolated from the reaction. A second reaction was set up using only pyrrole, and 13 was the product again. No reaction occurred with 2-pyrrylaldehyde.

Although the methane bridges in 7a and 7b seemed to be too sensitive to work with, it was still desired to use pyrrole as our starting material. We hoped that a dipyrrylpropane would be more stable to acid. Consequently, we switched to Scheme 2 and set out to make 8. Three-carbon bridges had been made by condensing pyrroles and

1,3,3-triethoxypropene,[29] to give dipyrryltrimethines. If the dipyrryltrimethine could be made from pyrrole and reduced, compound 8 would be made. Each time the reaction was tried, it would turn deep blue, as is characteristic of dipyrryltrimethines, but the only product obtained was an insoluble tar. For the reaction to proceed, a heavily substituted pyrrole was necessary or the product quickly decomposed.

Once again a new plan of attack was needed. All the pyrroles used had been unprotected on their β-positions, and we felt that this might have contributed to the poor yields of the desired products. While it is known that the α-positions of the pyrroles are more nucleophilic than the β-positions, the difference can be very slight and hard to control. Therefore, a good supply of β-protected pyrroles was required to eliminate reactions at the β-positions. If these pyrroles were not as acid-sensitive as unprotected pyrroles, a modified scheme, similar to Scheme 2, could be used to make a substituted platyrin. Van Leusen gave a source of 3,4-disubstituted pyrroles, when he reported a new general synthesis using tosylmethylisocyanide (TosMIC).[35] Under basic conditions, TosMIC reacted with α,β-unsaturated ketones, esters or nitriles to give 3-acyl-pyrroles, pyrrole-3-carboxylates and 3-cyanopyrroles, respectively. (See Scheme 4) The only problem with this approach was that these pyrroles were unsymmetrical. It would be very difficult to synthesize just

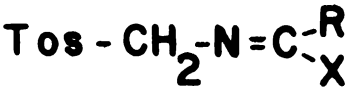
Scheme 4



(Where R^1 = aryl, alkyl, or H; R^2 = aryl, alkyl, or alkoxide)

one product in further reactions, since there were two non-equivalent, reactive α-positions on each pyrrole.

A later paper by van Leusen[36] apparently solved this nonequivalency problem when he reported the synthesis of 2,3,4-trisubstituted pyrroles using N-tosylmethylimino compounds, 15.

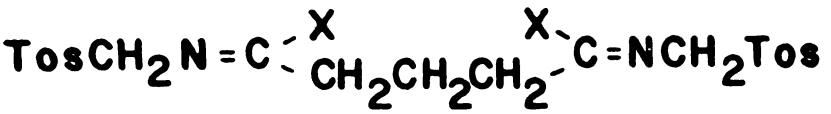


15

(Where R = alkyl, aryl; X = OCH_3, SCH_3)

The major advantage to this method was that the functional group on the 2-carbon could be an alkyl group such as propane. We proposed to make a bis-adduct connected by a three-carbon chain. After further reaction, the product would be a 1,3-dipyrrylpropane. We wanted N,N'-bis(tosylmethyl)-

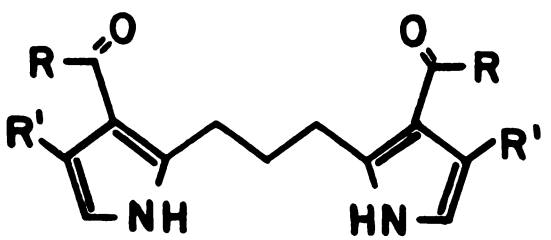
glutarimine, 16a,b, to react with an α,β-unsaturated ketone. This would give a 1,3-bis(3-acyl-4-alkyl-2-pyrryl)propane,



16a,b

(For 16a, X = OCH_3; for 16b, X = SCH_3)

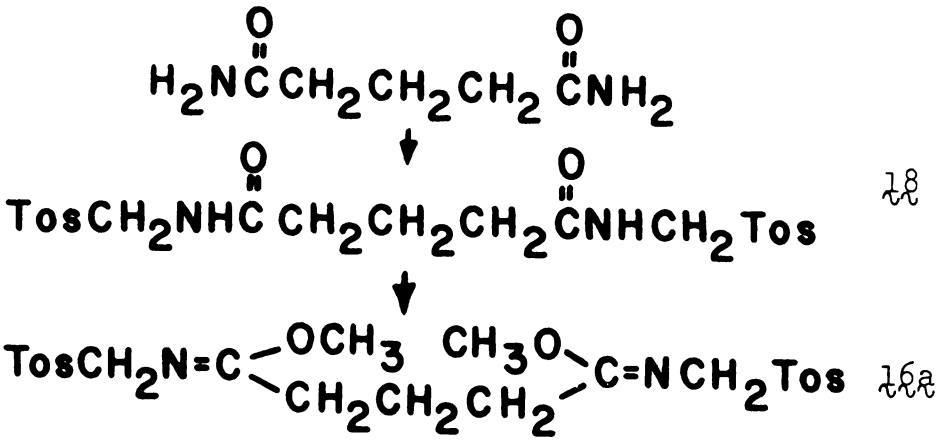
17. Using this approach, only one dipyrrylpropane would be synthesized.



17

Sodium p-toluenesulfinate, formaldehyde and glutaramide were condensed together in acid to give N,N'-bis(tosylmethyl)-glutaramide, 18. Compound 18 was then O-methylated with methyl fluorosulfonate (Magic Methyl) to produce dimethyl-N,N'-bis(tosylmethyl)glutarimidate, 16a. (See Scheme 5) Compound 16a was believed to be a mixture of <u>syn</u> and <u>anti</u>

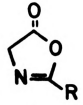
Scheme 5



isomers, since the PMR spectrum showed two unequal singlets at δ3.93 and 3.88 for the methoxy hydrogens. Attempts to make 17 from 16a were unsuccessful. Van Leusen[36] reported success using only methyl groups for "R" in Compound 15 in making a pyrrole. However, he was able to place a phenyl ring on the 2-carbon of a pyrrole if the reaction was run through a thioimine intermediate. Following this approach, Compound 18 was converted into N,N'-bis(tosylmethyl)thioglutaramide, 19, using P_2S_5 in p-dioxane. However,

S-methylation with Magic Methyl gave no identifiable material. Apparently, steric hindrance kept the pyrroles from forming, or the requirement of two reactions on the bis-adduct kept the yields too low for further work.

A second method for making 1,3-dipyrrylpropanes with the β-positions blocked was attempted through the use of Δ^2-oxazolium-5-ones, 20,[37] which were made by dehydrating amino acids. Such a synthesis would have proceeded as in Scheme 6.



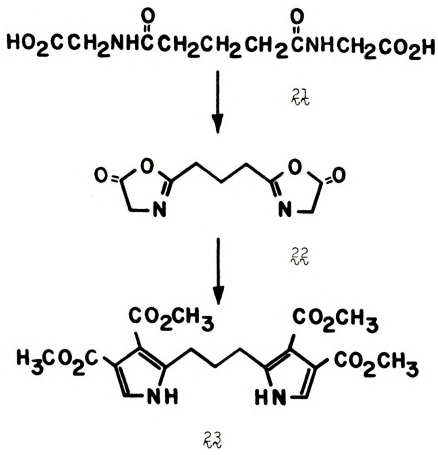
(Where R = alkyl)

20

Glycine and glutaroyl chloride were condensed to form N,N'-bis(glycyl)glutaramide, 21. If 21 was heated gently in acetic anhydride it should have formed Compound 22. However, compounds like 20 are highly reactive, and when synthesized, they are usually converted into another product, in situ. With dimethylacetylenedicarboxylate, a 1,3-dipolar addition to 22 was possible, and this should have given 1,3-bis(3,4-carbethoxypyrrol-2-yl)propane, 23. None of Compound 23 was ever isolated.

Even with a deactivated pyrrole system as found here, a Michael-type addition by the nitrogen on α,β-unsaturated carboxylates has been reported[38] to occur when the pyrrolic

Scheme 6



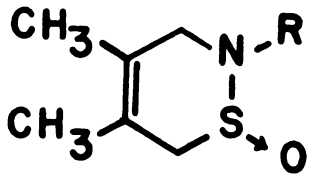
nitrogen is unprotected. Only a phenyl group on the α-position has prevented further reaction by the pyrrole.[39] The PMR spectra of the 1,3-cycloaddition reactions had always shown at least twice as many methyl groups as were desired. This led us to believe that a Michael-type reaction had occurred.

Since the new methods were unsuccessful for synthesizing a 1,3-dipyrrylpropane directly, another approach was tried.

First a 3,4-disubstituted pyrrole would be made, and then, the three-carbon linkage would be added between two pyrroles. Unless a symmetrical 3,4-disubstituted pyrrole could be easily made, the low yields inherent to unsymmetrical pyrrole reactions would have to be expected for the overall synthesis of platyrin.

SYNTHESIS OF THE PLATYRIN SYSTEM

Ideally, the pyrrole for the synthesis of the platyrin system should have both β-positions blocked with symmetrical functional groups that do not significantly reduce the reactivity of the unsubstituted α-positions. A compound similar to a 3,4-dialkylpyrrole was desired for the synthesis. Early in 1976, Ichimura, et al.[40] reported the synthesis of 3,4-dimethylpyrrole, 24, in good yields (34-48%) through a thiazine-1-oxide intermediate, 25. When 25 was treated with

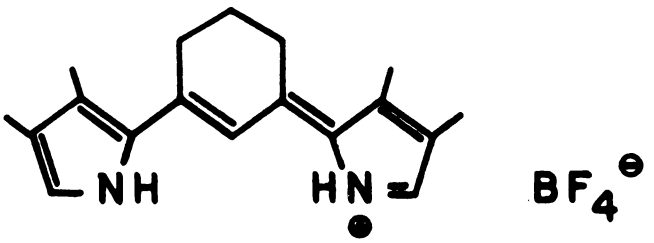


25

a strong base, 24 was isolated. Our group duplicated this work, since 24 seemed appropriate in our synthesis. However, some changes were necessary. When strong base was added to 25, the reaction was explosive and our yields were less than reported. A large excess of base was reported as necessary for good yields. We believed that 25 added to the base would fulfill this requirement. When this modification was tried, the reaction was much calmer and yields were increased to 50-55%.

Even with β-positions blocked, a trimethine formed from 24 and 1,3,3-trimethoxypropene might not be rigid enough

for later steps in the overall synthesis of platyrin. Consequently, we decided to make a bulky trimethine from the condensation of 24 and 1,3-cyclohexanedione.[27] This trimethine was 3,4,3',4'-tetramethyldipyrryl-2,2'-hexacyclotrimethine tetrafluoroborate, 26. Compound 26 was a blue, crystalline

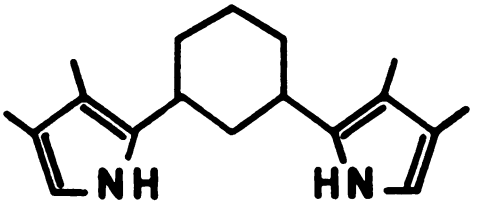


26

solid that could be characterized by PMR spectrometry. Some confusion occurred on the structure identification of 26, since the PMR location of the proton on the trimethine bridge was very solvent-dependent. The proton signal shifted through the α-pyrrolic hydrogen signal when the solvent was changed from deuterochloroform ($CDCl_3$) to deuterated dimethylsulfoxide (DMSO-d_6). In $CDCl_3$, the peak was at δ8.4 ppm while in DMSO-d_6, the peak was at δ7.2 ppm.

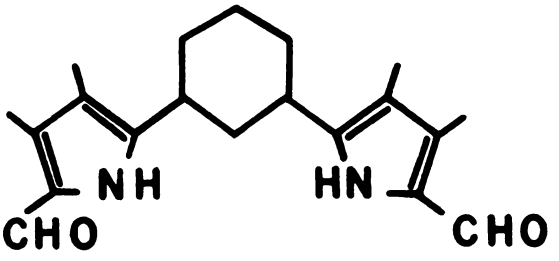
Since 26 now existed, it could be reduced and Scheme 2 would be viable again. A reduction of 26 was necessary since the conjugated system of a trimethine makes the α-positions of the pyrroles non-reactive to electrophilic attack by the reagents needed for further synthesis. However, a reduction with catalyst and hydrogen would remove the conjugation and reactivate the α-position on the pyrrole rings. The

reduction of 26 gave 1,3-bis(3,4-dimethylpyrrol-2-yl)cyclohexane, 27. Compound 27 was characterized by PMR spectrometry as a 1,3-disubstituted cyclohexane. Compound 27 was air-sensitive, as shown by a rapid color change when exposed to air. Therefore, 27 was always converted into another molecule



27

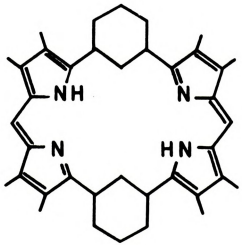
which was more stable. Since it was now possible to place functional groups on the remaining α-positions, 27 was usually converted into the next compound of Scheme 2. In this case, a formylation reaction with $POCl_3$/DMF was used to make, in 81% yield: 1,3-bis(5-formyl-3,4-dimethylpyrrol-2-yl)cyclohexane, 28. The PMR spectrum of 28 showed a single peak at



28

δ9.33 ppm for the two equivalent aldehyde hydrogens.

Many porphyrins have been synthesized by condensing a 5,5'-diformyl-2,2'-dipyrrylmethane with a 2,2'-dipyrrylmethane in acid solvents. The porphyrin formations were then completed by air oxidation. Generally, the air was not used at the beginning of the reaction, since dipyrrylmethanes may be oxidized to dipyrrylmethenes. When oxidized, they are not as active to condensation reactions. Therefore, an oxidizing agent was not wanted or required until all the condensation reactions were completed. We proposed to use a similar reaction with compounds 27 and 28. First, the condensation would occur in acid solvent and then air would be bubbled into the solvent to perform the oxidation. When this reaction was run, the product showed the air oxidation did not occur, although the condensation did and a sample was collected of the macrocycle: 3,4,8,9,17,18,22,23-octamethyl-30,31-33,34-tetraazaheptacyclo[23.3.1.1^{2,5}.1^{7,10}.1^{11,15}.1^{16,19}.1^{21,24}]-tetratriaconta-2,4,6,8,10(33),16,18,20,22,24(30)-decaene, 29.



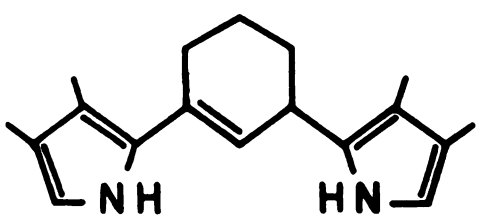
29

Compound 29 had the same structure as a platyrin except it lacked six oxidized carbons. The structure of compound 29 was determined by PMR spectrometry to be symmetrical and did not show any signs of a ring current. The mass spectrum of compound 29 gave a maximum m/e value of 560, which corresponded to the parent peak. If the oxidation had occurred, the parent value of the platyrin should have been 554. Also, the uv-visible spectrum showed a single broad band at 429 nm, which is characteristic of neutral dipyrrylmethenes. The electronic spectrum of a platyrin was expected to be much more complex in the visible region. There was some evidence in uv-visible spectra of some material with a more complex spectrum existing in the precipitated samples of 29. Since only trace amounts existed, none of this particular compound could be isolated as a solid. Solutions could be obtained which possessed this complex spectrum, and it was later proven to be the platyrin by comparison of uv-visible spectra with a genuine sample. Since no sample of this complex spectrum could be isolated as a solid for further characterization tests, we decided to try a variation of the synthesis that led to 29. We felt it was too difficult to oxidize a propane with oxygen.

We wanted two 3-carbon bridges to be oxidized. In a porphyrin synthesis, only one-carbon bridges were oxidized by air. To make our synthesis more like the construction of a porphyrin, we decided to reduce partially the trimethine

linkage in compound 26. This way, only one carbon at each of the four meso-bridges would need to be oxidized to complete the formation of the platyrin. Also, the intermediate, like 27, should still be reactive at the α-positions of the pyrroles, since most of the conjugation in the trimethine would have been reduced.

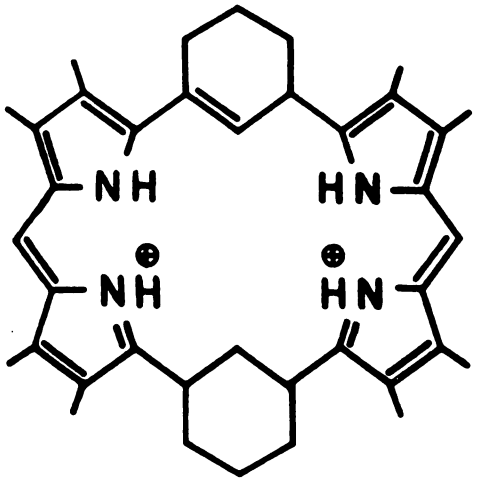
The partial reduction of 26 used a mild reducing agent.[41] A solution of 26 could be quickly reduced with sodium borohydride and leave as the only product: 1,3-bis(3,4-dimethylpyrrol-2-yl)cyclohex-1-ene, 30. When a PMR spectrum was taken of 30, its vinyl peak was at δ5.7 ppm. This gave a possible explanation for how samples of 29 contained a small amount of the platyrin. When 27 was made earlier, some of its PMR



30

spectra contained a small extra peak at δ6.1 ppm. This generally happened for short reaction times or low hydrogen pressure in the reduction. We believe that 30 was synthesized in the reduction as an intermediate and not all of it was converted to 27. When the cyclization reaction was run an oxidation intermediate, between 29 and the platyrin, might have been formed which could be much easier to air oxidize to the platyrin. Such a compound would have a structure

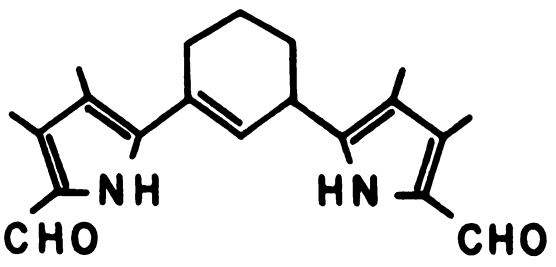
like 31. No compound like 31 was characterized, but that was



31

expected since 31 should have been converted to the platyrin. Indeed, if a molecule like 31 could be air-oxidized, our new intermediates might work.

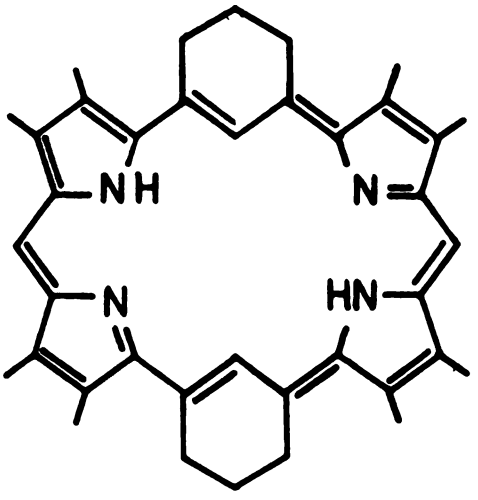
Trying to keep overall yields as high as possible, we decided not to react 30 and 28 to form 31. Instead, 30 was formylated with $POCl_3$/DMF to synthesize an 80% yield of 1,3-bis(5-formyl-3,4-dimethylpyrrol-2-yl)cyclohex-1-ene, 32.



32

The PMR spectrum of 32 showed two equal singlets at δ9.40 and 9.35 ppm for the aldehydes. This was reasonable, since with the double bond in 32, it was expected that the two aldehydes should not be equivalent. The methyls on the two pyrroles were also not equivalent in the PMR spectrum. Now we felt that the final condensation could be attempted to synthesize a platyrin.

Condensation of 30 and 32 in HBr/methanol, with air bubbled into the solution, gave a small amount of a greenish material with a melting point greater than 300°C. We assigned the following name to this compound: 3,4,8,9,17,18,22,23-octamethyl-30,31,33,34-tetraazaheptacyclo[23.3.1.$1^{2,5}$.$1^{7,10}$-.$1^{11,15}$.$1^{16,19}$.$1^{21,24}$]tetratriconta-1,3,5,7(33),8,10,15(32)-16,18,20,22,24(30),25(29)-tridecaene, 33. Its trivial name is bis(trimethylene)octamethylplatyrin. At room temperature, the PMR spectrum showed a very strong ring current effect. This was consistent with 33 being an aromatic macrocycle. (See Table 1). The two one-carbon meso-bridges were external to the ring and they were shifted down-field to δ11.64 ppm. The two protons located on the middle carbon of the three-carbon meso-bridges were in the interior of the ring and they were shifted up-field to δ-8.97 ppm. The PMR spectrum was taken in $CDCl_3$-CF_3CO_2H so that all four nitrogens were protonated. These acidic protons were equivalent and shifted up-field to δ-5.6 ppm. The values obtained for the exterior meso-protons and the interior



33

Table 1. Nuclear Magnetic Resonance Absorption of Bis(trimethylene)octamethylplatyrin and Related Compounds[42,a]

Compound	CH_3	Meso CH	NH
Bis(trimethylene)octamethylplatyrin bis-trifluoroacetate salt[b]	4.22 4.17	11.64[c] -8.97[d]	-5.6
Octamethylporphyrin bis-trifluoroacetate salt[e]	3.76	10.98	-4.82
Decamethylsapphyrin bis-trifluoroacetate salt[e]	4.31 4.15		-6.15 -6.46 -6.73

[a]As δ-values referred to internal tetramethylsilane. [b]Taken in deuterochloroform with trifluoroacetic acid. [c]Exterior of ring. [d]Interior of ring. [e]Taken in trifluoroacetic acid.

nitrogen protons of the platyrin are consistent with values that have been determined on similar compounds such as octamethylporphyrin and decamethylsapphyrin.[42] The spectrum of the neutral platyrin was not obtained since it was not soluble in deuterated solvents in which it was stable. Treatment of 33 with acidic deuterated solvents gave rapid proton exchange of all meso and nitrogen protons.

The uv-visible spectra were taken for both the "free base" platyrin and its dication. (See Table 2) Both the free base and dication showed Soret-like bands at 477 nm with very intense absorptions. They also possessed a much weaker series of bands in the visible region that were very similar to the spectra reported for the free base and dication forms of octamethylporphyrin and decamethylsapphyrin.[42] Solutions of 33 and its dication were generally green and dark yellow, respectively, but they were very solvent dependent. Only on a uv-visible spectrophotometer can the spectrum of a new sample be compared with authentic samples in solution. In each case the same bands were present, but some were a little sharper, while others might be broader. This was the cause of the apparent visual changes. Reasonably reproducible molar absorptivities were obtained for the Soret band, but it is probably wiser to consider the absorptivities to be minimum values.

Each time a sample of 33 was dissolved in a solvent or used for a reaction, a small fraction of the compound would disappear. The samples did not appear to be light or

Table 2. Electronic Absorption of Bis(trimethylene)octamethylplatyrin and Related Compounds.[42]

Compound	λ_{max}, nm (ε)
Bis(trimethylene)octamethylplatyrin[a]	453sh(60,400), 477(398,000), 607(11,800), 649(9,340), 747 (2,100), 767sh(1,520), 846 (1,850).
Bis(trimethylene)octamethylplatyrin bistrifluoroacetate salt[a]	453sh(53,200), 477(398,000), 625sh(9,030), 637(10,700), 647sh(9,130), 672(5,190), 688 (6,640), 705(7,990), 717sh (6,220), 734sh(3,630), 788 (6,220).
Octamethylporphyrin[b]	377sh(55,000), 398(168,000), 497(14,400), 533(10,320), 567 (6,930), 619(5,250).
Octamethylporphyrin dihydrochloride[b]	380sh(55,000), 414(266,700), 529sh(3,240), 551(16,300), 556 (16,500), 575(6,490), 597(8,720).
Decamethylsapphyrin[b]	455(329,000), 533, 594, 643, 660sh, 720, 730.
Decamethylsapphyrin dihydrochloride[b]	431(56,000), 456.5(594,000), 579(3,400), 625(14,000), 677(21,000), 689(17,200).

[a]Measured in methylene chloride.

[b]Measured in chloroform.

oxygen-sensitive, but weights and spectral values were hard to duplicate. Solutions of 33 were not durable, and purified, stabilized solvents were required to minimize losses. Reagent samples of chloroform are stabilized with 0.7% ethanol to prevent the formation of phosgene,[43] while spectrograde chloroform and $CDCl_3$ are highly purified, but not stabilized, solvents. It was believed that early purification methods and spectral data were invalidated by trace quantities of phosgene in our solvents. The main support for this conclusion was a mass spectrum of 33 that had just been removed from chloroform. It gave a peak at m/e 580. This corresponded to loss of two hydrogens and the addition of carbon monoxide to the parent peak value of m/e 554 for 33.

The mass spectrum of 33 was partially helpful in determining its structure. Around the parent peak value of m/e 554, a large number of large peaks were observed. Hydrogens, very easily lost from the ring, satisfied this observation, but made it very difficult to locate the parent peak.

One goal after making a platyrin was to determine its ability to coordinate with metals. At first glance, the platyrin should be able to easily incorporate even some very large metals. However, this did not take into account the presence inside the ring of two hydrogens attached to the carbons. (See Figure 3) These hydrogens take up a large amount of space in the cavity and hinder replacement of

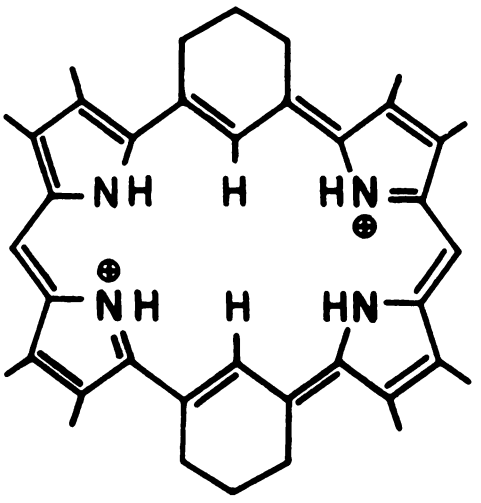


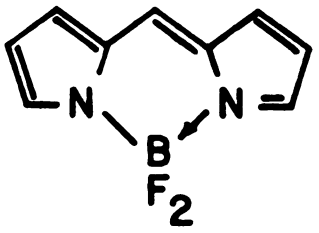
Figure 3. Internal structure of Bis(trimethylene)octamethylplatyrin dication.

the nitrogen protons with metals. Attempts to place copper (II) and nickel (II) in the ring showed a rapid change in the color of their solutions. In each case, the uv-visible spectra were simplified to leave only one or two peaks. This indicated a loss of aromaticity. Reaction with nickel (II) acetate gave a band at 522 nm with shoulders at 500 and 540 nm. Reaction with copper (II) acetate gave a single band at 548 nm. Neither metal gave stable samples that could be analysed by IR, PMR or mass spectrometry. Hydrolysis of these metal complexes with weak to strong acids did not regenerate the diprotonated platyrin. Each complex gave similar uv-visible spectra on acid treatment that were not characteristic of the platyrin. It was possible that the

metals sat on the top of the macrocycle and wrapped the platyrin around themselves like a blanket. If so, the conjugation of the platyrin would be disrupted, so that the uv-visible spectrum would show only fragments of the macrocycle. Depending on which way the wrapping occurred could lead to spectra of dipyrrylmethenes (similar to the nickel complex) or dipyrryltrimethines (similar to the copper complex). This explanation is unlikely, since degradation of these complexes should have led to completely different uv-visible spectra for each metal. Yet, the metals did form complexes. It is conceivable that the complexes were warped. This could leave one of the meso-bridges susceptible to acid attack. Instead of displacing the metal, the meso-bridge would be broken and a new product formed. It is unknown what type of complexes were formed and how stable they might be to further reactions.

A three-dimensional model was built of the platyrin 5. It was determined from this model that the two internal hydrogens on the carbons were situated such that their electron clouds were almost touching. When the hydrogens were removed from the nitrogens, the remaining cavities left room for only a very small atom such as boron. Also, the configuration of the nitrogen and intruding hydrogens would allow an atom that coordinated in a tetrahedral shape the best chance to fit in the macrocycle. Treibs has reported[44] that dipyrrylmethenes have reacted with boron

trifluoride etherate to give solids with a structure like 34. The boron was in a tetrahedral configuration and the three-dimensional model of platyrin suggested that there was enough room to fit two boron difluoride groups in the two



34

cavities, one group for each cavity in the interior of the ring. When the reaction was attempted, a vivid color change occurred with the growth of two strong bands at 516 and 538 nm. An oily sample was collected by liquid chromatography, but no spectral data were obtained that would elucidate the structure of the product.

The platyrin can be viewed as an aromatic macrocycle that may be easily decomposed by several mild reactions. Its ability to possess a ring current at room temperature is an unusual, but not unknown, development which may prove useful to the study of large, planar molecules. The lack of stability may hinder its use as a ligand. While, its similarity to the porphyrins is now confined to PMR and uv-visible spectra, possibly, a large supply of a platyrin would enable the study of its reactions to electrophilic substitution.

The overall goal of achieving a 22 π-electron system capable of aromaticity at room temperature was accomplished with this synthesis. The use of the porphyrin system as a model proved successful and it may be a critical stepping-stone to the determination of aromatic character in large macrocycles.

EXPERIMENTAL

General Procedure

The melting points were determined on a Thomas Hoover Unimelt melting point apparatus and are uncorrected.

The infrared spectra were recorded on a Perkin-Elmer Model 237B spectrophotometer. The PMR spectra were obtained on Varian T-60 and Brucker 180 spectrometers with chemical shifts reported in δ-units measured from tetramethylsilane as the internal standard. The CMR spectra were obtained on a Varian CFT-20 spectrometer with chemical shifts reported in δ-units measured from tetramethylsilane as the internal standard. The UV-Visible spectra were recorded using a Unicam Model SP-800 spectrophotometer using 1/2 cm quartz cells, or using a Cary 17 spectrophotometer using 1 cm quartz cells. Mass spectra were obtained with a Hitachi Perkin-Elmer RMU-6 mass spectrometer. Microanalyses were not obtained due to the extreme unstability of the compounds.

2,2'-Dipyrrylmethane (6)

The procedure of Clezy[30,31] was used and the product was purified by crystallization from petroleum ether (30-60°C), mp 72-3°C. Compound 6 was air-sensitive and stored at -20°C.

5,5'-Bis(3-oxo-butenyl)-2,2'-dipyrrylmethane (7a)[32]

Compound 6 (0.500 g) and 3-butynone (0.700 g) were dissolved in 125 ml of oxygen-purged methanol and refluxed under nitrogen for 68 hours. Water was added and the yellow precipitate collected by filtration. Recrystallization from ethanol-water gave 0.3035 g (31.4% yield) of 7a: mp 210°C (dec.); IR (KBr): 3265 cm^{-1}(N-H), 1665 cm^{-1}(C=O), 1615, 1555, and 1475 cm^{-1}(C=C); PMR (DMSO-d_6): δ7.15 (d, J = 15 Hz, 2H, trans H-C=C-H), 6.28 (m, 2H, β-pyrrolic hydrogens), 6.22 (d, J = 15 Hz, 2H, trans H-C=C-H), 5.80 (m, 2H, β-pyrrolic hydrogens), 3.83 (s, 2H, $-CH_2-$), 2.15 (s, 6H, $CH_3-C=O$); UV-Vis λ_{max} (CH_2Cl_2): 350 nm; mass spectrum (70 eV): m/e 282 (parent).

5,5'-Bis(3-oxo-propenyl)-2,2'-dipyrrylmethane (7b)[32]

Compound 6 (0.1045 g) was dissolved in 2.5 ml of oxygen-purged methanol under nitrogen. A solution of 0.0847 g of propargyl aldehyde[33] in 2.5 ml of oxygen-purged methanol was slowly dripped into the rapidly stirred solution of 6. The reaction was stirred at room temperature for 48 hours. Then 10 ml of water was added and the precipitate collected by filtration. The powder was chromatographed on silicic acid with methylene chloride-ethyl acetate (1:1) as the eluant and recrystallized from ethanol-water to give 51.6 mg (28.4% yield) of 7b: mp 203°C (dec.); IR (Nujol): 3210

cm^{-1}(N-H), 1655 cm^{-1}(C=O), 1620, 1590, and 1555 cm^{-1}(C=C); PMR (DMSO-d_6): δ9.23 (d, J = 8 Hz, 2H, -C<u>H</u>O), 7.27 (d, J = 15 Hz, 2H, trans <u>H</u>-C=C-<u>H</u>), 6.45 (m, 2H, β-pyrrolic hydrogens), 6.32 (c, 2H, trans <u>H</u>-C=C-<u>H</u>), 5.88 (m, 2H, β-pyrrolic hydrogens), 3.90 (s, 2H, -C<u>H</u>$_2$-); UV-Vis λ_{max} (CH_2Cl_2): 352 nm; mass spectrum (70 eV): m/e 254 (parent).

<u>Attempted Synthesis of 2,2'-Dipyrrylpropane (8)</u>

Stoichiometric amounts of pyrrole and 1,3,3-trimethoxypropene were dissolved in acetic acid and let sit until deep blue (λ_{max} 580 nm). A deep blue tar was collected by addition of water, but its reduction to 8 was not attempted. The same results were found upon reaction of 6 and 1,3,3-trimethoxypropene.

<u>Triphenylmethylfluoroborate (12)</u>

The procedure of Dauben, <u>et al</u>.[45] was used to obtain the orange solid, 12. The product was stored in a desiccator.

<u>2,5-Bis(triphenylmethyl)pyrrole (13)</u>

Compound 12 (6.60 g) was dissolved in 200 ml of acetonitrile. Pyrrole (0.70 g) was added dropwise to the stirred solution at room temperature. Colorless crystals formed immediately. The solution was cooled to 0°C in an ice-water bath and the crystals were collected by filtration.

Recrystallization from chloroform-hexane gave 5.50 g (99.8% yield) of 13: mp 229-30°C; IR (Nujol): 3430 cm^{-1}(N-H), 1600 and 1540 cm^{-1}(C=C), 1080 and 1035 cm^{-1}(mono-substituted benzene); PMR ($CDCl_3$): δ7.05 (s, 30H, phenyl), 5.78 (d, J = 2 Hz, 2H, β-pyrrolic hydrogens); CMR ($CDCl_3$): δ145.9, 137.2 (α-pyrrolic carbon), 130.2, 127.6, 126.3, 109.2 (d, β-pyrrolic carbon, 60.4 (tetra-substituted methyl); mass spectrum (70 eV): m/e 551 (parent).

Dimethyl-N,N'-bis(tosylmethyl)glutarimidate (16a)[36]

Compound 18 (2.20 g) was dissolved in 30 ml of nitromethane under nitrogen with slight warming. Methylfluorosulfonate (4.39 g) was quickly added and the reaction stirred for 16 hours. The solvent was removed under reduced pressure along with excess methylfluorosulfonate. The residual oil was dissolved in $CHCl_3$. This solution was washed with very dilute HCl (20:1), dried with $MgSO_4$ and the solvent was removed. The remaining oil gradually turned waxy with sitting. The product obtained was the bisfluorosulfonate of 16a: PMR (DMSO-d_6): δ8.62 (t, J = 7 Hz, 2H, $\underline{H}N-CH_2$), 4.57 (d, J = 7 Hz, 4H, $HN-C\underline{H}_2$), 3.93 and 3.88 (6H, syn- and anti-$OC\underline{H}_3$).

Dimethyl-N,N'-bis(tosylmethyl)thioglutarimidate (16b)[36]

The same procedure was used as for 16a, using 19 as starting material, but no product was isolated.

N,N'-Bis(tosylmethyl)glutaramide (18)

Sodium p-toluene sulfinate (80.0 g), 37% formaldehyde (35 ml), and glutaramide (26.0 g) were mixed together in 400 ml of water and heated to 90°C. To this hot solution was added 100 ml of 90% formic acid. After 16 hours the reaction was cooled to 0°C and the crystals were collected. Recrystallization from $CHCl_3$ gave 43.8 g (47% yield) of 18: mp 156-7°C; IR (Nujol): 3300 cm^{-1} (N-H), 1655 cm^{-1} (C=O), 1535 cm^{-1} (R-N<u>H</u>-C=O); PMR (DMSO-d_6): δ8.70 (t, J = 6 Hz, 2H, N-H), 4.58 (d, J = 6 Hz, 4H, C<u>H</u>$_2$-NH), 2.35 (s, 6H, C<u>H</u>$_3$-), 1.97 (t, J = 6 Hz, 4H, CH_2-C<u>H</u>$_2$-C=O), 1.50 (m, 2H, C<u>H</u>$_2$-CH_2-C=O).

N,N'-Bis(tosylmethyl)thioglutaramide (19)

Compound 18 (25.00 g) was added to 700 ml of dioxane and heated to 60°C with stirring under nitrogen. Phosphorus pentasulfide (24.00 g) was added and the solution was stirred for 7 hours. The orange solution was filtered and the solvent removed under reduced pressure. The residue was recrystallized from chloroform-ethanol to give 24.40 g (98.7% yield) of a pale yellow solid, 19: mp 154-5°C; IR (Nujol): 3260 cm^{-1} (N-H), 1510 cm^{-1} (mono-substituted benzene), 1270 cm^{-1} (C=S); PMR (DMSO-d_6): δ10.50 (t, J = 6 Hz, 2H, CH_2-N-<u>H</u>), 5.23 (d, J = 6 Hz, 4H, C<u>H</u>$_2$-NH), 2.43 (t, J = 7 Hz, CH_2-C<u>H</u>$_2$-C=O), 1.73 (p, J = 7 Hz, 2H, C<u>H</u>$_2$-CH_2-C=O).

N,N'-Bis(glycyl)glutaramide (21)

Glycine (7.5 g) was dissolved in 40 ml of 2.5 N NaOH and cooled with an ice bath to 0°C. In separate addition funnels were placed 8.45 g of glutaroyl chloride and 40 ml of 2.5 N NaOH. Both were dripped into the stirred solution at the same rate over 5 minutes. The solution was stirred an additional 10 minutes, then acidified to Congo Red end point with conc. HCl. The solution was cooled to 0°C and filtered to give 8.7 g (71% yield) of white crystals, 21: mp 172-4°C; PMR (DMSO-d_6): δ8.00 (t, J = 6 Hz, 2H, CH_2-N<u>H</u>), 3.70 (d, J = 6 Hz, 4H, C<u>H</u>$_2$-NH), 2.13 (t, J = 6 Hz, 4H, CH_2-C<u>H</u>$_2$-C=O), 1.82 (p, J = 6 Hz, 2H, C<u>H</u>$_2$-CH_2-C=O).

Attempted Synthesis of 1,3-Bis(3,4-dicarbethoxypyrrol-2-yl)-propane (23)[37]

Compound 21 (1.23 g) and dimethylacetylenecarboxylate (1.25 ml) were mixed together in 15 ml of acetic anhydride and heated at a variety of temperatures from 60°C to reflux. When the solvent was removed under reduced pressure, the remaining oil could not be identified.

3,4-Dimethylpyrrole (24)

The procedure of Ichimura[40] was followed except for the following changes: 1) When the pyridine and thionyl chloride were added to the reaction, the thionyl chloride

was added slightly ahead of the pyridine. 2) The oily residue of 2-ethoxycarbonyl-3,6-dihydro-4,5-dimethyl-1,2-thiazine-1-oxide was added to 135 g of potassium hydroxide dissolved in 300 ml of methanol. If the second step was not followed, the reaction would explode through the condenser. Typical yields were 50-55% based on ethylcarbamate. The product was vacuum-distilled with an air condenser, since it melts at slightly above room temperature. Compound 24 may be stored at least 6 months at 0°C under nitrogen without discoloring.

3,4,3',4'-Tetramethyldipyrryl-2,2'-hexacyclotrimethine tetrafluoroborate (26)[27]

1,3-Cyclohexanedione (2.75 g) was dissolved in 20 ml of ethanol and filtered to remove the stabilizing reagent. Compound 24 (4.50 g) was dissolved in 80 ml of ethanol and the two solutions were mixed together and heated to reflux. Tetrafluoroboric acid (8 ml) was added dropwise to the reaction and the heating continued for 5 minutes. The reaction was cooled slowly. It was allowed to stand at room temperature for 4 days protected from light. The deep blue crystals were collected by filtration and washed repeatedly with ethyl ether until the ether washings were very pale blue. There was obtained 2.9 g (35% yield) of 26: mp 245-6°C; IR (Nujol): 3350 cm^{-1} (N-H), 1565 and 1535 cm^{-1} (C=C); PMR (DMSO-d_6): δ7.5 (d, J = 3 Hz, 2H, α-pyrrolic hydrogens), 7.18 (s, 1H, C=C<u>H</u>-C); 2.9 (t, J = 5 Hz, 4H, C<u>H</u>$_2$-C=C), 2.32 (s, 6H, 4,4'-

$C\underline{H}_3$), 2.00 (s, 6H, 3,3'-$C\underline{H}_3$), 1.9 (m, 2H, $C\underline{H}_2$); CMR (DMSO-d_6): δ158.9, 135.5, 134.7, 132.2, 126.2, 116.6 (α-pyrrolic carbon), 27.4, 21.0, 18.6, 13.8, 9.8; UV-Vis λ_{max} ($CHCl_3$): 540sh and 580 nm; mass spectrum (70 eV): m/e 266 (parent - HBF_4).

The method given was a general procedure for the preparation of dipyrryltrimethines. The same ratio of reactants was used to prepare 3,5,3',5'-tetramethyl-4,4'-diethyldipyrryl-2,2'-hexacyclotrimethine tetrafluoroborate (34) from 2,4-dimethyl-3-ethylpyrrole and 1,3-cyclohexanedione in 63% yield: mp 213-3°C; IR (Nujol): 3350 cm^{-1} (N-H), 1535 and 1520 cm^{-1} (C=C); PMR ($CDCl_3$): δ7.08 (s, 1H, C=C$\underline{H}$-C), 2.88 (t, J = 6 Hz, 4H, $C\underline{H}_2$-C=C), 2.43 (s, 6H, 5,5'-$C\underline{H}_3$), 2.4 (q, J = 8 Hz, 4H, CH_3-$C\underline{H}_2$-), 2.30 (s, 6H, 3,3'-$C\underline{H}_3$), 1.03 (t, J = 8 Hz, 6H, $C\underline{H}_3$-CH_2-); CMR ($CDCl_3$): δ154.4, 146.2, 135.0, 131.1, 129.8, 112.9, 27.5, 22.0, 16.9, 14.6, 13.7, 11.8; UV-Vis λ_{max} ($CHCl_3$): 560sh and 599 nm; mass spectrum (70 eV): m/e 322 (parent - HBF_4).

1,3-Bis(3,4-dimethylpyrrol-2-yl)cyclohexane (27)

Compound 26 (2.5 g) was mixed with 5 g of sodium acetate and 0.1 g Pd/C. Ethanol (100 ml) was added and the mixture was shaken on a Parr Hydrogenator at 50 psi for 5 hours. The mixture was filtered through anhydrous K_2CO_3 and the solvent removed under reduced pressure to give a pale yellow oil of 27: PMR ($CDCl_3$): δ7.27 (broad, 2H, N-$\underline{H}$), 6.20 (c, 2H, α-pyrrolic hydrogens), 1.97 (s, 6H, 4,4'-$C\underline{H}_3$), 1.92 (s, 6H, 3,3'-

CH_3), 2.0-1.0 (corresponded to a 1,3-dialkylcyclohexane).

Compound 27 was always used immediately since it was air-sensitive.

1,3-Bis(5-formyl-3,4-dimethylpyrrol-2-yl)cyclohexane (28)

Calcium hydride-dried dimethylformamide (1.7 ml) was cooled to -5°C under nitrogen with stirring. Phosphorus oxychloride (2.0 ml) was added dropwise by syringe. The mixture generally solidified and was dissolved in 10 ml of dichloroethane. A sample of 27 was prepared as reported above and dissolved in 10 ml of dichloroethane. This solution was added dropwise to the cold reaction mixture. After stirring at 0°C for 15 minutes it was then refluxed for 15 minutes. After slight cooling the reaction mixture was added to a solution of 35 g of sodium acetate in 200 ml of water, which was heated at reflux for 15 minutes. The resulting oil was extracted 3 times with chloroform. The extracts were combined and washed twice with a saturated sodium chloride solution. The extracts were dried with anhydrous K_2CO_3 and the solvent removed under reduced pressure. The oil was crystallized from chloroform-pentane to give 1.86 g (80.6% yield) of a yellow solid, 28: mp 220-2°C; IR (Nujol): 3260 and 3210 cm^{-1} (N-H), 1640 cm^{-1} (C=O); PMR ($CDCl_3$): δ9.33 (s, 2H, -CHO), 2.87 (m, 2H, tertiary CH), 2.20 (s, 6H, 4,4'-CH_3), 1.90 (s, 6H, 3,3'-CH_3), 1.87 (m, 8H, 1,3-disubstituted cyclohexane); UV-Vis λ_{max} ($CHCl_3$): 313 nm; mass spectrum (70 eV): m/e

326 (parent).

3,4,8,9,17,18,22,23-Octamethyl-30,31,33,34-tetraazaheptacyclo-[23.3.1.1^{2,5}.1^{7,10}.1^{11,15}.1^{16,19}.1^{21,24}]tetratriaconta-2,4,6,8,10(33),16,18,20,22,24(30)-decaene (29)

The actual preparation involved the synthesis of the bis-tetrafluoroborate salt which gave 29 on deprotonation.

Compound 27 (0.38 g)(prepared from 0.50 g of 26 as described above) and Compound 28 (0.462 g) were dissolved in 200 ml of acetic acid. The solution was heated at reflux for two hours with air bubbling into the reaction. Then 1 ml of 48% HBF_4 was added and the reflux continued for 16 hours. The reaction was cooled to room temperature and let sit for 24 hours. The metallic blue (overtones) crystals were collected by filtration to give 0.2468 g (23.7% yield) of the HBF_4 salt of 29. The salt may be neutralized by dissolving the blue crystals in ethanol and treating with aqueous sodium hydroxide followed by extraction with chloroform. After removal of the solvent, the yellow solid was chromatographed on basic alumina with chloroform and the first band was 29: mp 301-4°C; IR (Nujol): 3350 cm^{-1} (N-H), 1620 cm^{-1}(C=C); PMR ($CDCl_3$): δ6.50 (s, 2H, meso-methene), 2.07 (s, 12H, CH_3-), 1.92 (s, 12H, CH_3-), 3.0-1.0 (c, 20H, 1,3-disubstituted cyclohexanes); UV-Vis λ_{max} ($CHCl_3$): 429 nm for 29, 462 nm for HBF_4 salt; mass spectrum (70 eV): m/e 560 (parent).

1,3-Bis(3,4-dimethylpyrrol-2-yl)cyclohex-1-ene (30)[41]

Compound 26 (2.50 g) and 2.5 g of sodium borohydride were mixed together in 200 ml of acetonitrile. The mixture was heated on a steam bath until all the blue color was gone (circa 5 minutes). The solvent was removed under reduced pressure and the residue was washed with an ether-water mixture. The ether solution was dried with anhydrous potassium carbonate and filtered. The solvent was removed under reduced pressure to give an oil of essentially quantitative yield, 30. The oil was pale yellow, but quickly became green on exposure to air: IR (neat): 3380 cm^{-1} (N-H), 1625 and 1580 cm^{-1} (C=C); PMR ($CDCl_3$): δ7.4 (broad, 2H, N-H), 6.25 (c, 2H, α-pyrrolic hydrogens), 5.67 (c, 1H, -C=C-H), 3.60 (c, 1H, CH_2-C=C), 2.4-1.5 (6H, 1,3-disubstituted cyclohexene), 2.07 (s, 3H, CH_3- closest to vinyl), 1.98 (s, 9H, CH_3-).

Compound 30 was never stored but immediately used to make 32 or 33.

1,3-Bis(5-formyl-3,4-dimethylpyrrol-2-yl)cyclohex-1-ene (32)

From a sample of 30, as prepared above, was made 32, in the same manner as for the synthesis of 28. Compound 32 was made in 80.2% (1.84 g) yield, based on 2.50 g of 26, through this procedure: mp 174-6°C (dec.); IR (Nujol): 3250 cm^{-1} (N-H), 1630 cm^{-1} (C=O); PMR (DMSO-d_6): δ9.40 (s, 1H, -CHO), 9.35 (s, 1H, -CHO), 5.83 (m, 1H, C=C-H), 3.6 (m, 1H, CH_2-C=C), 2.22 (s, 6H, 4,4'-CH_3), 1.98 (s, 3H, 3-CH_3),

1.93 (s, 3H, 3'-C<u>H</u>$_3$), 2.6-1.6 (c, 6H, 1,3-disubstituted cyclohexene); mass spectrum (70 eV): m/e 326 (parent).

<u>3,4,8,9,17,18,22,23-Octamethyl-30,31,33,34-tetraazaheptacyclo[23.3.1.1^{2,5}.1^{7,10}.1^{11,15}.1^{16,19}.1^{21,24}]tetratriaconta-1,3,5,7(33),8,10,15(32),16,18,20,22,24(30),25(29)-tridecaene (33)</u>

Compound 26 (0.1092 g) was reduced, as shown previously, with $NaBH_4$ to give 30 which was dissolved in 20 ml of methanol. Compound 32 (0.0992 g) was dissolved in 20 ml of dichloromethane and diluted with 40 ml of methanol. The two solutions were mixed together and added dropwise to a refluxing solution of 5 ml of 48% HBr in 100 ml of methanol with air bubbling into the solution. After the addition was complete, another 2 ml of HBr was added with refluxing and air bubbling continued for 30 minutes. The reaction then sat in the dark for 36 hours. The product was collected and neutralized by diluting the reaction with 200 ml of water and 20 ml of 30% NaOH. The solution was extracted 2 times with dichloromethane. The CH_2Cl_2 layer was condensed and chromatographed on neutral alumina ("Baker Analyzed" Reagent) with dichloromethane, followed by 1% methanol in dichloromethane. The green band was collected and the solvent removed to give 32.2 mg (19% yield) of 33: mp >300°C; PMR ($CDCl_3$-CF_3CO_2H): δ11.64 (s, 2H, meso-C<u>H</u>), 4.22 (s, 12H, C<u>H</u>$_3$-), 4.17 (s, 12H, C<u>H</u>$_3$-), 2.4-1.0 (c, 12H, corresponded to 6 C<u>H</u>$_2$), -5.64 (s, 4H, N-<u>H</u>),

-8.97 (s, 2H, internal C=C<u>H</u>-C); UV-Vis λ_{max} (CH_2Cl_2): 230 nm (ε 13,600), 265 (12,000), 276 (11,900), 298 (11,400), 326 (11,900), 390sh (14,200), 453 (60,400), 477 (398,000), 607 (11,800), 649 (9340), 747 (2100), 767sh (1520), 846 (1850); UV-Vis λ_{max} (CH_2Cl_2)(bis-tetrafluoroborate salt): 231 nm (ε 19,900), 281 (9130), 290 (8920), 307 (7470), 375 (10,800), 408 (10,500), 453sh (63,200), 477 (398,000), 625sh (9030), 637 (10,700), 647sh (9130), 672 (5190), 688 (6640), 705 (7990), 717sh (6270), 734sh (3630), 788 (6220); mass spectrum (70 eV): m/e 552 (parent - 2).

When dissolved in DMSO-d_6 with a D_2O contamination, the PMR signals at δ11.64, -5.64, and -8.97 disappeared. The signals reappeared after a H_2O wash.

<u>Attempted Complexation of Compound 33</u>

Samples of 33 were treated with nickel (II) acetate or copper (II) acetate in dimethylformamide at reflux. In each case, a color change was immediately visible. Solid samples were collected by addition of water followed by filtration. No chemical characteristics could be determined for either sample due to a lack of solubility in solvents such as $CHCl_3$, CH_2Cl_2, or benzene. Addition of acetic, trifluoroacetic or sulfuric acid to either complex did not regenerate Compound 33.

Nickel(II)-platyrin complex: UV-Vis λ_{max} (DMF): 522 nm. Addition of acid gave a peak at 490 nm.

Copper(II)-platyrin complex: UV-Vis λ_{max} (DMF): 548 nm. Addition of acid gave a peak at 490 nm.

Reaction Between Compound 33 and Borontrifluoride[44]

A sample of 33 (10 mg) was dissolved in dry benzene (20 ml) and added to a solution of triethylamine (2.0 ml) and borontrifluoride etherate (1.8 ml) under nitrogen. The reaction was heated for 10 minutes at reflux, then cooled to room temperature and washed 3 times with water. The benzene layer was dried with $MgSO_4$ and the solvent removed under reduced pressure to leave a red oil. The oil was chromatographed on neutral alumina with methylene chloride, followed by 2% methanol in methylene chloride. The major red band was collected and the solvent removed to give a red tar: UV-Vis λ_{max} (CH_2Cl_2): 516 and 538 nm. No further data could be obtained by IR or PMR spectrometry due to the small amount of material.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. F. A. Kekule, Bull. Soc. Chim. France, 3, 98 (1865).

2. F. A. Kekule, Ann., 162, 77 (1872).

3. J. Thiele, Ann., 306, 87 (1899).

4. R. Willstatter and M. Heidelberger, Ber., 46, 517 (1913).

5. J. W. Armit and R. Robinson, J. Chem. Soc., 127, 1604 (1925).

6. H. Heitler and F. London, Z. Phys., 44, 455 (1927).

7. E. Hückel, Z. Physik., 70, 204 (1931); 72, 310 (1931).

8. D. P. Craig, Non-Benzenoid Aromatic Compounds, D. Ginsburg, ed., (New York: Interscience Publishers, Inc., 1959), p. 14.

9. L. Pauling, Perspectives in Organic Chemistry, A. R. Todd, ed., (New York: Interscience Publishers, Inc., 1956), p. 6.

10. M. J. S. Dewar and G. J. Gleicher, J.A.C.S., 87, 685 (1965); L. H. Chung and M. J. S. Dewar, J. Chem. Phys., 42, 756 (1965).

11. C. C. Leznoff and F. Sondheimer, J.A.C.S., 89, 4247 (1967).

12. R. M. McQuilkin, B. W. Metcalf, and F. Sondheimer, Chem. Comm., 1971, 338.

13. M. J. S. Dewar, J.A.C.S., 74, 3353 (1952).

14. R. Breslow, J. Brown, and J. J. Gajewski, J.A.C.S., 89, 4383 (1967).

15. M. J. S. Dewar, Aromaticity Special Publication No. 21 of the Chemical Society, London, pp. 177-198 (1967).

16. H. P. Figeys, Tet., 26, 5225 (1970).

17. L. Pauling, J. Chem. Phys., 4, 673 (1936).

18. F. London, J. Phys. Radium., 8, 397 (1937).

19. E. D. Bergman, J. Horau, A. Pacault, A. Pullman, and B. Pullman, J. Chim. Phys., 49, 474 (1952).

20. J. A. Pople, J. Chem. Phys., 24, 1111 (1956).

21. F. Sondheimer, Acct. Chem. Res., 5, 81 (1972).

22. L. M. Jackman, F. Sondheimer, Y. Amiel, D. A. Ben-Efraim, Y. Gaoni, R. Wolovsky, and A. A. Bothner-By, J.A.C.S., 84, 4307 (1962).

23. J. Griffiths, Colour and Constitution of Organic Molecules (New York: Academic Press, Inc., 1976), p. 226.

24. I. C. Calder and F. Sondheimer, Chem. Comm., 1966, 904.

25. R. M. McQuilkin, P. J. Garrett, and F. Sondheimer, J.A.C.S., 92, 6682 (1970).

26. B. W. Metcalf and F. Sondheimer, J.A.C.S., 93, 5271 (1971).

27. A. Treibs and E. Hermann, Ann., 589, 207 (1954).

28. M. Strell and F. Kreis, Chem. Ber., 87, 1011 (1954).

29. K. J. Reed, U.S. Patent 2,739,148; Chem. Abstr., 51, 901c (1957).

30. P. S. Clezy and G. A. Smythe, Aust. J. Chem., 22, 239 (1969).

31. R. Chong, P. S. Clezy, A. J. Liepa, and A. W. Nichol, Aust. J. Chem., 22, 229 (1969).

32. A. W. Johnson, J. Chem. Soc., 1947, 1626.

33. J. C. Sauer, Org. Syntheses Coll. Vol. 4, N. Rabjohn, ed., (New York: John Wiley and Sons, Inc., 1963), p. 813.

34. E. Khotinsky and R. Patzewitch, Ber., 42, 3104 (1909).

35. A. M. van Leusen, H. Siderius, B. E. Hoogenboom, and D. van Leusen, Tet. Let., 1972, 5337.

36. H. A. Hovwing, J. W. Idman, and A. M. van Leusen, Tet. Let., 1976, 143.

37. R. Hulagen, H. Gotthardt, H. O. Bayer, and F. C. Schafer, Chem. Ber., 103, 2611 (1970).

38. H. O. Bayer, H. Gotthardt, and R. Hulagen, Chem. Ber., 103, 2356 (1970).

39. F. M. Hershenson, J. Org. Chem., 40, 1260 (1975).

40. K. Ichimura, S. Ichikawa, and K. Imamura, Bull. Chem. Soc. Japan, 49, 1157 (1976).

41. C. Jutz, A. F. Kisschner, and R. M. Wagner, Chem. Ber., 110, 1259 (1977).

42. M. M. King, Ph.D. Thesis, Harvard University, 1970.

43. L. F. Fieser and M. Fieser, Reagents for Organic Synthesis, Vol. 1, (New York: John Wiley and Sons, Inc., 1967), p. 130.

44. A. Treibs and F. H. Kreuzer, Ann., 718, 208 (1968).

45. H. J. Dauben, Jr., L. R. Honnen, and K. M. Harmon, J. Org. Chem., 25, 1442 (1960).

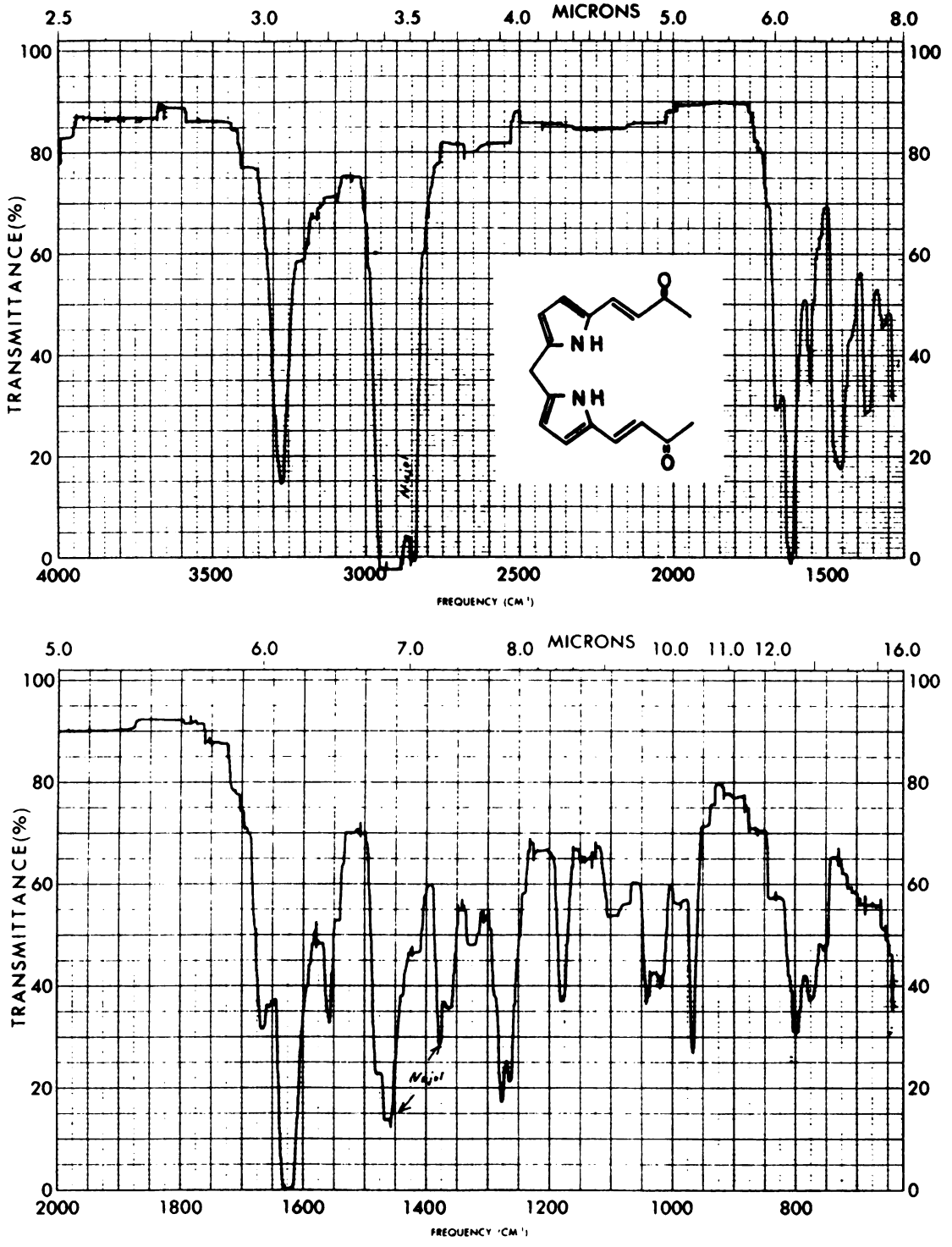


Figure 4. Infrared spectrum of 5,5'-Bis(3-oxo-butenyl)-2,2'-dipyrrylmethane (7a).

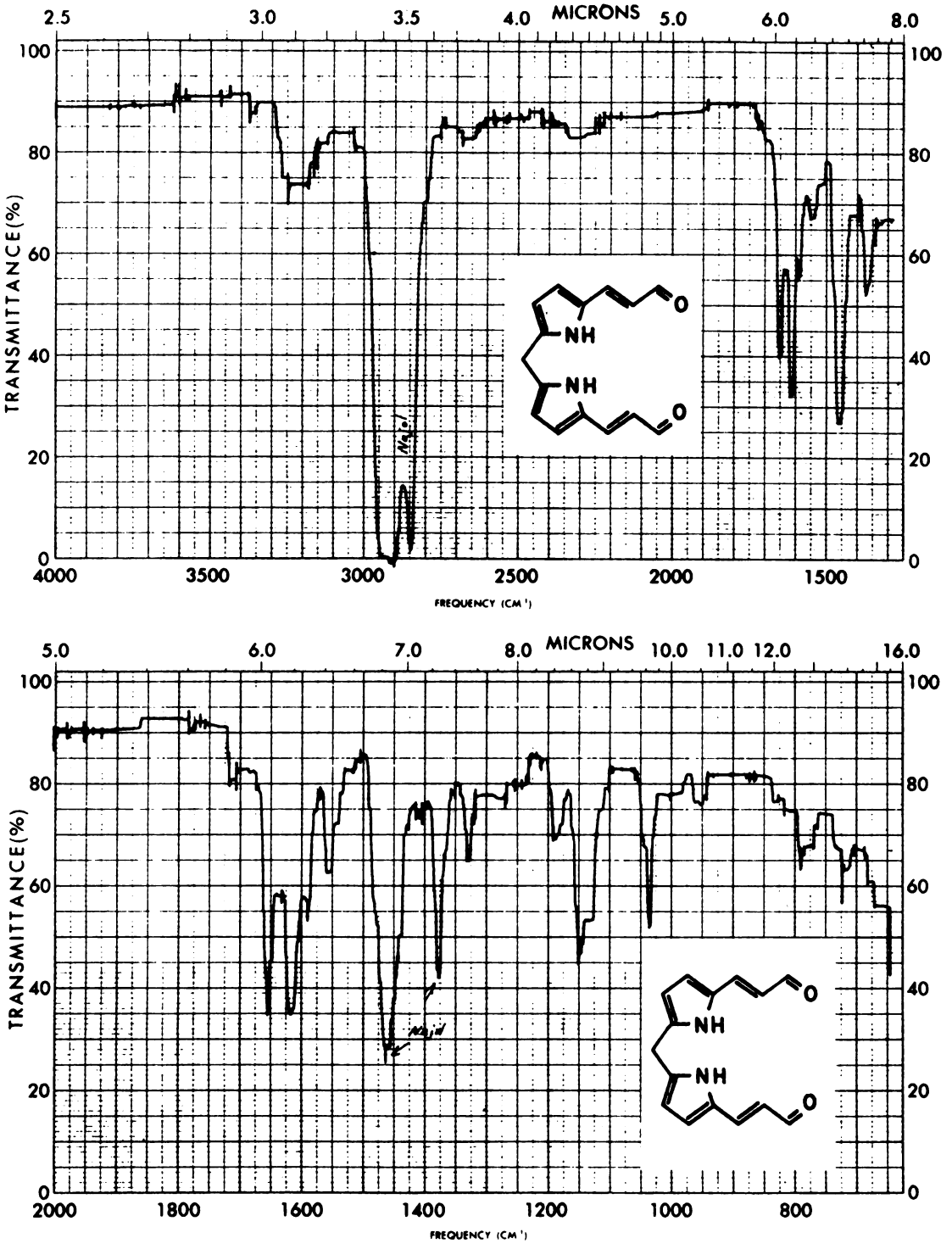


Figure 5. Infrared spectrum of 5,5'-Bis(3-oxo-propenyl)-2,2'-dipyrrylmethane (7k).

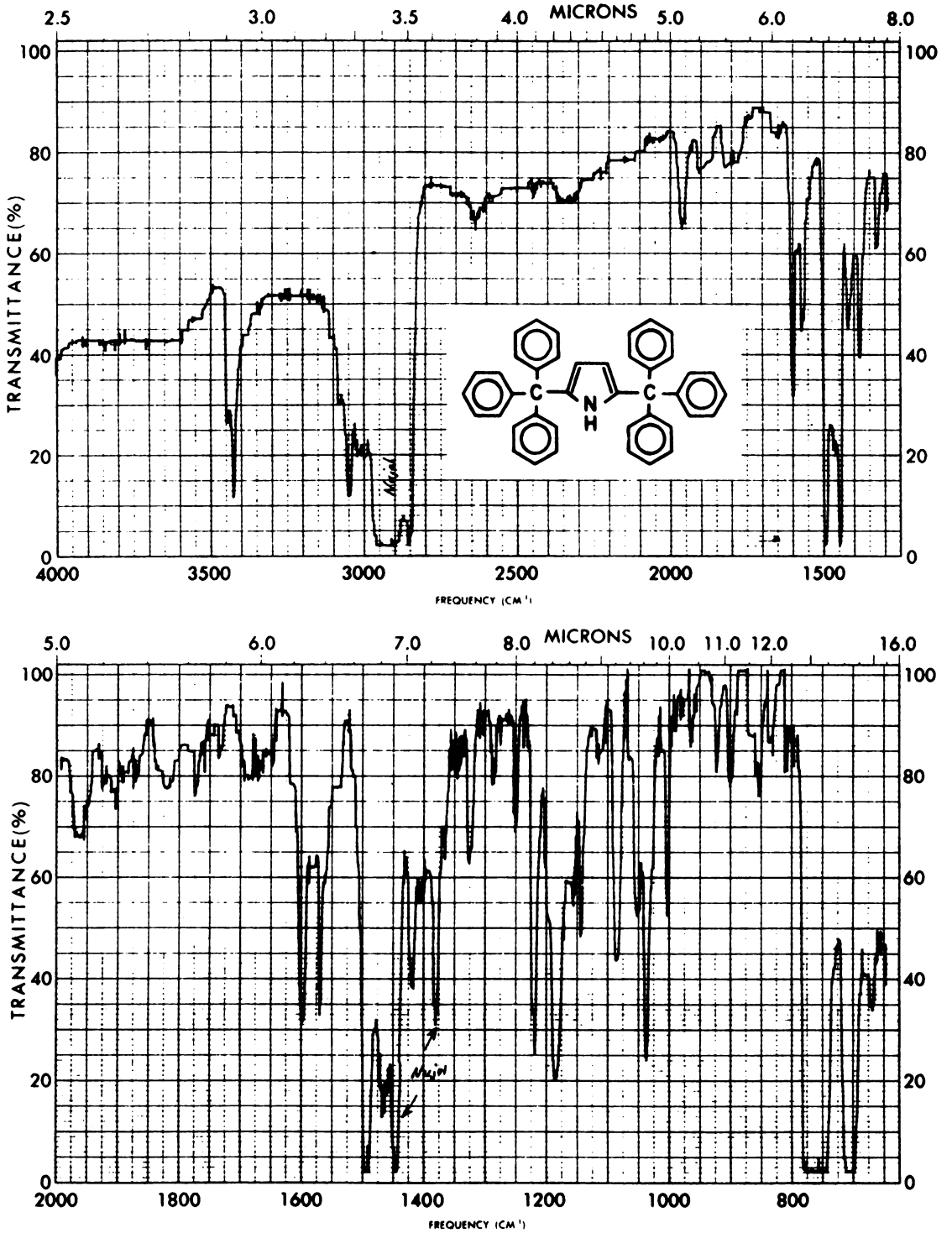


Figure 6. Infrared spectrum of 2,5-Bis(triphenylmethyl)-pyrrole (13).

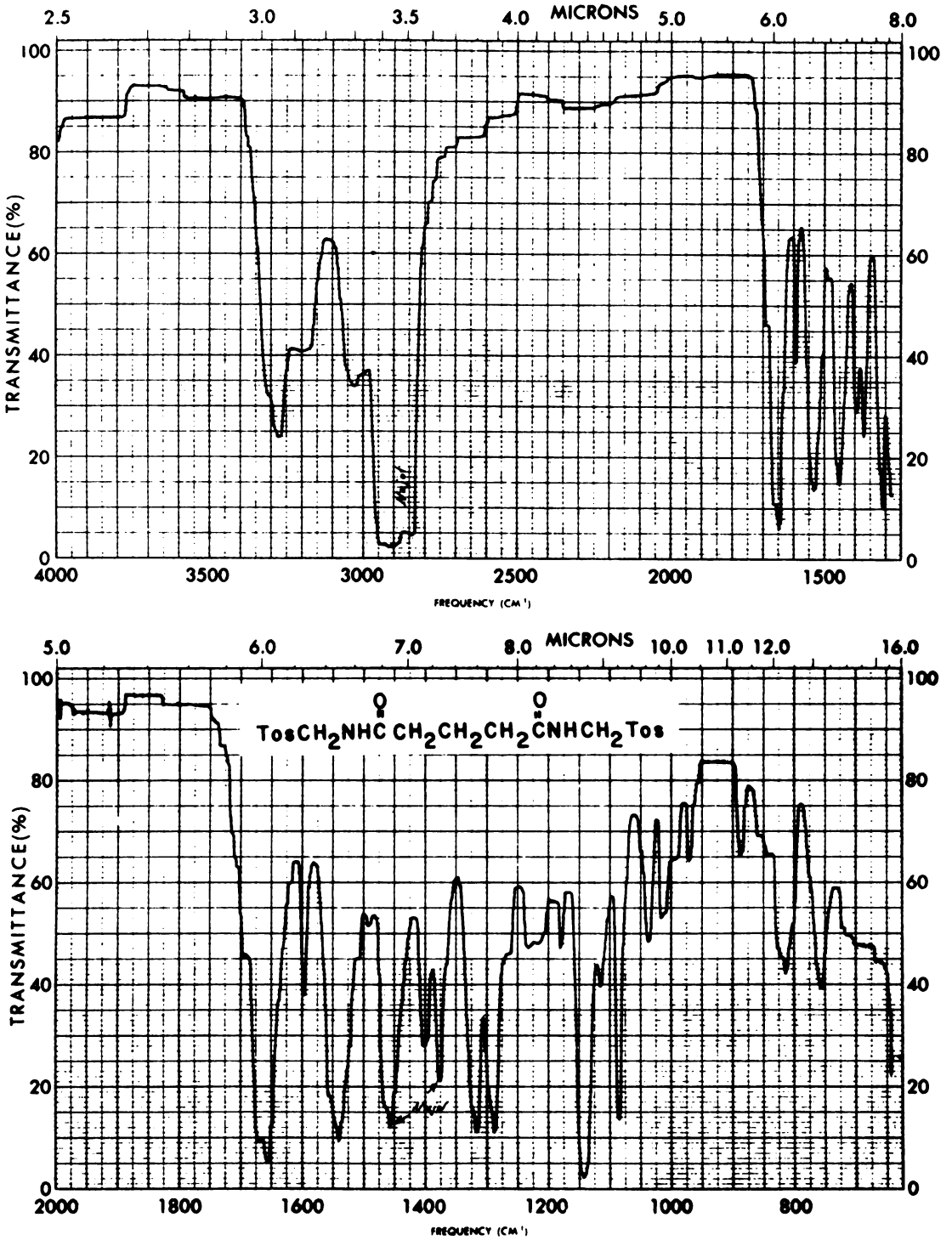


Figure 7. Infrared spectrum of N,N'-Bis(tosylmethyl)-glutaramide (18).

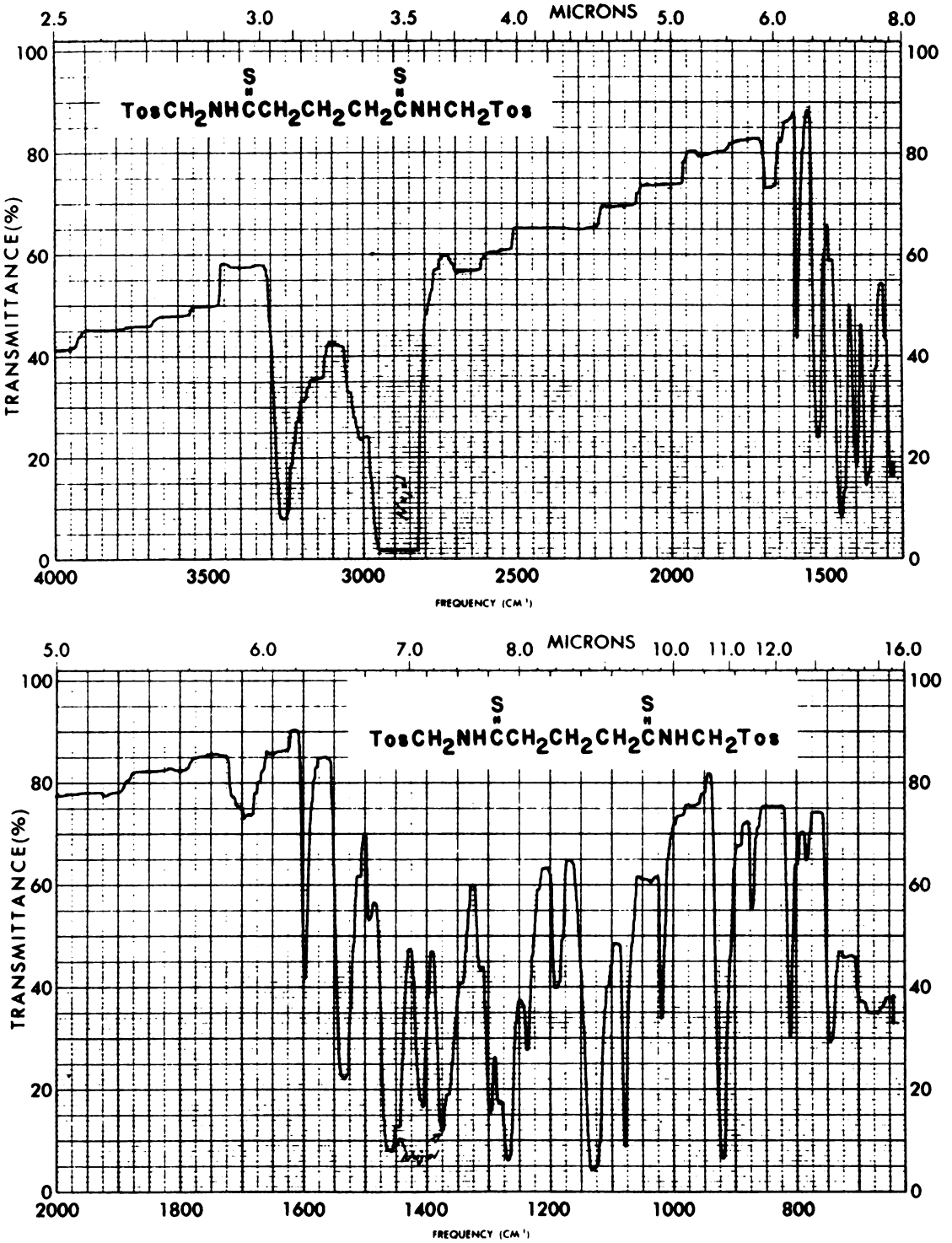


Figure 8. Infrared spectrum of N,N'-Bis(tosylmethyl)thioglutaramide (19).

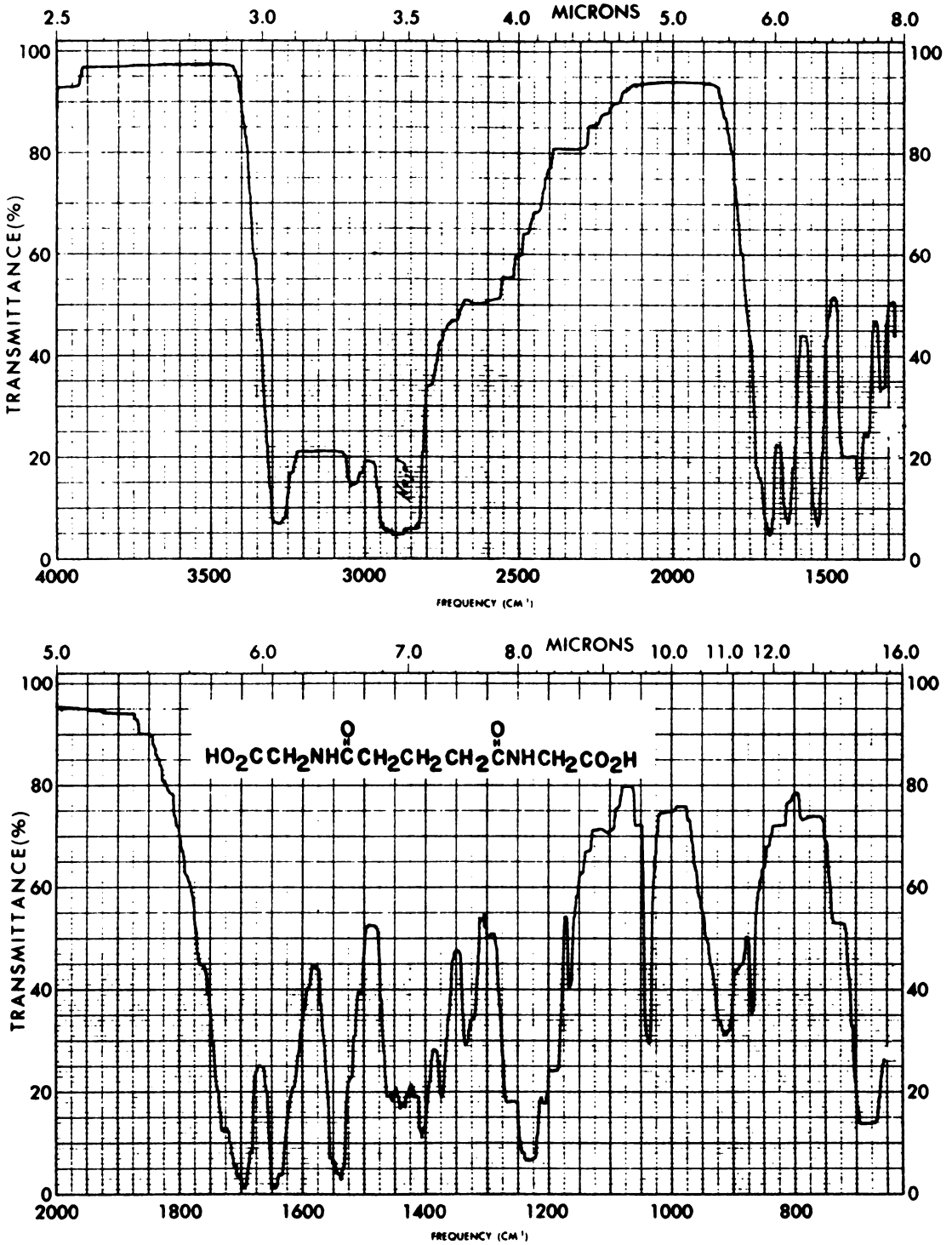


Figure 9. Infrared spectrum of N,N'-Bis(glycyl)glutaramide (21).

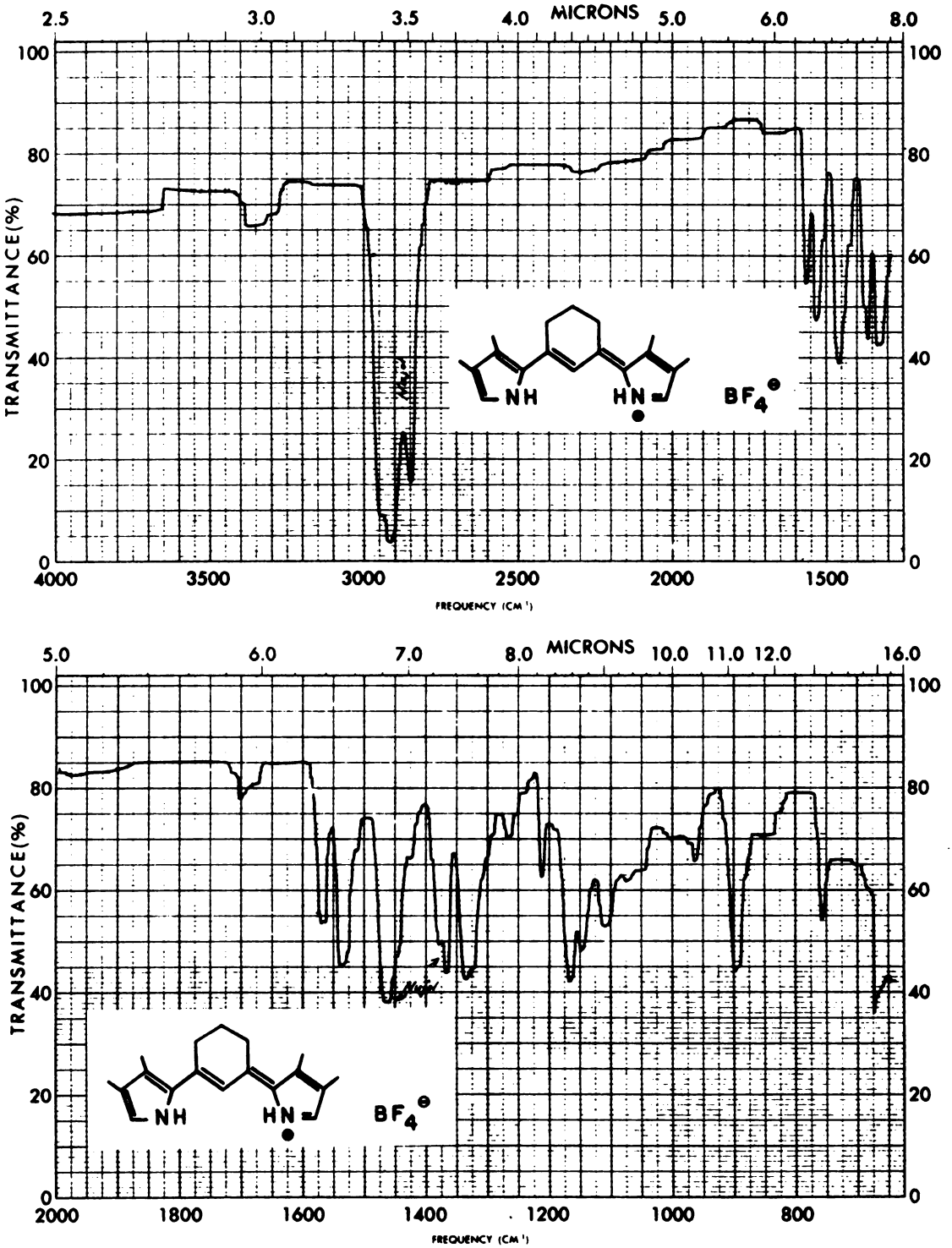


Figure 10. Infrared spectrum of 3,4,3',4'-Tetramethyldipyrryl-2,2'-hexacyclotrimethine tetrafluoroborate (26).

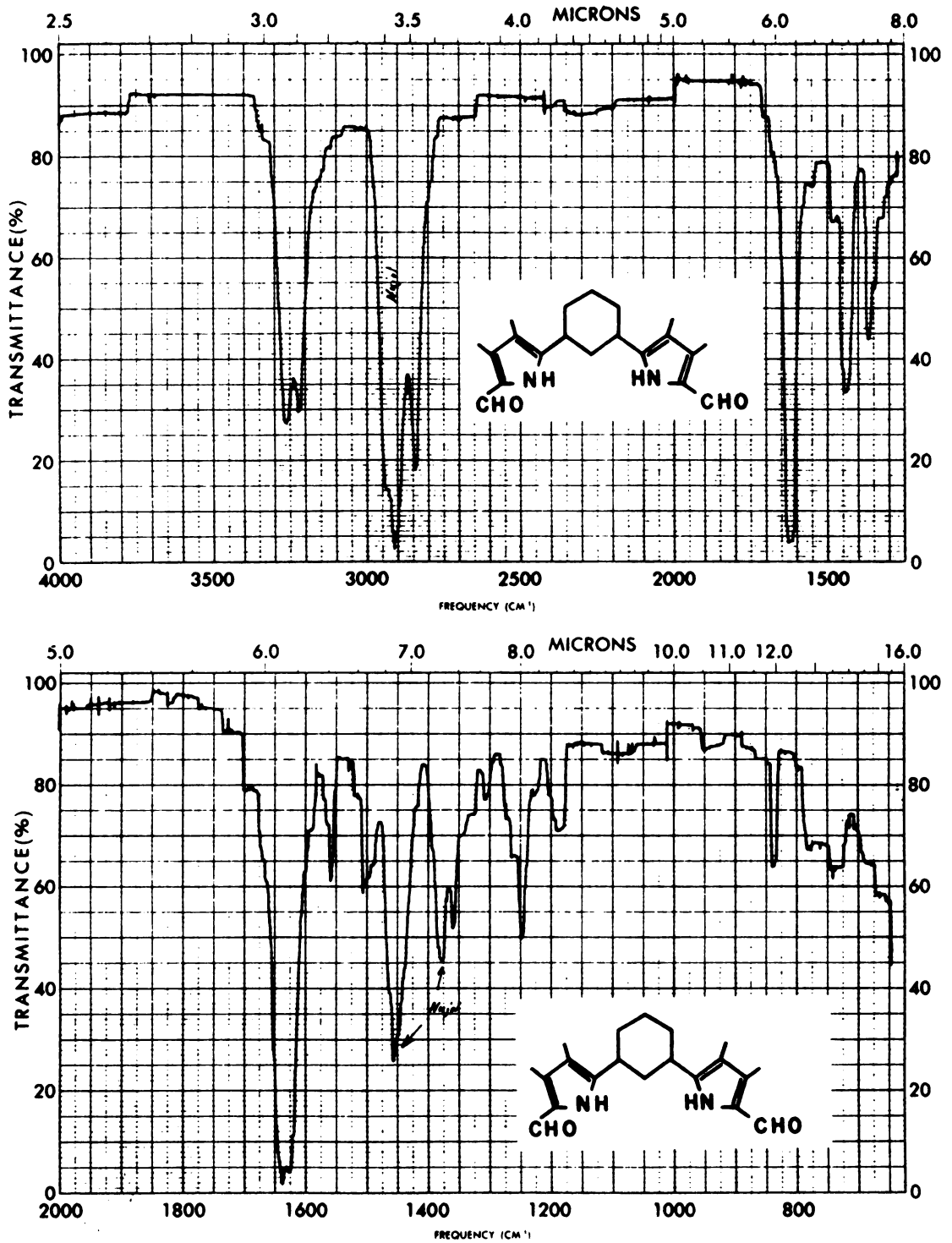


Figure 11. Infrared spectrum of 1,3-Bis(5-formyl-3,4-dimethyl-pyrrol-2-yl)cyclohexane (28).

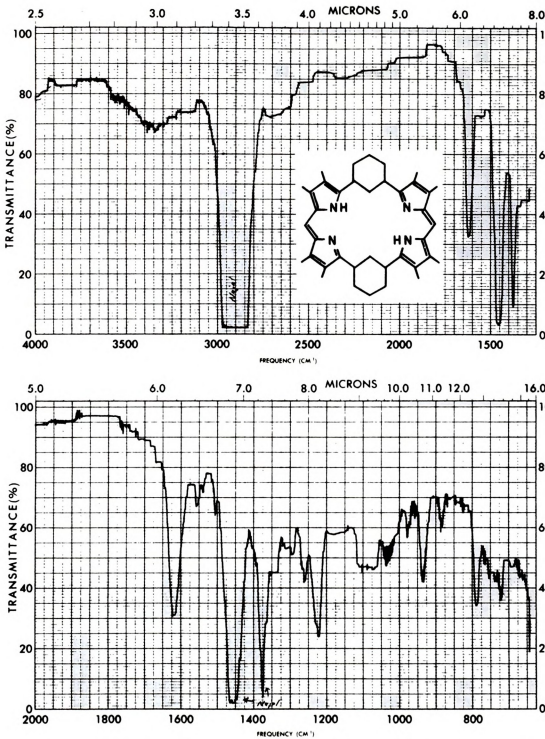


Figure 12. Infrared spectrum of 3,4,8,9,17,18,22,23-Octamethyl-30,31,33,34-tetraazaheptacyclo[23.3.1.1^{2,5}.1^{7,10}.1^{11,15}.1^{16,19}.1^{21,24}]tetratriaconta-2,4,6,8,10-(33),16,18,20,22,24(30)-decaene (29).

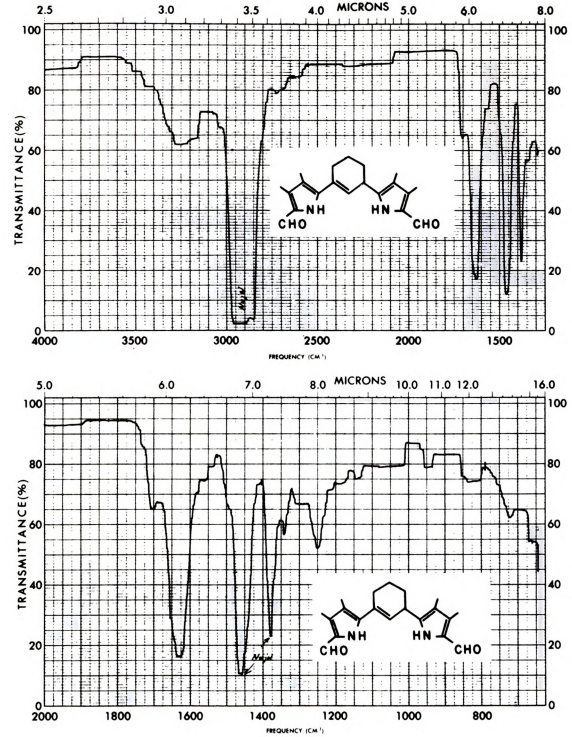


Figure 13. Infrared spectrum of 1,3-Bis(5-formyl-3,4-dimethyl-pyrrol-2-yl)cyclohex-1-ene (32).

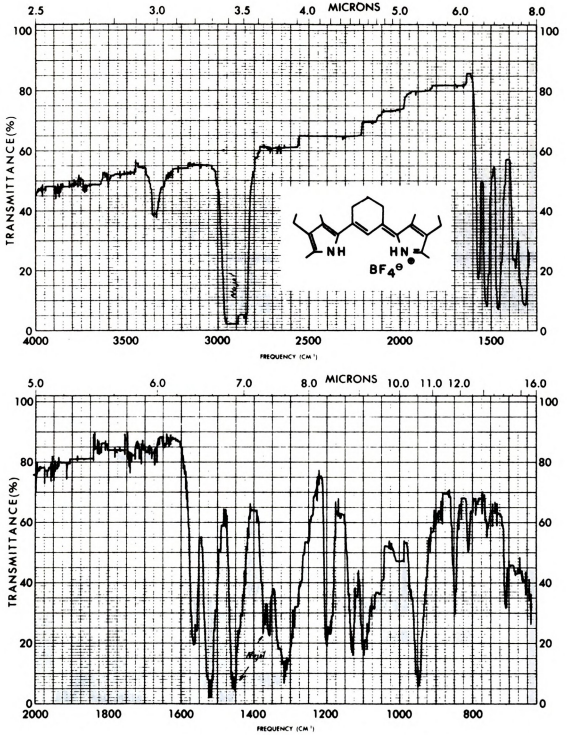


Figure 14. Infrared spectrum of 3,5,3',5'-tetramethyl-4,4'-diethyldipyrryl-2,2'-hexacyclotrimethine tetrafluoroborate (34).

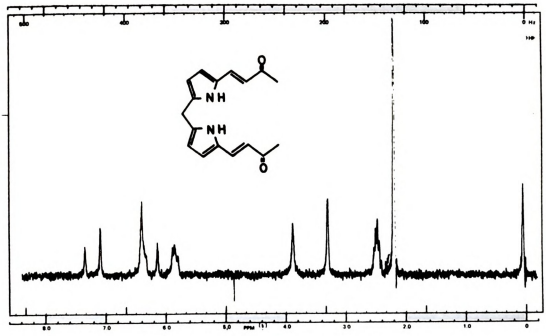


Figure 15. PMR spectrum of 5,5'-Bis(3-oxo-butenyl)-2,2'-dipyrrylmethane (7a).

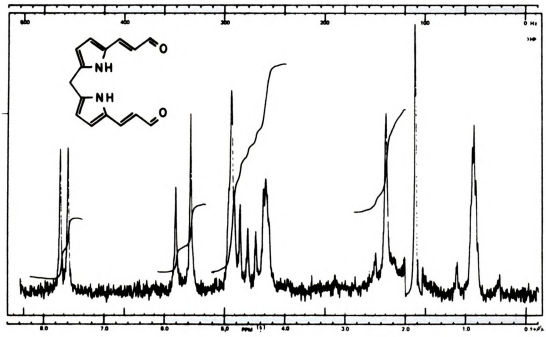


Figure 16. PMR spectrum of 5,5'-Bis(3-oxo-propenyl)-2,2'-dipyrrylmethane (7b).

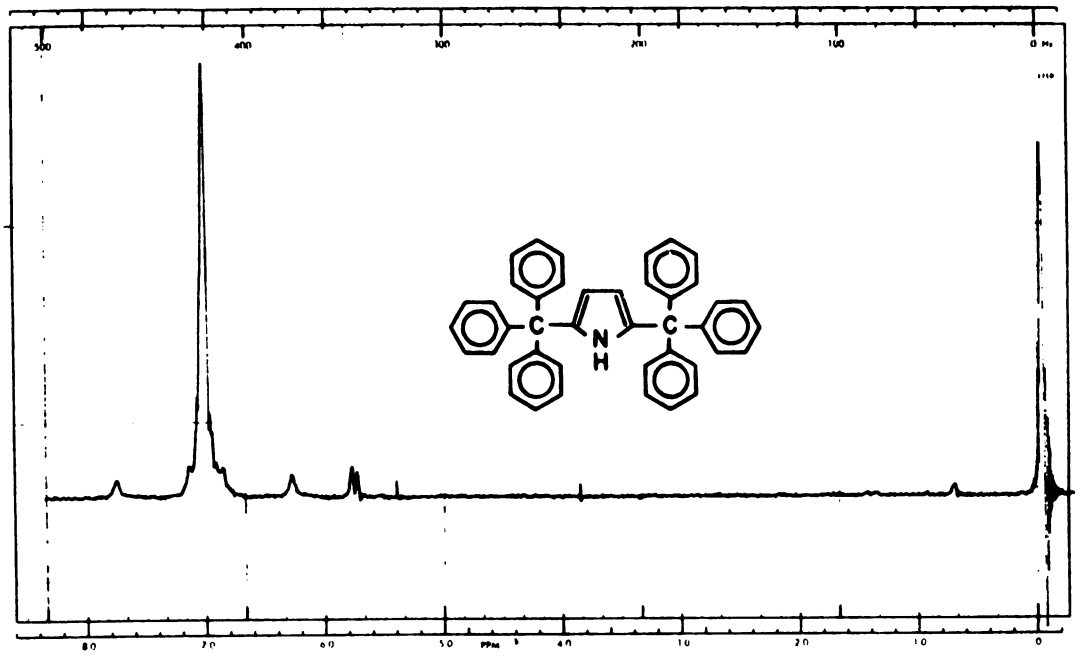


Figure 17. PMR spectrum of 2,5-Bis(triphenylmethyl)pyrrole (13).

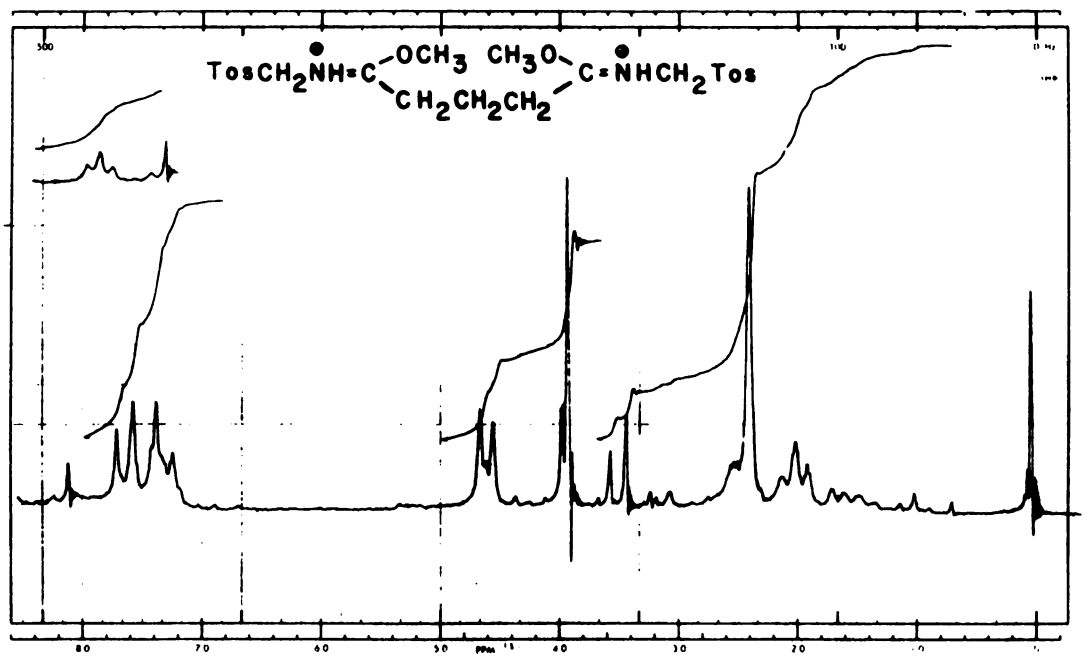


Figure 18. PMR spectrum of dimethyl-N,N'-Bis(tosylmethyl)-glutarimidate (16a).

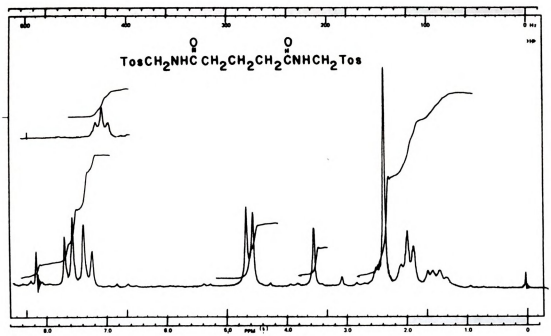


Figure 19. PMR spectrum of N,N'-Bis(tosylmethyl)glutaramide (18).

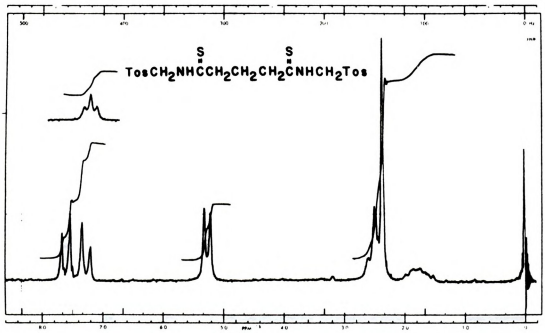


Figure 20. PMR spectrum of N,N'-Bis(tosylmethyl)thioglutaramide (19).

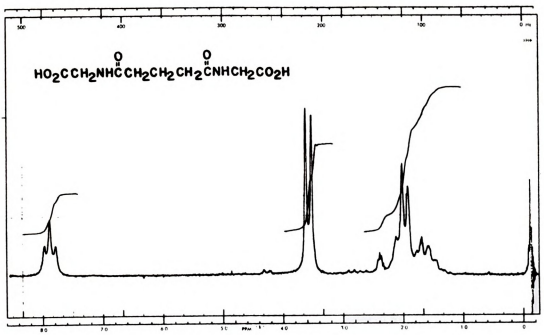


Figure 21. PMR spectrum N,N'-Bis(glycyl)glutaramide (21).

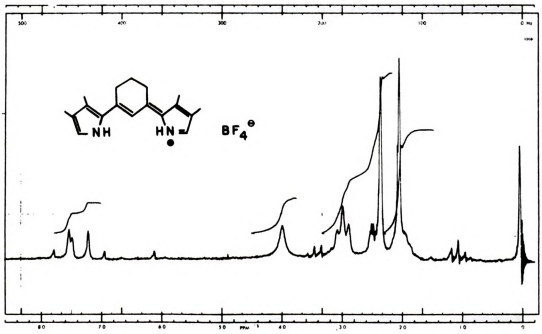


Figure 22. PMR spectrum of 3,4,3',4'-Tetramethyldipyrryl-2,2'-hexacyclotrimethine tetrafluoroborate (26).

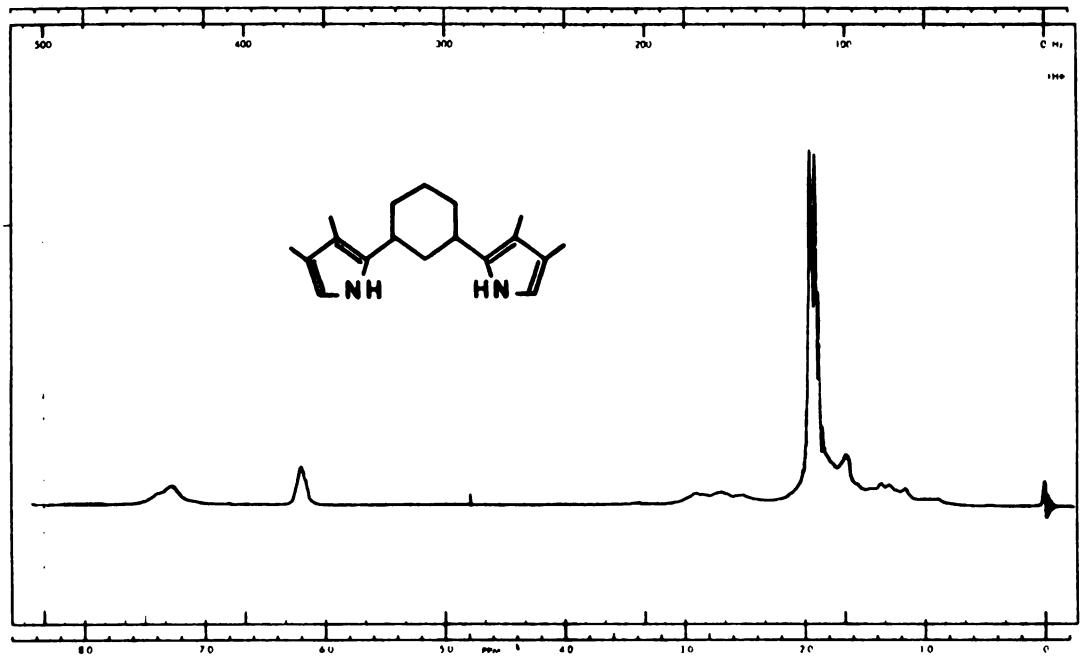


Figure 23. PMR spectrum of 1,3-Bis(3,4-dimethylpyrrol-2-yl)-cyclohexane (27).

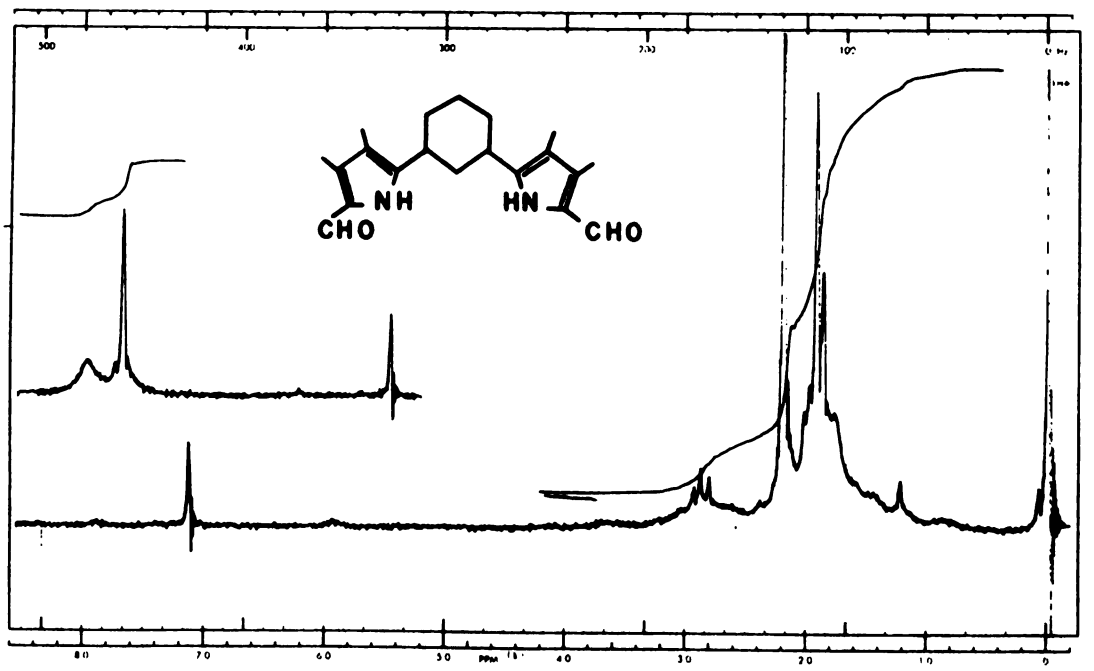


Figure 24. PMR spectrum of 1,3-Bis(5-formyl-3,4-dimethyl-pyrrol-2-yl)cyclohexane (28).

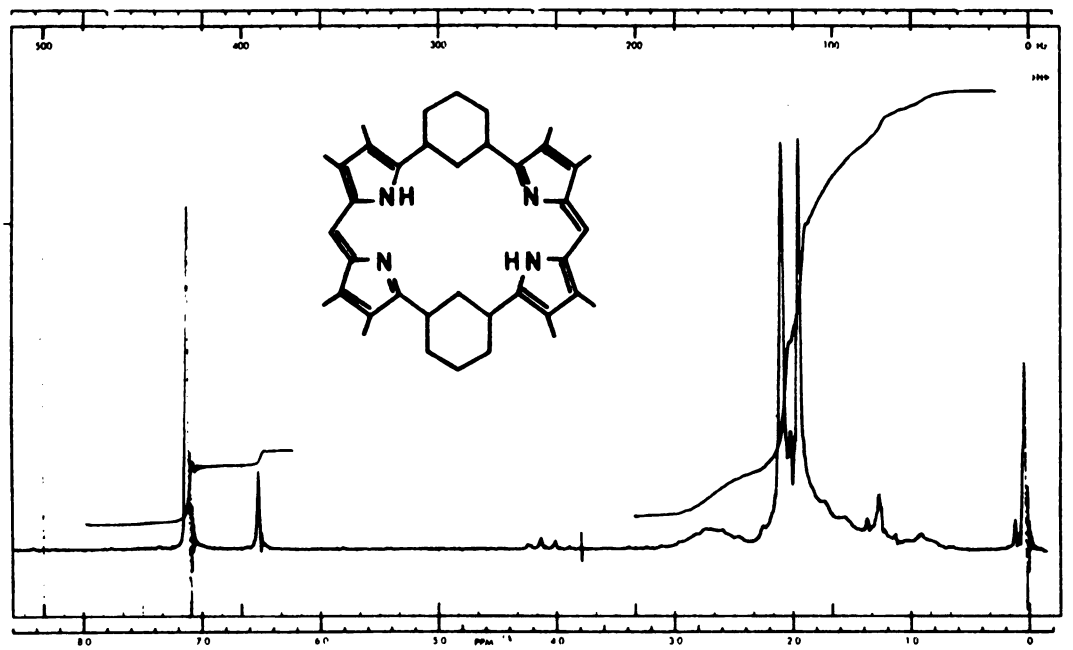


Figure 25. PMR spectrum of 3,4,8,9,17,18,22,23-Octamethyl-30,-31,33,34-tetraazaheptacyclo[23.3.1.1^{2,5}.1^{7,10}.1^{11,15}.1^{16,19}.1^{21,24}]tetratriaconta-2,4,6,8,10(33),16,18,-20,22,24(30)-decaene (29).

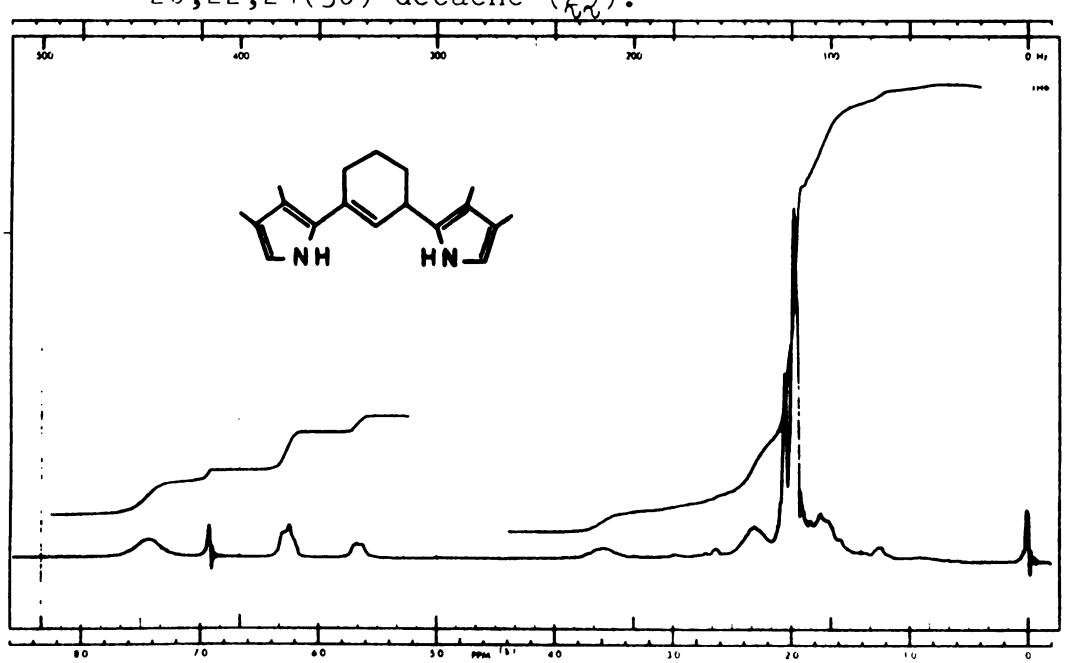


Figure 26. PMR spectrum of 1,3-Bis(3,4-dimethylpyrrol-2-yl)-cyclohex-1-ene (30).

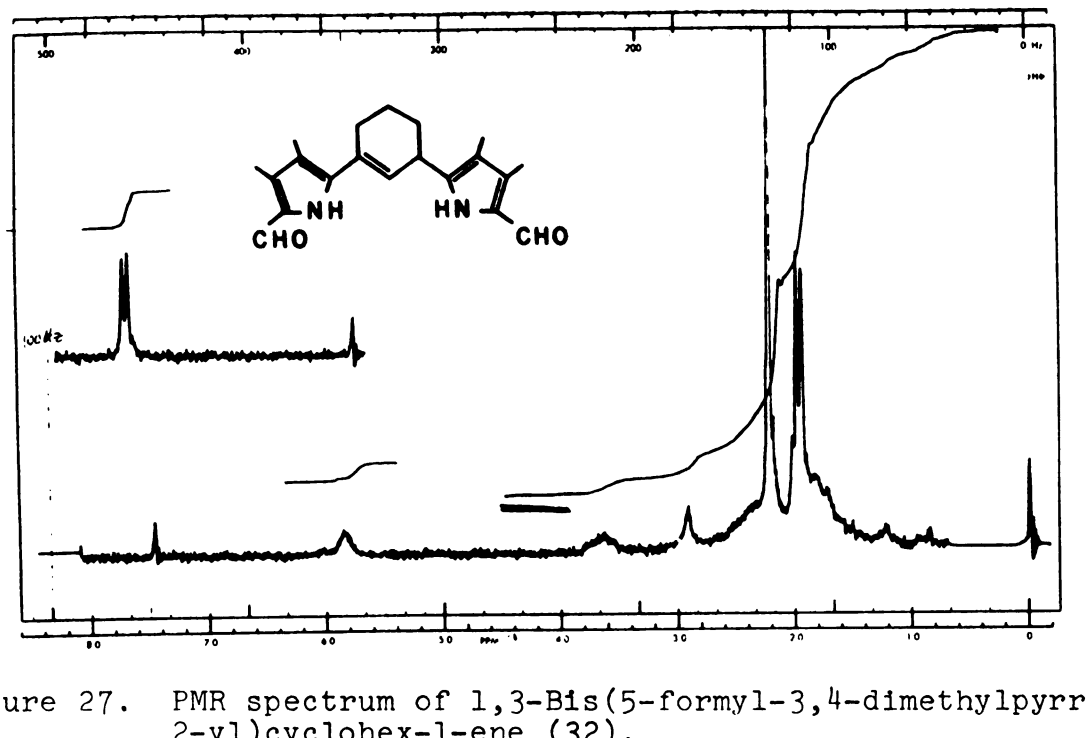


Figure 27. PMR spectrum of 1,3-Bis(5-formyl-3,4-dimethylpyrrol-2-yl)cyclohex-1-ene (32).

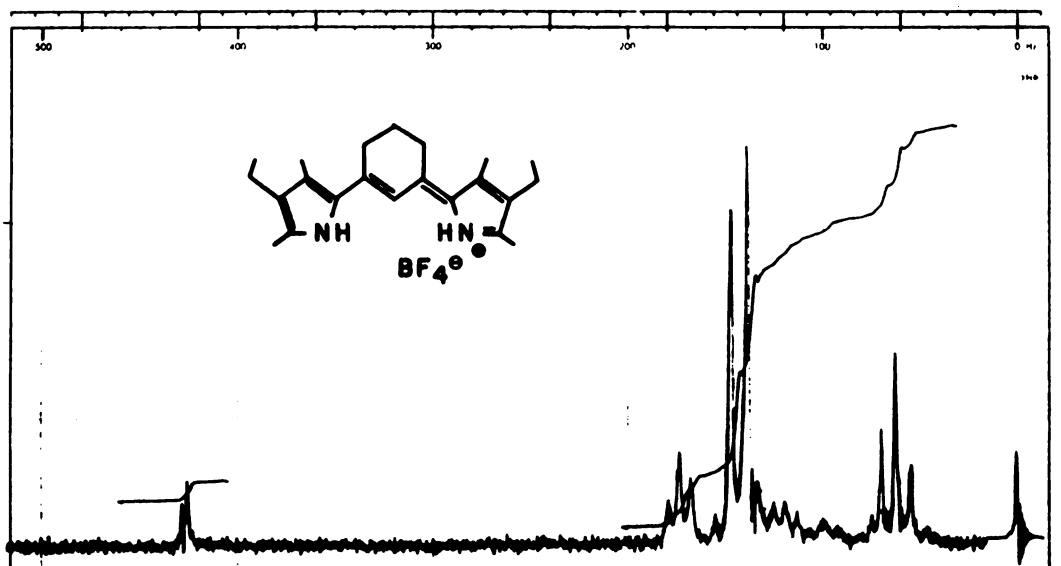


Figure 28. PMR spectrum of 3,5,3',5'-tetramethyl-4,4'-diethyldipyrryl-2,2'-hexacyclotrimethine tetrafluoroborate (34).