A NEW SYNTHESIS OF DIMETHYLDIHYDROPYRENE-2,7-QUINONE AND THE STUDY OF ITS REACTIONS IN THE SYNTHESIS OF NOVEL AROMATIC AND OTHER INTERESTING MOLECULES

by

XIN JIN

M.Sc., Beijing Institute of Technology, CHINA 1987

A THESIS SUBMITTED IN PARTIAL FULFILMENTS OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

in the Department of Chemistry

We accept this thesis as conforming to the required standard

[redacted]

Dr. R. H. Mitchell

[redacted]

Dr. C. Spino

[redacted]

Dr. A. Watton

University of Victoria

Supervisor: Dr. Reginald H. Mitchell

ABSTRACT

A new synthesis of *trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, **17**, was developed via the oxidation of *trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, **21**, using both NBS and PDC as oxidants. Through this route, **17** can be prepared in a 19% over-all yield by a 12 step procedure comparing to a 1.6% over-all yield and 16 steps in the previous synthesis route.

The Diels-Alder reactions of **17** with dienes (isobenzofuran and *o*-xylylene) have been investigated under different conditions. The results suggested that quinone **17** is not a useful D-A dienophile. Thus the attempt to develop a general and efficient route to [e]-annelated derivatives of **21** via the D-A reaction of **17** was unsuccessful.

The condensation reaction of quinone **17** with malononitrile led to α,α,α',α'-tetracyano-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinodimethane, **34**. As a TCNQ analogue, **34** has the potential as a organic conductor. The formation of a charge transfer complex with N,N-diethylamine was indicated by the appearance of long wave length absorption in its electronic spectrum.

The re-investigation of the addition reaction of dimethylsulfonium methylide and **17** led to the finding of a new product, 2,7-bis(hydroxymethyl)-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, **60**. The first macrocyclophane

with a DMDHP unit, **66,** was synthesised by the coupling reaction of **60** and adipoyl chloride. The NMR study of **66** indicated that the two DMDHP rings are not in the face to face conformation.

The bromination of quinone **17** gave two regio isomers of dibromoquinone, 1,8-dibromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, **82,** and 1,6-dibromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, **83**. From these two isomers, 1,8-dibromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, **94**, and 1,6-dibromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, **96**, were synthesised.

Examiners:

[redacted]

Dr. R. H. Mitchell, Supervisor (Department of Chemistry)

[redacted]

Dr. C. Spino, (Department of Chemistry)

[redacted]

Dr. A. Watton, (Department of Physics and Astronomy)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Ar	aromatic ring
^{13}C NMR	carbon-13 nuclear magnetic resonance spectrum
DDQ	2,3-dichloro-5,6-dicyano-1,4-benzoquinone
DMDHP	dimethyldihydropyrene
DMF	dimethylformamide
DMSO	dimethylsulfoxide
eq.	equation
^{1}H NMR	proton nuclear magnetic resonance spectrum
d	doublet
dd	doublet of doublets
in	internal
m	multiplet
s	singlet
t	triplet
IR	infrared spectrum
m	medium
s	strong
w	weak
Me	methyl
MS	mass spectrum

CI	chemical ionization
EI	electron impact
NBS	N-bromosuccinimide
PDC	pyridinium dichromate
TCNQ	7,7,8,8-tetracyanoquinodimethane
THF	tetrahydrofuran
UV	ultraviolet spectrum

ACKNOWLEDGEMENTS

I would like to express my sincere thanks to Professor R. H. Mitchell for his encouragement and guidance throughout the course of this work.

I would also like to thank all of the member of the department, particularly Mrs. C. Greenwood for her help in recording the NMR spectra and Dr. D. McGillivray for recording the mass spectra. I am indebted to my colleagues and friends for their helpful suggestions, discussions and support during my stay in Victoria.

I am grateful to the University of Victoria and the Department of Chemistry for financially supporting me during my study here.

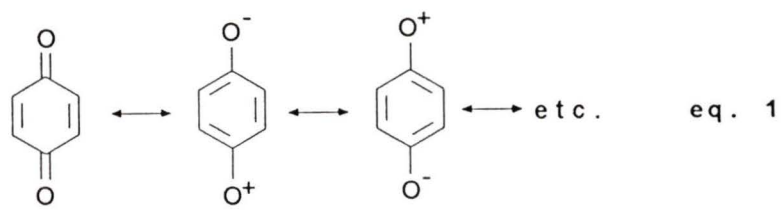
Finally I wish to thank my parents, my wife and my brothers and my friends in China for their deep loving encouragement, patience and friendship.

CHAPTER ONE

INTRODUCTION

1.1 Quinones

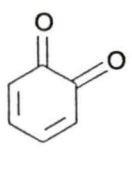
Quinones are planar conjugated cyclic diketones. Because of their importance in organic synthesis, the pigment and the photographic industries as well as in biological systems, the chemistry of quinones has been of great research interest for over a century, and probably will continue to be an active area in the future. Quinones have more stability than expected on the basis of bond energies alone, e.g. 1,4-benzoquinone has a stabilization energy[1] of 5 kcal/mol. This used to be considered due to the contribution of resonance structures: eq. 1



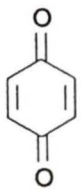
eq. 1

Recently, X-ray crystallographic data[2] show that the bond lengths of quinones are close to that of classical diketones. This means quinones have little aromatic character.

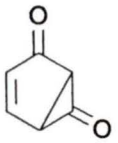
Many quinone type compounds have been prepared. Among them the simplest examples are 1,2- or *o*-benzoquinone, **1**, and 1,4- or *p*-benzoquinone, **2**. 1,2-Quinones usually are less stable than 1,4-quinones, and are more



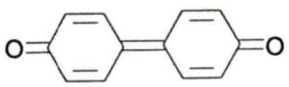
1



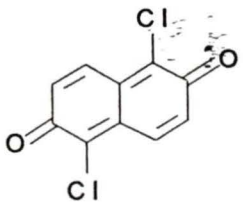
2



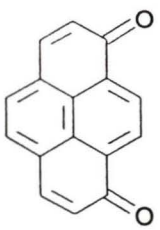
3



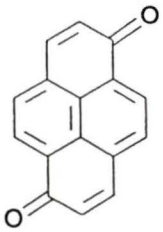
4



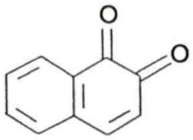
5



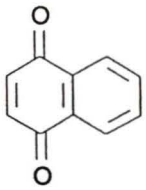
6



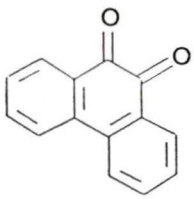
7



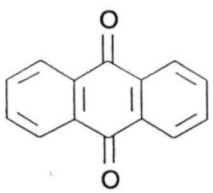
8



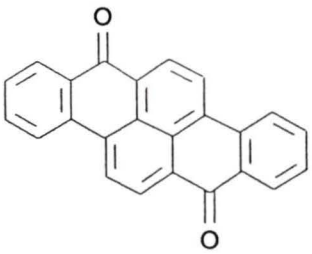
9



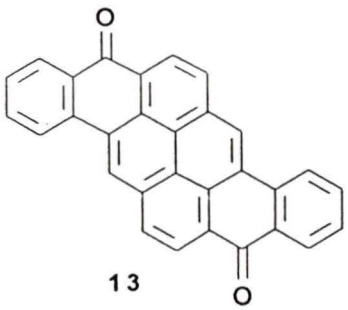
10



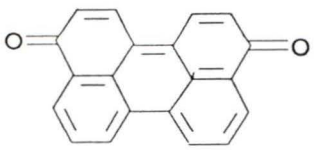
11



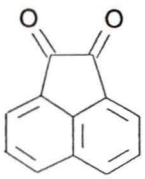
12



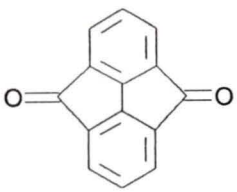
13



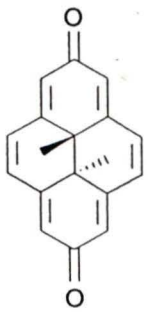
14



15



16



17

difficult to prepare. No 1,3-quinones, **3**, for which normal Kekulé structures can not be drawn, are known. Other quinones can be considered as 1,2- or 1,4-benzoquinones separated by conjugated double bonds system, e.g. **4**, **5**, or aromatic systems, e.g. **6**, **7**, or as 1,2- or 1,4-benzoquinones fused with aromatic system on one side, e.g. **8**, **9**, or on both sides, e.g. **10**, **11**. Some polycyclic quinones have a combination of the structural features above, e.g. **12**, **13**, **14**. There are also some conjugated diketones, e.g. **15**, **16**, which are called quinones, but strictly speaking, they are more likely benzophenones than quinones. The one exception is *trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, **17**, which was prepared as a precursor in the synthesis[3] of the bridged 14-annulene, *trans*-10b,10c-dimethyl-10b,10c-dihydropyrene[4]. Before discussion of the synthesis of dimethyldihydropyrenequinone (DMDHPQ) **17** and of its reactions and synthetic applications in our system, a general review of the generation and reactions of quinones will be given. Since many quinones are known, our discussion will be restricted to the mono and polycyclic quinones. Those important in the pigment and the photographic industries and in biological systems will not be considered here, but will be mentioned briefly under chemical reactions of quinones.

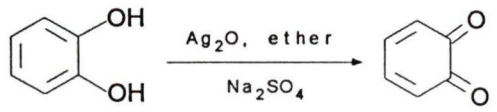
1.2. Preparation of Quinones

Quinones have been obtained in numerous ways. However, from a synthetic stand-point, methods which give acceptable yields, via convenient procedures and use general reagents are limited. Among the most common methods are oxidation, annelation, cyclization and condensation.

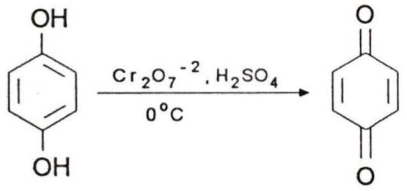
1.2.1. Oxidation

Most quinones have been prepared by oxidation, usually of phenols, hydroquinones, aromatic amines and diamines, or of aromatic hydrocarbons. Hydroquinones are the easiest to oxidize. The oxidation of phenols and aromatic amines, which require introduction of one atom of oxygen, are less easy. The oxidations of aromatic hydrocarbons are the most difficult, since they require introduction of two atoms of oxygen. The relative ease of oxidation is indicated by comparison of the redox potentials of the substrates.[5]

The oxidation of hydroquinones is the easiest method for the preparation of both 1,2-and 1,4-quinones, provided that the corresponding quinols are available. The oxidation reagents commonly used are chromic acid, silver oxide, DDQ, and chloranil, and in some case even quinone itself can be used as a mild oxidant, eq. 2, 3 and 4. The yields for the oxidation of quinols range between quantitative and good.



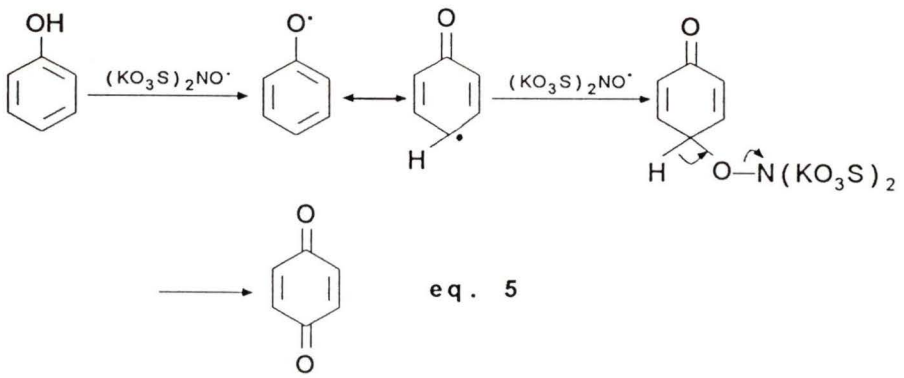
eq. 2



eq. 3

eq. 4

The Teuber reaction[6], which uses Fremy's salt (potassium nitrosodisulphonate, $(KO_3S)_2NO$) as oxidant, is the most widely used method for the oxidation of phenols. It gives excellent yields and proceeds under mild conditions. The reaction is carried out in aqueous alcohol or acetone, using two equivalents of Fremy's salt and is buffered with phosphate or acetate. The

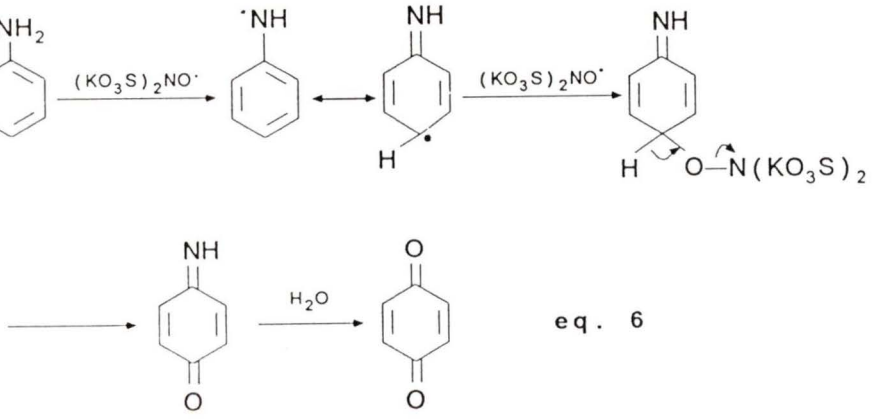


eq. 5

mechanism shown in eq. 5 was confirmed both by using ^{18}O Fremy's salt[7] and by isolation of the intermediate[8]. When the *p*-position of phenol is blocked, 1,2-benzoquinone resulted. If the substituent on the *p*-position is a good leaving group such as a halogen or a t-butyl group, elimination will occur and lead to a 1,4-quinone.

Another widely used oxidant in the oxidation of phenols is chromic acid, however in cases which lack a good leaving substituent at the *p*-position, the yields are usually low. Other methods include anodic oxidation[9], fuming nitric acid in the oxidation of highly substituted phenols[10], and thallium (III) trifluoroacetate in the oxidation of *p*-halogeno- and *p*-t-butylphenols[11]. These methods usually give acceptable yields, and in the last case the yield is almost quantitative.

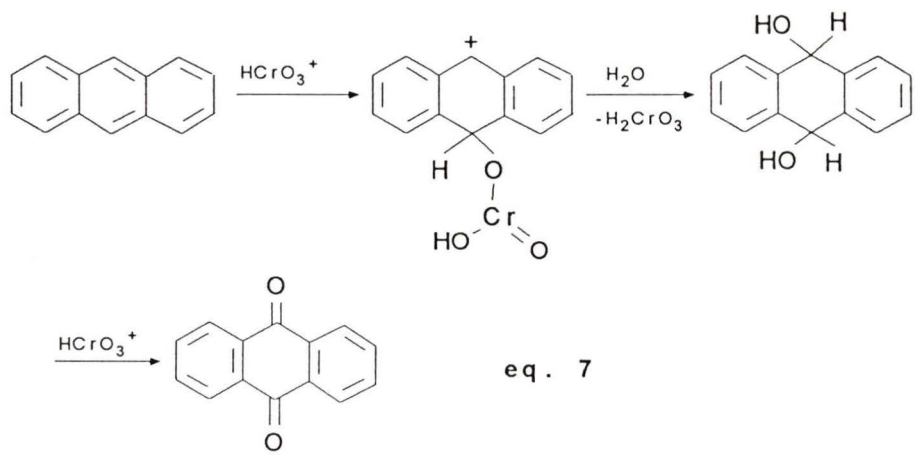
The oxidation of aromatic amines using Fremy's salt is not as efficient as the oxidation of phenols and the yields for the amines lacking a *p*-substituent are usually poor. The mechanism for this reaction is similar to that for phenols, eq. 6.



eq. 6

Other oxidants used in the oxidation of aromatic amines are acidic dichromate, manganese dioxide and ferric sulphate. The reactions proceed more easily with *p*-substituted amines, and *p*-diamines are best. The main disadvantage in the preparation of quinones via oxidation of amines are the side-reactions, e.g. oxidation of the amino to a nitroso group[12].

Aromatic hydrocarbons are the most difficult to oxidize, hence methods are limited and yields are generally not high. Since the first step in the oxidation of an aromatic hydrocarbon is the formation of a cation or radical-cation, the oxidation of a condensed polycyclic aromatic hydrocarbon is much easier because of the extensive delocalization of the charge. A good example is the oxidation of anthracene to 9,10-anthraquinone, eq. 7. Oxidants used for this purpose have been nitric acid, chromic acid, sodium chlorate[13], periodic



eq. 7

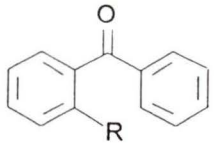
acid in DMF[14] and vanadium(V) oxide. Besides chemical oxidation, anodic

oxidation also gives acceptable yields. The oxidation of simple aromatic hydrocarbons to quinones usually gives poor yields. The oxidation of naphthalene by chromium trioxide in acetic acid gave only 32% of 1,4-naphthoquinone[15]. For oxidation of benzene into benzoquinone there is no really useful laboratory process. Generally, for the oxidation of aromatic hydrocarbons there is no commonly useful oxidant, such as Fremy's salt for the oxidation of phenols and amines.

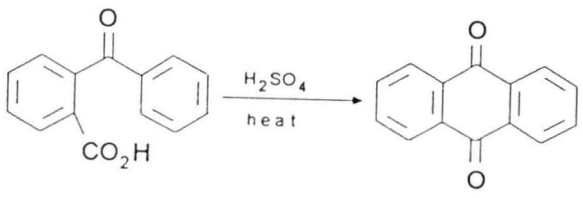
1.2.2. Cyclization

Cyclization methods are widely used in the generation of polycyclic quinones, usually by an intramolecular reaction. The reactions employed are Friedel-Crafts reactions, electrophilic substitution followed by oxidation-the Scholl reaction, and nucleophilic substitution followed by oxidation.

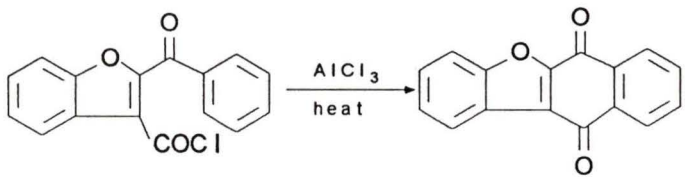
In preparation of a quinone by a cyclization method, the starting material would normally have the structure below:



When R- = -COOH or -COCl, the Friedel-Crafts reaction can be used to achieve

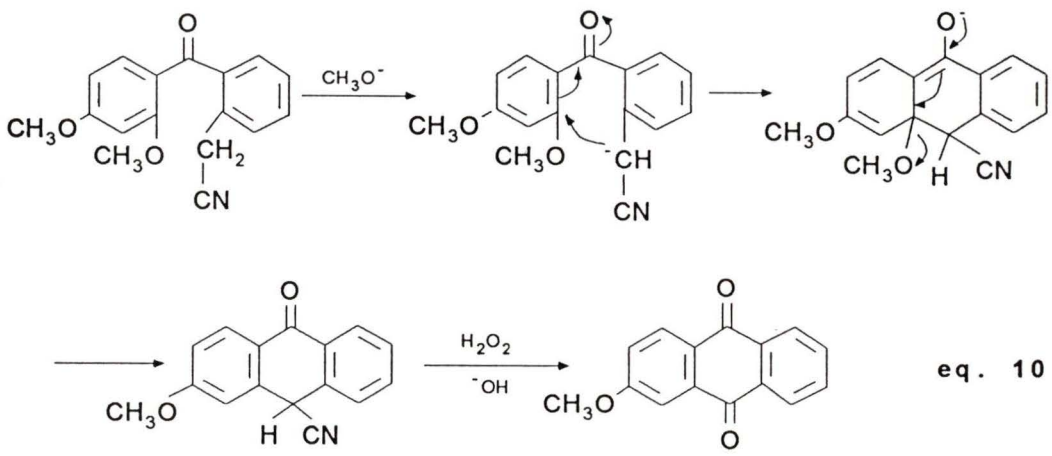


eq. 8

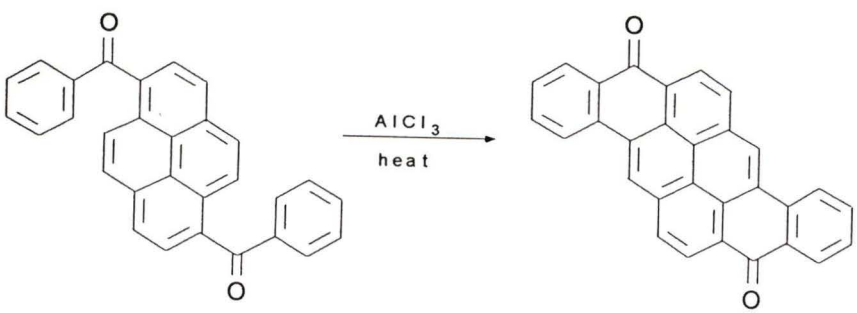


eq. 9

the cyclization[16], eq. 8 and 9. In cases where R- is -CH_2CN, a nucleophilic substitution reaction is used to achieve the cyclization[17], eq. 10.



eq. 10

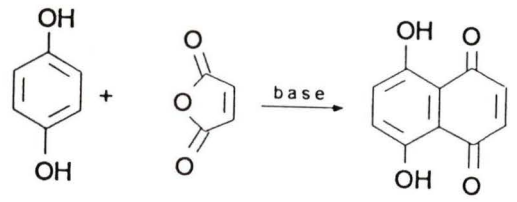


eq. 11

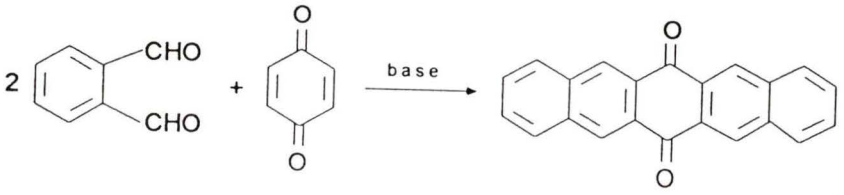
Scholl reactions[18] are regarded as a radical coupling or radical substitution followed by an oxidation. They are mainly used in preparation of higher polycyclic quinones. The reactions are carried out by heating the substrate with aluminum chloride, eq. 11.

1.2.3. Condensation

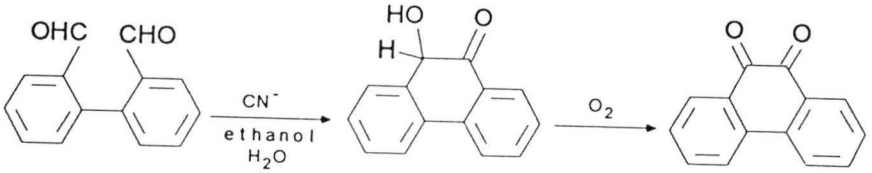
Condensation methods employ the reaction of a quinol with either a cyclic anhydride or dialdehyde or 1,4-diketone. Thus condensation of quinol with maleic anhydride gives naphthazarin[19], eq. 12.



eq. 12



eq. 13



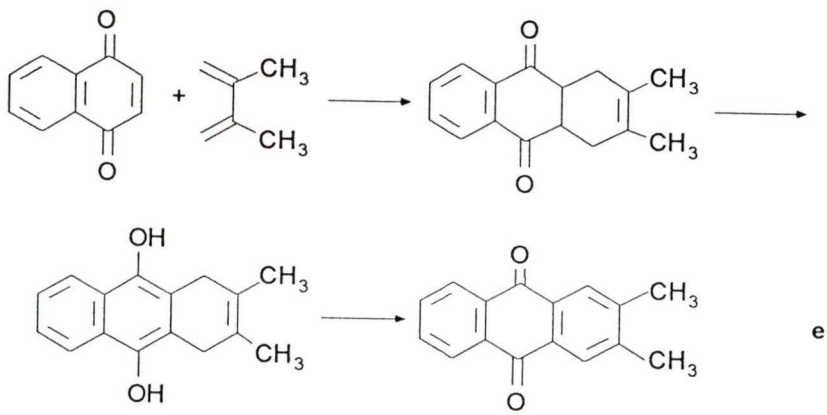
eq. 14

The reaction of two moles of phthalaldehyde with 1,4-quinone in the presence of a base gives pentacenequinone in good yield[20], eq. 13. In some cases an intramolecular benzoin condensation occurs which lead to an *o*-quinone[21], eq. 14.

1.2.4. Annellation

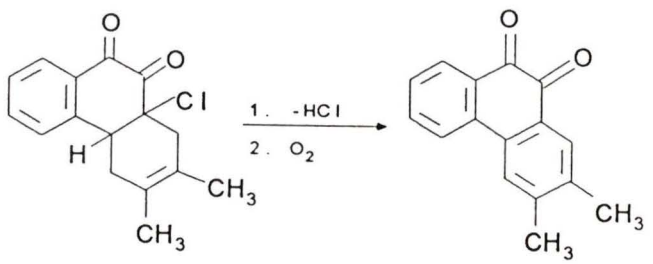
Annellation is also a widely used method in the preparation of higher polycylic quinones. One of the rings in the structure is constructed by a cyclo-addition reaction between a starting quinone and either a diene or a 1,3-dipolar species. In the cyclo-addition reaction with a diene species, Diels-Alder reaction, the starting quinone acts as a dienophile, or acts both as a dienophile and as a diene in the case where the starting quinone is an *o*-quinone.

Normally the synthesis of a quinone via the Diels-Alder reaction involves three steps: addition of a conjugated diene to the starting quinone, aromatization of the adduct and oxidation of resulting quinol, eq. 15. The



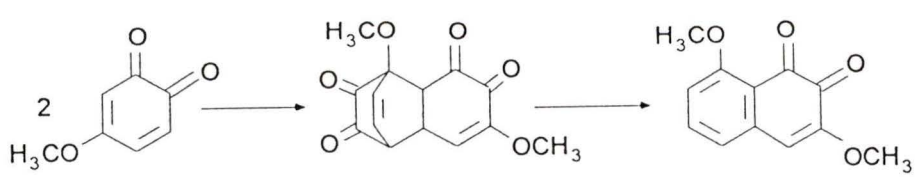
eq. 15

aromatization can be induced by chromatography on alkaline alumina[22], heating the adduct in high boiling point solvent[23], and by dehydrogenation. For the adducts formed from halogenated quinones or halogenated dienes, the aromatization goes readily by loss of hydrogen halide and give the expected quinone directly, eq. 16.



eq. 16

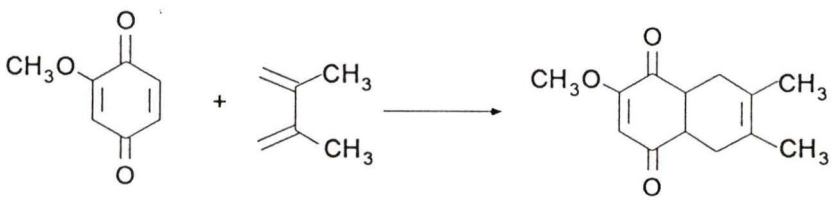
o-Benzoquinone can behave both as dienophile and as diene. Thus two molecules of 4-methoxy-1,2-benzoquinone, one as dienophile, the other as diene, form the Diels-Alder adduct which on oxidation with periodate gives the *o*-quinone[24], e



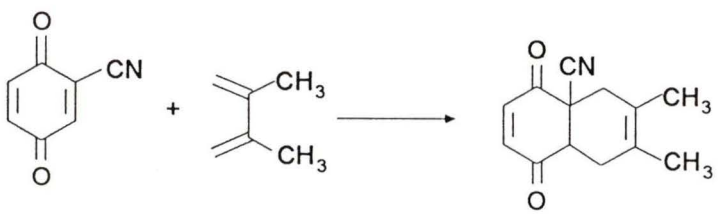
eq. 17

For substituted quinones, the Diels-Alder reaction takes place

preferentially at the electron-deficient double bond. The addition of 2,3-dimethylbutadiene to methoxybenzoquinone occurs at the unsubstituted double bond[22], eq. 18, while to cyanobenzoquinone at the substituted double bond[22], eq. 19. The details of the regio and stereo control of Diels-Alder addition will be discussed later.



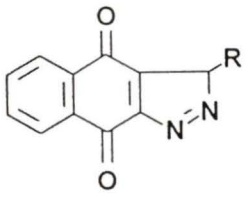
eq. 18



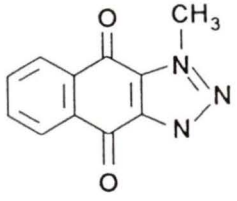
eq. 19

Since an aromatization in eq. 15 (or eq. 18) leads to hydroquinone, the final oxidation step is easily achieved by most of the oxidants mentioned above in the oxidation of hydroquinones.

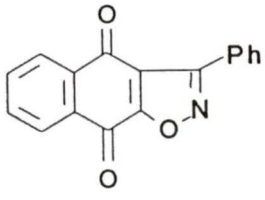
1,3-Dipolar cycloaddition reactions using quinone and a dipolar species are not very common, but their potential in the synthesis of heterocyclic quinones has been demonstrated. The dipolar species used for this purpose include diazoalkanes[25], azides[26] and nitrile oxides[27]. Similar to the Diels-Alder adducts, the 1,3-dipolar adducts, after aromatization and oxidation, give the corresponding quinones, e.g. **18**, **19** and **20**.



18



19

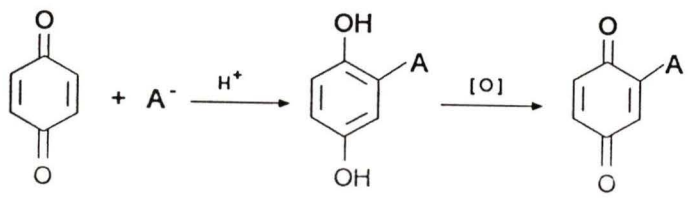


20

1.3. Reactions of Quinones

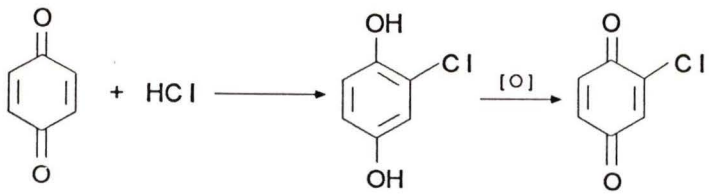
1.3.1. 1,4-addition

Quinones are α,β-unsaturated ketones. The majority of the reactions of quinones can be characterized as 1,4-additions of the Michael type. The addition products, hydroquinones, are susceptible to oxidation. The total process is in effect a direct substitution of the quinone, eq. 20.



eq. 20

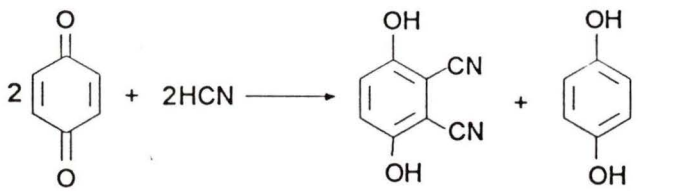
The earliest reported 1,4-addition reaction of quinone is the addition of HCl[28], eq. 21.



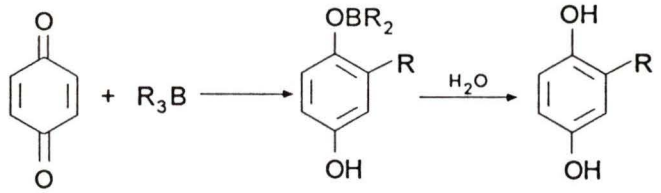
eq. 21

Other addition reactions of quinones can be classified by the attacking atoms of the nucleophilic reagents. The typical examples for carbon, nitrogen,

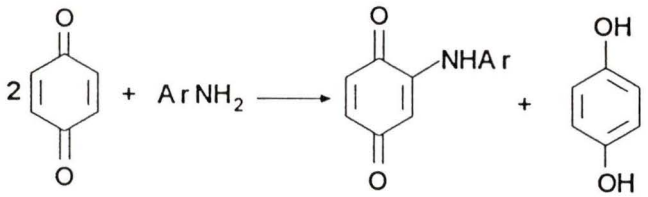
sulphur and oxygen addition as well as some other nucleophilic reagents are listed below.



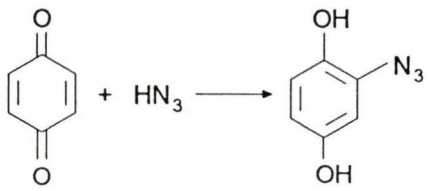
eq. 22[29]



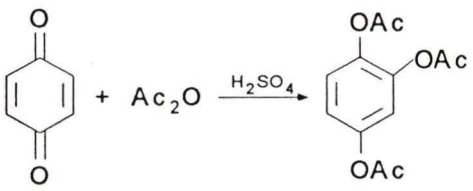
eq. 23[30]



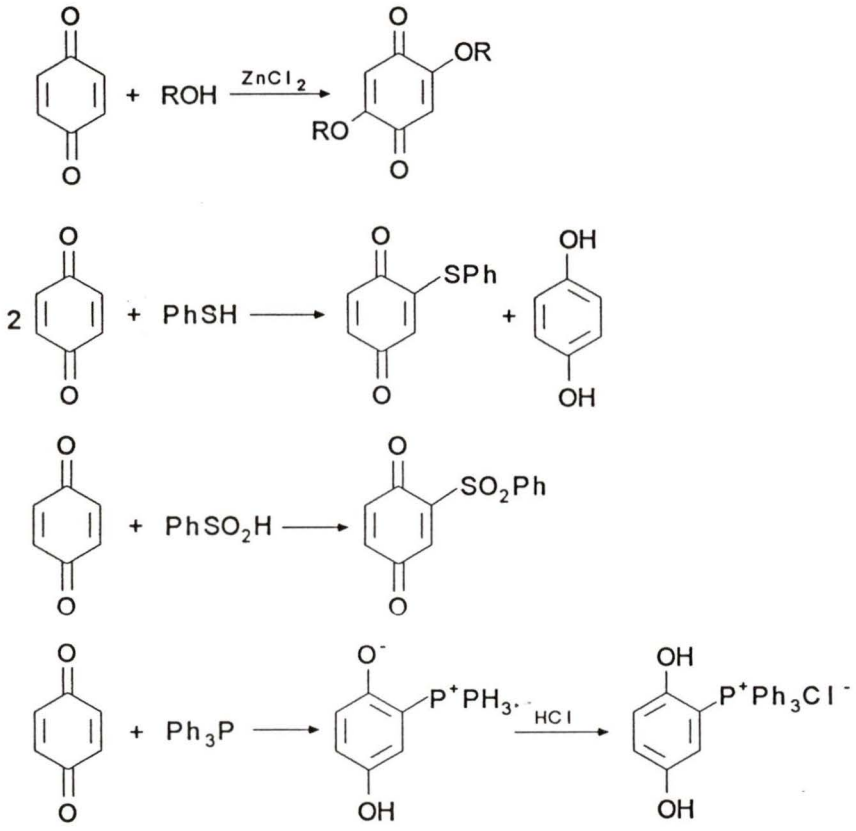
eq. 24[31]



eq. 25[32]



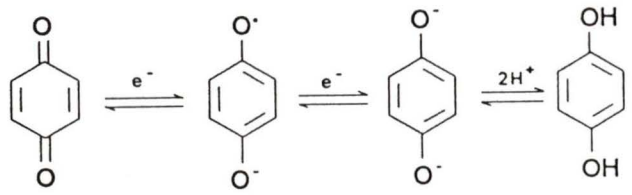
eq. 26[33]



1.3.2. Reduction

Another characteristic and important reaction of quinones is reduction to the corresponding hydroquinones. The driving force to form the fully aromatic system eases the reduction of quinone, which is a two-electron process. The intermediate formed after the quinone accepts the first electron is a radical-anion, called a semiquinone, eq. 31.

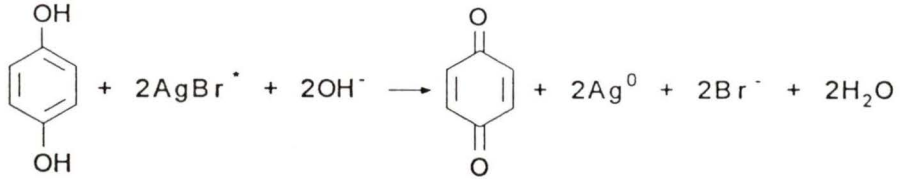
It is this reversible quinone-hydroquinone reduction-oxidation process which accounts for the importance of quinones in the photographic and dye



eq. 31

industries and in biological systems. In the dye industry the insoluble quinone dye, normally an anthraquinone derivative, is reduced to a hydroquinone compound in basic solution. In this solution the hydroquinone compound dissolves as the sodium salt. In its ionic form the hydroquinone has a high affinity for the fibre. After exposure to air, oxidation takes place and regenerates the quinonoid dye which remains attached to the fibre.[38]

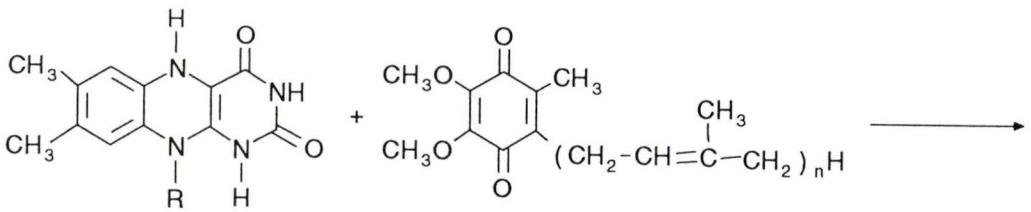
As photographic developers, hydroquinone reduces the activated form of silver bromide (which was exposed to light) to silver metal much faster than the inactivated form (which was not exposed to light), eq. 32. Removal of the unreduced silver bromide leaves the silver metal image in the photographic negative[1].



eq. 32

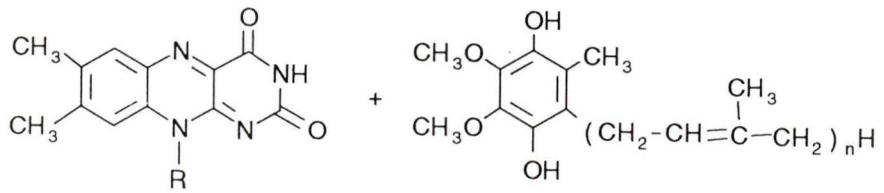
In biological systems, an important example is the reduction of a quinone called coenzyme Q (CoQ) to the corresponding hydroquinone ($CoQH_2$), see eq. 33. This reduction plays an important role in the metabolic oxidation of NADH by oxygen. The electron transferring sequence from NADH to oxygen may be summarized as[39]

$$NADH \rightarrow FMNH_2 \rightarrow CoQH_2 \rightarrow \text{cytochromes} \rightarrow O_2$$



$FMNH_2$ **CoQ**

[$R=CH_2CHOHCH_2OPO_3^{-2}$] [n = 6 - 10]



FMN **CoQH**

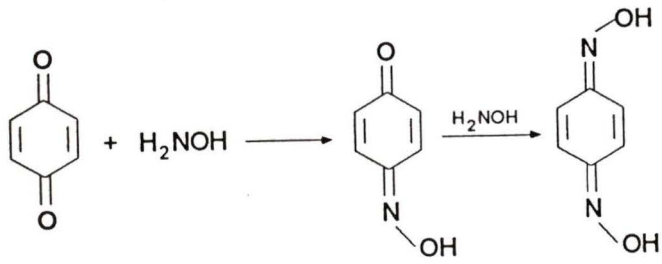
eq. 33

1.3.3. Reactions on the carbon-oxygen double bond

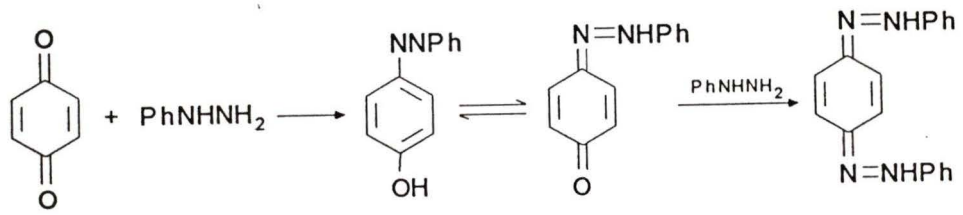
As mentioned before, quinones are α,β-unsaturated ketones. They also can undergo typical carbonyl group reactions, e.g. with hydroxylamine to give the expected oximes[40], eq. 34.

The addition of arylhydrazine to a quinone gives a monohydrazone, in equilibrium with its azo form, which reacts with a second molecule of

hydrazine to from dihydrazone[41], eq. 35.

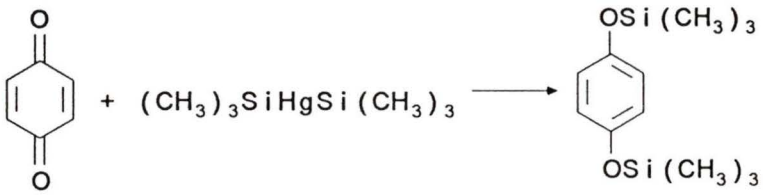


eq. 34

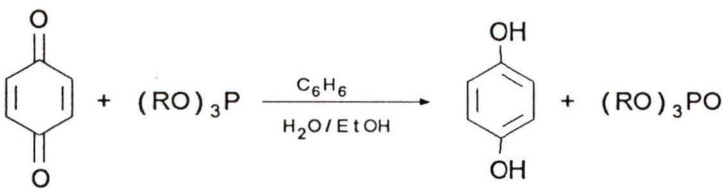


eq. 35

In some cases, reductive additions occures, e.g. eq. 36[42] and eq. 37[43].



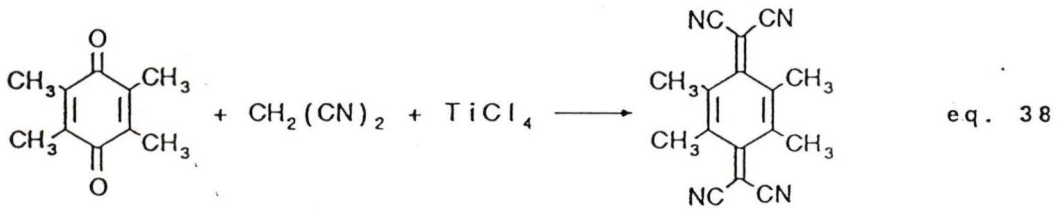
eq. 36



eq. 37

The addition of malononitrile to quinones using the catalyst, $TiCl_4$[44],

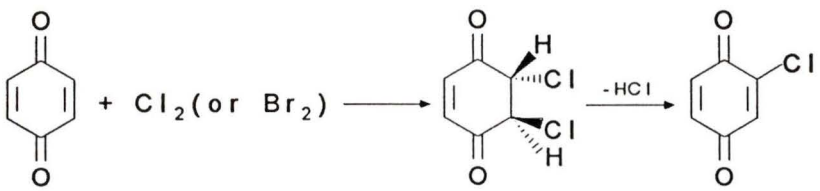
gives an important class of quinodimethanes, which are analogues of TCNQ, and have potential as organic conductors, eq. 38.



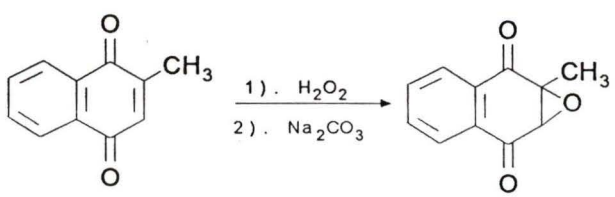
eq. 38

1.3.4. Reactions on the carbon-carbon double bond

Besides halogen addition[45] to, eq. 39, and epoxidation[46] of , eq. 40, quinone carbon-carbon double bond, an important reactions is the Diels-Alder



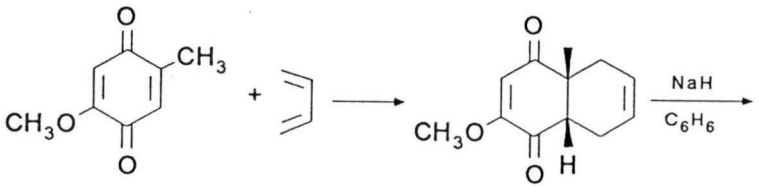
eq. 39

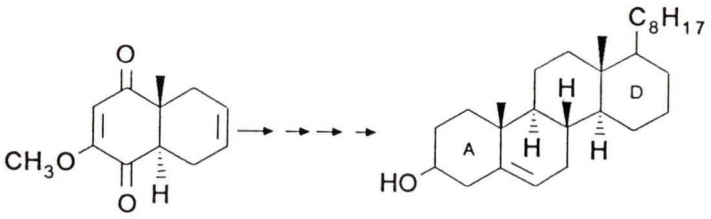


eq. 40

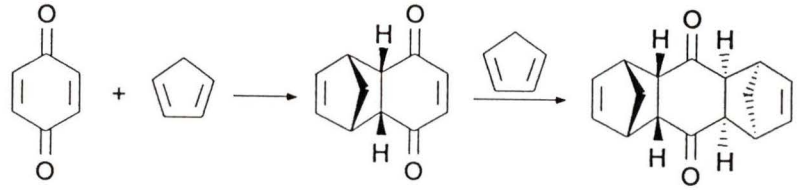
cycloaddition reaction. The importance of this reaction is due to not only that

it is useful in the synthesis of policyclic quinones, but also due to its regio- and stereo-selectivity which makes it a very powerful tool in the synthesis of many natural products. A good example is Woodward's total synthesis of the cholesterol[47], eq. 41. The *trans* C/D ring junction in the final





eq. 41

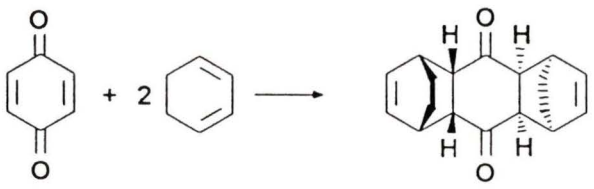


eq. 42

product is achieved by a Diels-Alder cycloaddition of quinone and butadiene followed by a base catalyzed isomerization of the initially formed *cis* ring junction.

The high selectivity of these cycloadditions was illustrated by the cycloaddition of cyclopentadiene to 1,4-benzoquinone, eq. 42. Only the *endo-cis* adduct was found out of 4 possible monoadduct isomers and only the *endo-cis*,

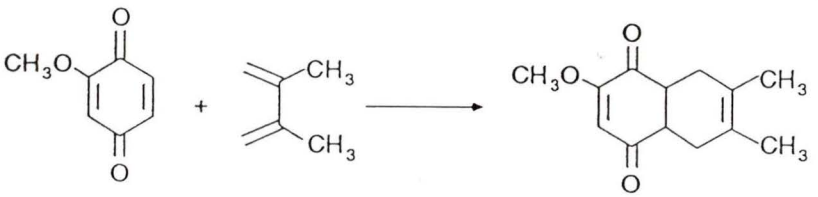
anti, *cis-endo* adduct was found out of 16 possible bisadduct isomers[48]. This



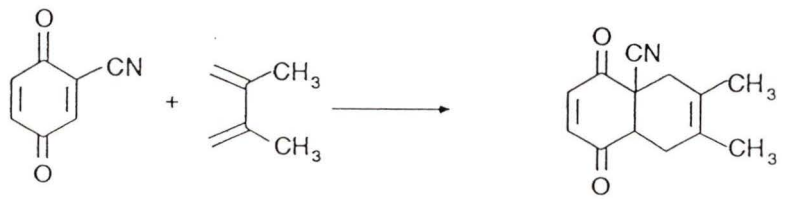
eq. 43

was futher confirmed recently by a C^{13} and X-ray study[49] of the bis(1,3-cyclohexadiene) and 1,4-benzoquinone adduct, eq. 43, only the *endo*, anti, *endo* adduct was found.

The regio and stereochemistry of the Diels-Alder cycloaddition of quinones depends on both electronic and steric factors. For substituted



eq. 18

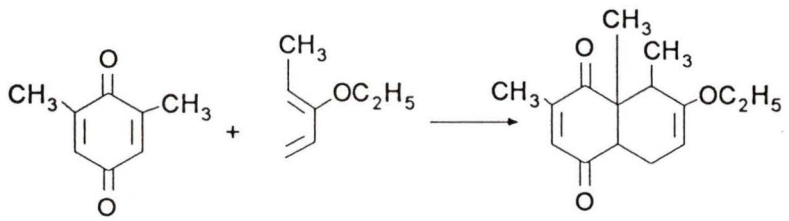


eq. 19

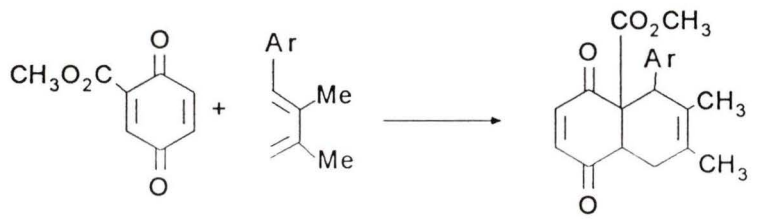
quinones, the diene will add to the electron deficient double bond of a quinone, thus, the addition is preferred to the more substituted double bond if the

substituent is an electron-withdrawing group, eq. 18, or to the less substituted double bond if the substituent is an electron-donating group, eq. 19.

With substituted dienes, the factors are more complicated. Addition is still preferred to the double bond bearing the electron-withdrawing group. When the double bond being attacked has only one substituent, the unsymmetrical diene approaches the quinone in such a way as to give the product with the substituent of quinone and the substituent on the terminal carbon of the 1,3-diene in an *ortho* relationship on the newly formed ring, eq. 44[50] and 45[51].

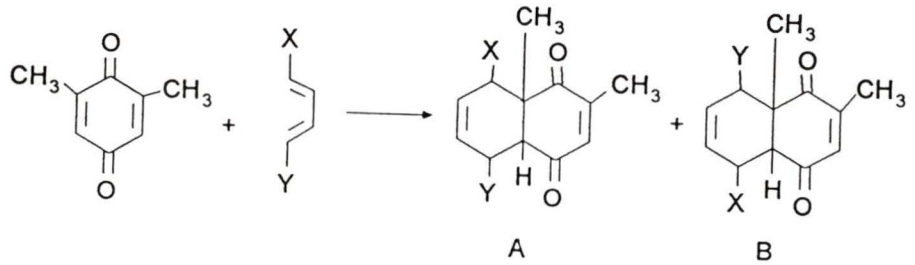


eq. 44



eq. 45

Futher study has shown that both electron-withdrawing ($-CO_2CH_3$) and electron-donating ($-OCOCH_3$) substituents on the diene have the same orientation effects on the regio-selectivity of this reaction[52], eq. 46. These



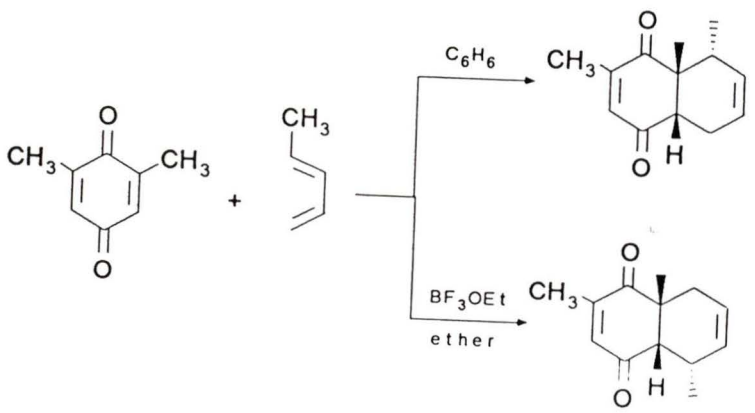
A : B

$X=CH_3COO$, $Y=CH_3$ 4 : 1

$X=COOCH_3$, $Y=CH_3$ only

$X=CH_3O$, $Y=CH_3$ only

eq. 46



eq. 47

studies lead to the following order of orientation ability of the terminal substituent of the diene in the Diels-Alder cycloaddition of quinones: MeO = MeO_2C > AcO > Me > H. The regioselectivity of the Diels-Alder cycloaddition of quinones can be changed by using Lewis acid catalysts[53], eq. 47. This

further increases the synthetic potential of Diels-Alder cycloadditions on quinones.

The stereochemistry of the Diels-Alder cycloaddition of quinones has not been investigated intensively. Both the *endo* and the *exo* transition state have been postulated. The additions of 1,4-benzoquinone to both cyclopentadiene and 1,3-cyclohexadiene have been shown to involve an *endo* transition state, in the addition of the first and the second molecule of dienes. In both cases, the bisadduct product has *endo-cis*, *anti*, *cis-endo* conformation, eq. 42 and 43. For the Diels-Alder cycloaddition of open chain dienes to 1,4-benzoquinones, the *exo* transition state [54, 55, 56] is involved for most examples. In some cases, the isomerization of the *cis*-ring junction to *trans*-ring junction occurs[54].

1.4. *trans*-10b,10c-Dimethyl-10b,10c-dihydropyrene, 21 and *trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, 17

trans-10b,10c-Dimethyl-10b,10c-dihydropyrene-2,7-quinone, **17**, is a bridged [14] annulene quinone derivative. It was prepared by Boekelheide and Phillips[3] as a precursor in the synthesis of *trans*-10b,10c-dimethyl-10b,10c-dihydropyrene (DMDHP), **21** in 1963. Since then little has been done regarding the chemistry and reactions of quinone **17**. The only report was the reaction of quinone **17** with dimethylsulfonium methylide by Mitchell, Boekelheide et al[57].

DMDHP **21** is a rigid planar 14 annulene with the internal methyl groups held rigidly in the centre of the cavity of the aromatic π-electron cloud, see Fig. 1. The internal methyl protons are highly shielded by the

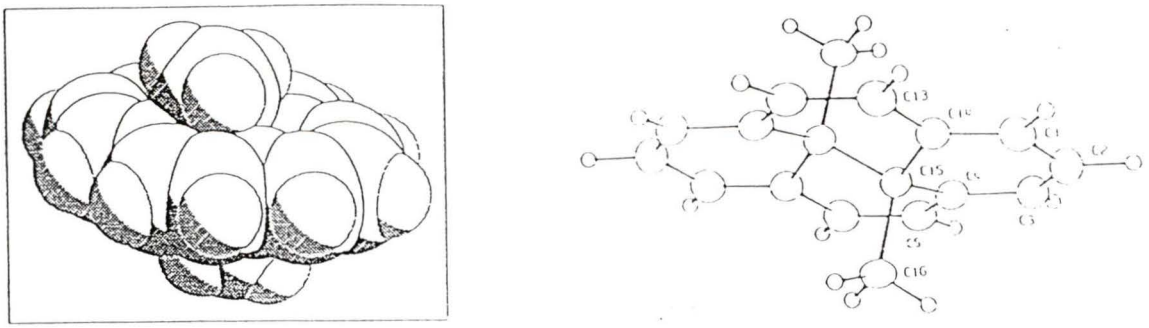


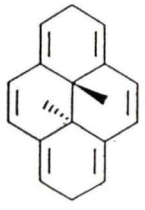
Fig. 1. A). PCMODEL drawing of **21**. B). ORTEP drawing of **21**.

Fig. 1

induced magnetic field of the ring current when the molecule is in an external magnetic field, e.g. in an NMR experiment. Because of this shielding effect the internal methyl protons of **21** resonate at a higher field (δ = -4.25) than those of its bis-triene derivative **22** (δ = 0.97). The ability to sustain an induced ring current in a conjugated cyclic π-electron system has been the most accepted criterion of aromaticity for a compound[58, 59, 60]. Since the internal methyl protons are three σ bonds distance from the π system and are even further away from any external groups (substituents), the chemical shifts of these protons are not subject to large change by anisotropic or inductive effects. This is demonstrated by the chemical shifts of internal methyl protons of substituted derivatives of **21**, see Table 1. Thus the up-field shift of the

Table 1. The chemical shifts of the internal methyl protons of several substituted derivatives of **21**

Substituent	Position	δ (Me_{in})	Ref.
H	2	-4.25	61
Br	2	-4.07, -4.08	62
NO_2	2	-4.03	63
$COCH_3$	2	-4.03	63
Ph	2	-4.03, -4.00	64
CHO	2, 7	-3.92	57
CH_3	2, 7	-4.09	57
Br	2, 7	-4.02	63
$OCOCH_3$	2, 7	-4.03	65



22

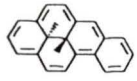
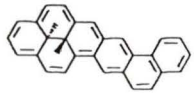
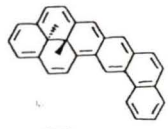
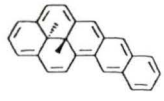
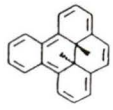
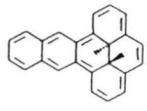
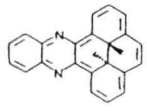
internal methyl protons is mainly caused by the shielding effect of the induced ring current, in other words, the chemical shift of the internal methyl protons

is directly related to the ring current, hence, is directly related to the aromaticity of **21**. This offers us a probe to measure aromaticity by NMR spectroscopy.

The early works of Sondheimer[66] and Nakagawa[67] showed that fusion of an aromatic ring, such as benzene or naphthalene, onto an aromatic macro ring system, changed the ring current in the parent macro ring system. Preparation of fused derivatives of **21**, and measurement of the chemical shifts of the internal methyl protons and then comparison of these chemical shifts with those caused by fusion of benzene to **21** will enable the comparison of the aromaticities of various fused aromatic rings. In the past decade, many annelated derivatives of **21**, mostly [a]-fused, have been prepared in our group and their NMR properties were studied, see Table 2. A plot of δ (Me_{in}) vs J_b-J_a in [a]-fused annelated derivatives of **21**, Fig. 2, clearly show that ring current falls as J_b-J_a increases. J_b-J_a is an indicator of bond lengths in aromatic systems[73], which is correlated to the degree of bond alternation, another measure of the aromaticity of aromatic compounds. For the [e]-fused annulenes, although the data in Table 2 show the same trend, additional [e]-fused annulenes are needed such that corresponding NMR data can be obtained to confirm this relationship.

The previous syntheses[70, 71] of the [e]-fused DMDHP **28** and **29** were acheived by the same methodology, shown in Scheme 1. The only difference is that for **28** 1,2-dibromobenzene is used as starting material while for **29** the

Table 2. ^{1}H NMR data of some annelated derivatives of **21**

	Componds	δ (Me_{in})	J_b	J_a	J_b-J_a	Ref.
	[a]-fused					
21		-4.25	7.54	7.54	0	61
23		-4.24	7.68	7.68	0	68
24		-1.62	8.85	6.52	2.33	69
25		-0.90	9.03	6.36	2.69	69
26		-0.88	9.06	6.35	2.71	69
27		**-0.44**	9.07	6.17	2.90	69
	[e]-fused					
28		-1.85	8.97	6.84	2.13	70
29		-0.74	8.82	6.51	2.31	71
30		-0.72	8.85	6.54	2.31	72

starting material is 2,3-dibromonaphthalene. The synthesis of **30**[72] applied the condensation of *o*-phenylenediamine with the benzil derivative **31** to form the quinoxaline **32**. From **32**, the subsequent steps were similar to those in Scheme 1.

The above methodology has been very successful, but the sequence involved is long (9 steps) and for each new system a new starting material is needed. Mitchell and Zhou[69] developed a general and efficient route to several

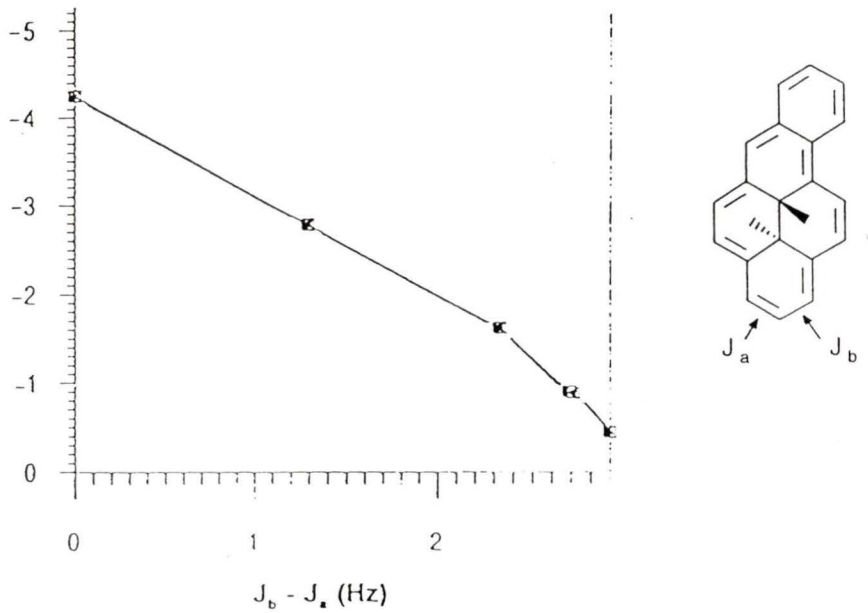
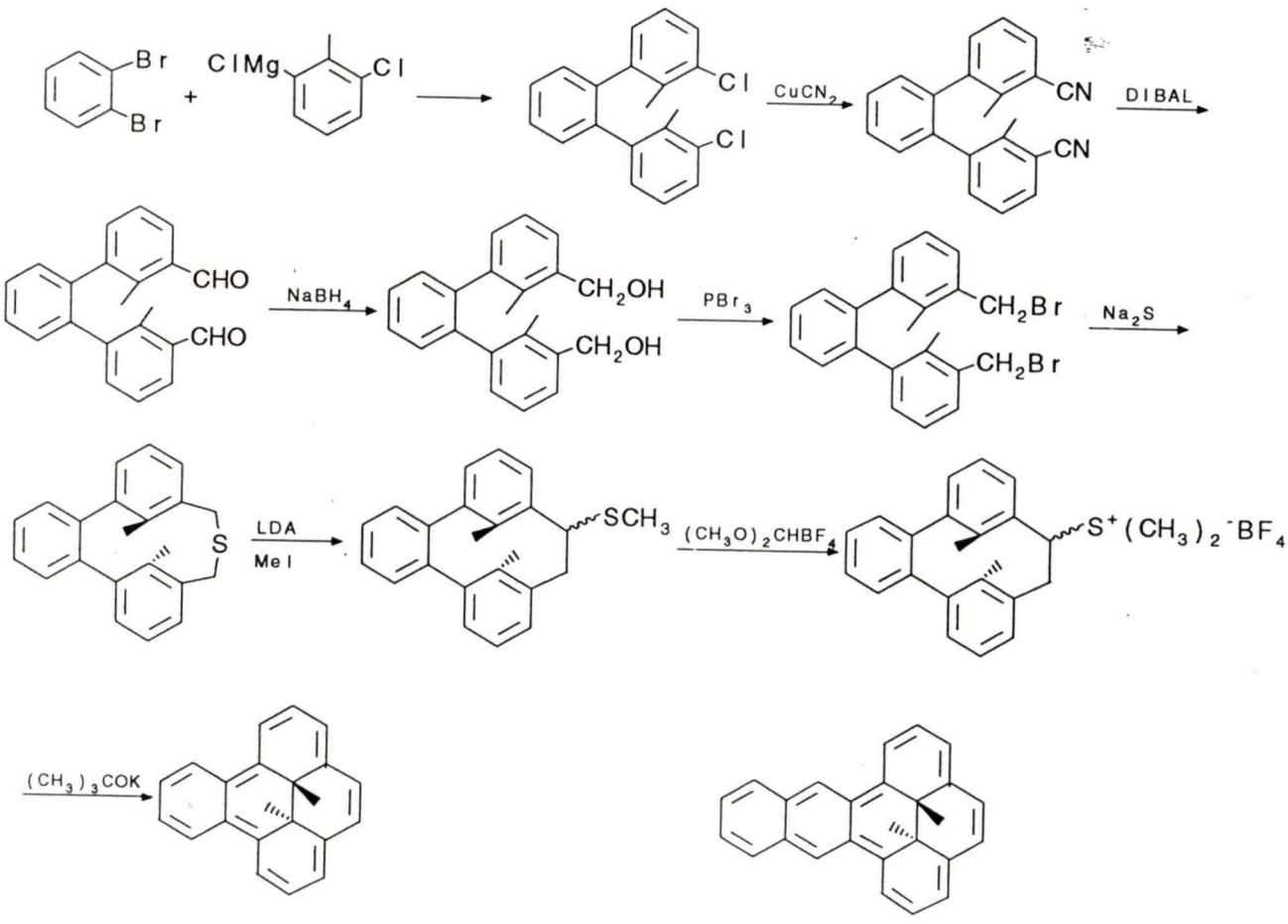


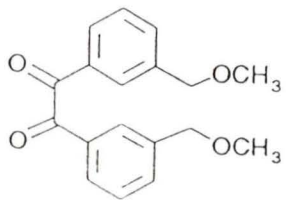
Fig. 2. A plot of $\delta(Me_{in})$ vs the difference of coupling constants, $J_b - J_a$, for the [a]-fused derivatives of **21**



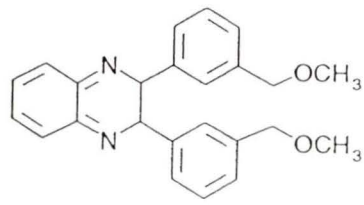
28

29

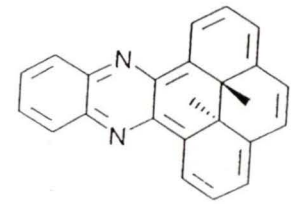
Scheme 1



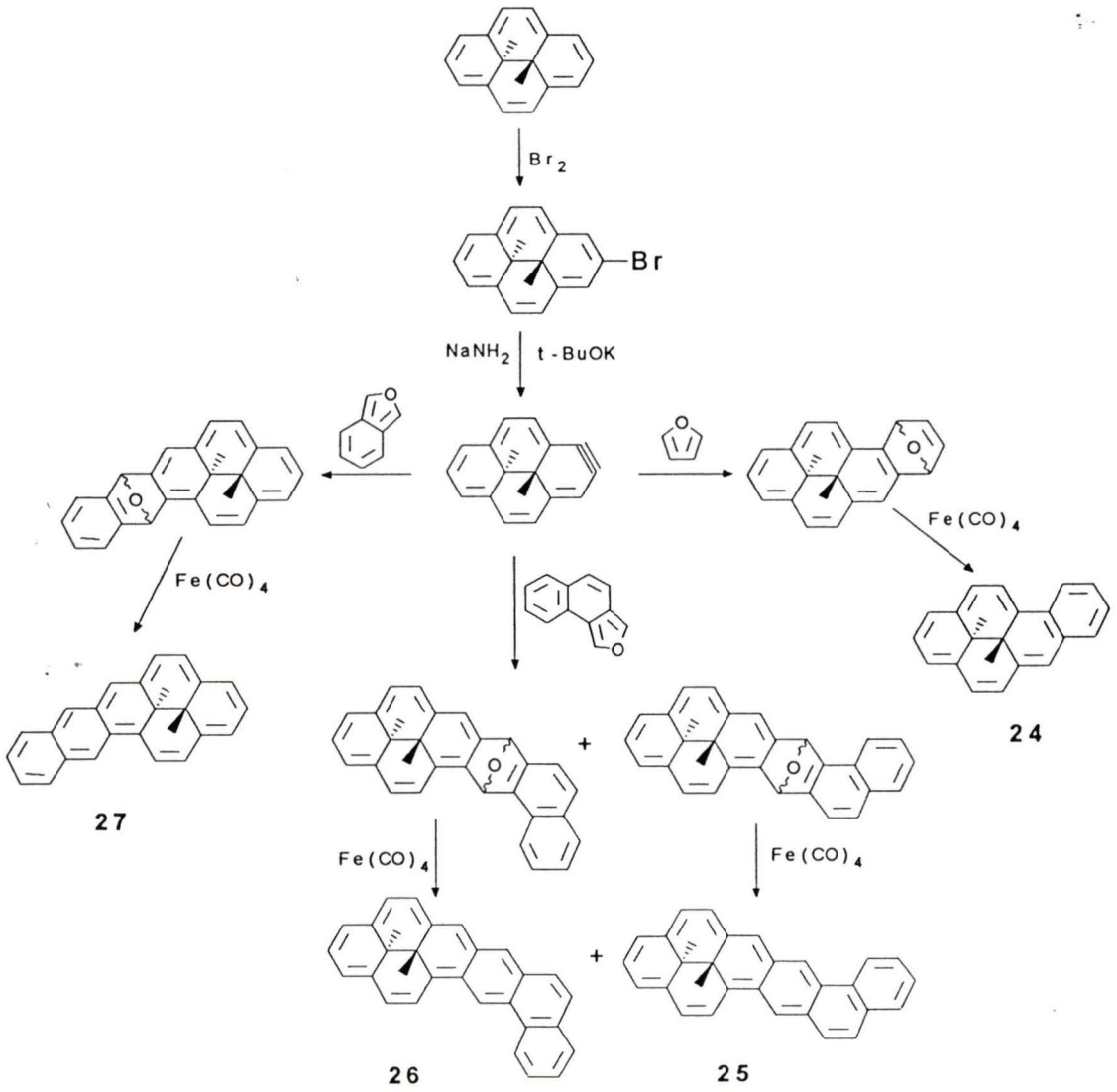
31



32



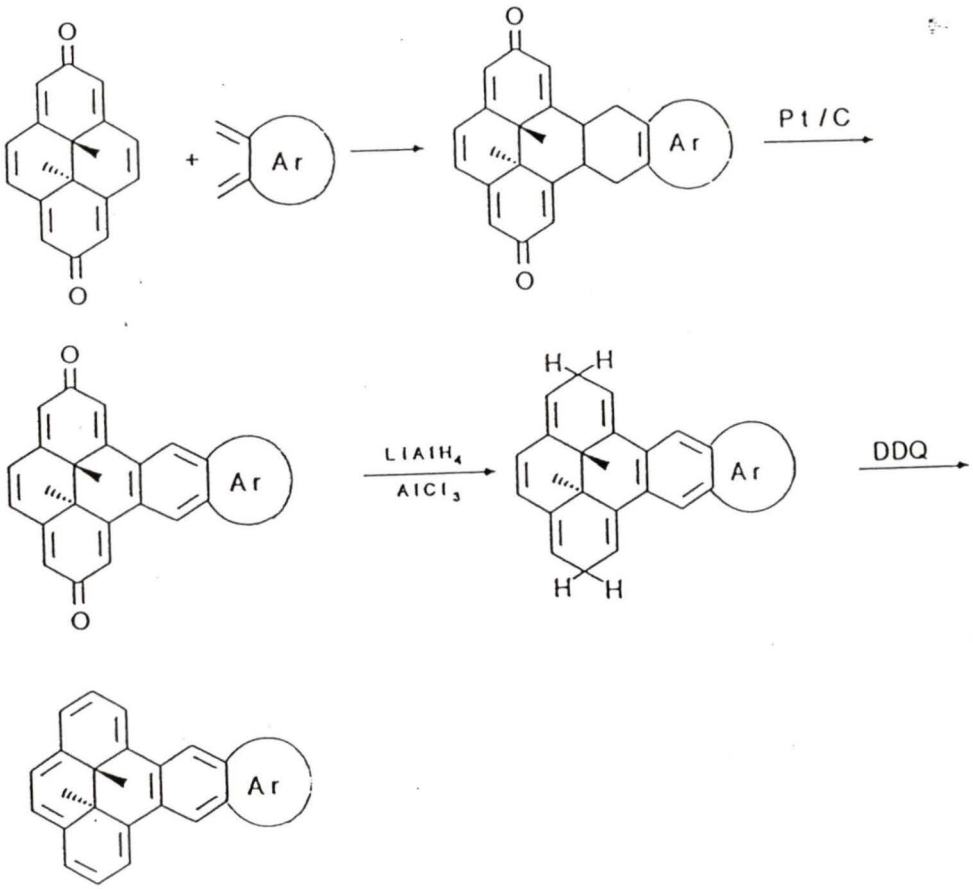
30



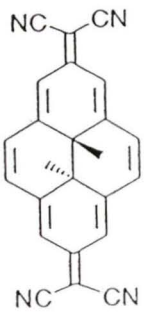
Scheme 2

[a]-fused derivatives **21**, see Scheme 2, which involved a Diels-Alder addition of an aryne derivative of **21** to a diene (a furan) followed by the deoxygenation of the adducts. The success of this method, and the paucity of other methods to prepare [e]-fused derivatives of **21**, led us to search for a general and efficient route to [e]-fused derivatives of **21**. We first decided to investigate whether or not a method similar to that shown in Scheme 2 can be used. This would require the starting material, the bromide **33**. Earlier studies[63] of the electrophilic substitution reactions of **21** have shown that the preferred positions for attack are position 2 and position 7. The bromination of **21** with 1 equiv. of NBS and with 2 equiv. of NBS gave the 2-bromo and 2,7-dibromo derivatives respectively. Thus an alternative route to **33** is needed.

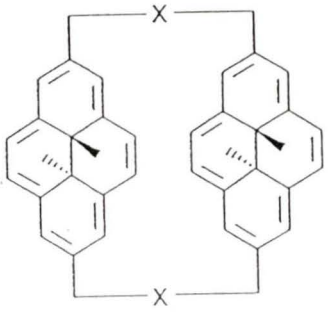
As mentioned in the previous section, the Diels-Alder cycloaddition reaction of quinones has been a useful method to build polycyclic sytems. Review of the synthesis of **21**[3] indicates that the quinone **17** can be easily converted to **21** by reduction and dehydrogenation. If quinone **17** can be successfully used as a dienophile in its Diels-Alder cycloaddition with dienes, the sequence shown in Scheme 3 will be a general and efficient route to [e]-fused derivatives of **21**. To investigate the Diels-Alder addition and other reactions of **17**, a reasonable quantity of quinone **17** is required. The previous synthesis of quinone **17**[3] involved 14 steps and the total yield was 4.2%, which is not very suitable. Thus we directed our initial research effort to the development of a new synthesis of quinone **17**, and then to the investigation



Scheme 3



34



35

of its Diels-Alder cycloaddition reactions and to other reactions which have the potential for the synthesis of practically and theoretically interesting molecules such as the TCNQ derivative **34** and the macrocycle **35**.

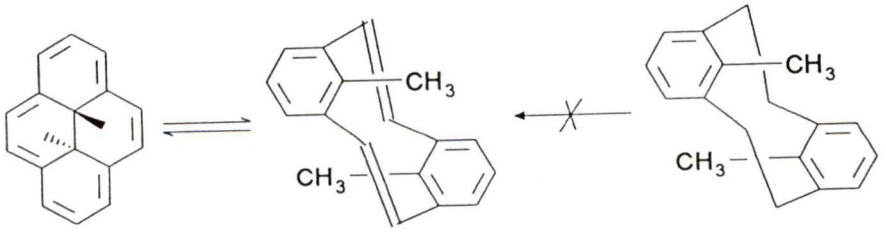
CHAPTER TWO

RESULTS AND DISCUSSION

2.1. The synthesis of *trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, 17

2.1.1. The previous synthesis of *trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, 17

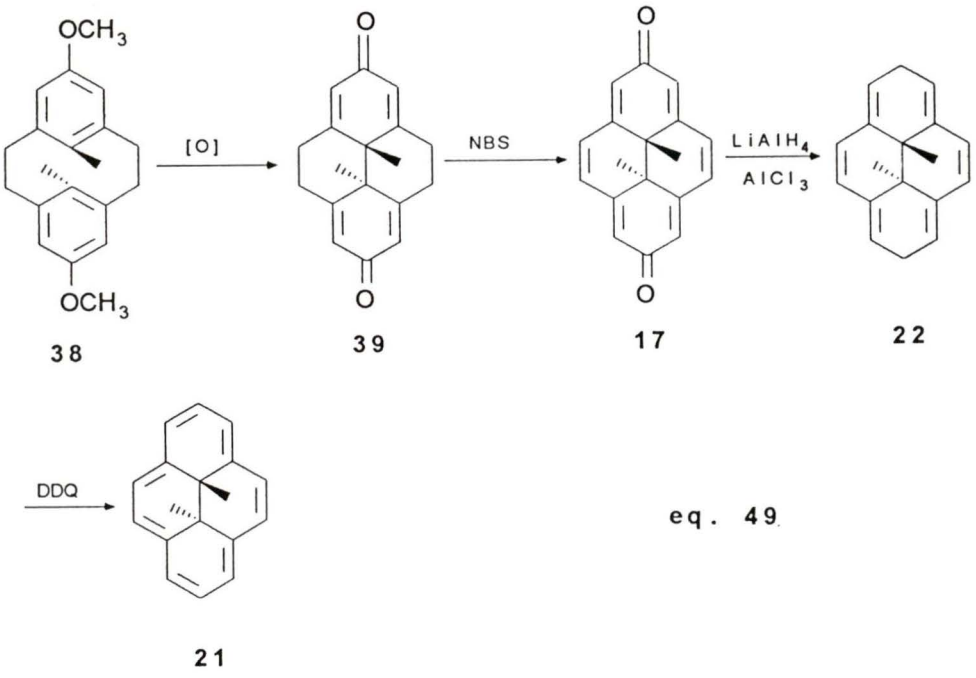
trans-10b,10c-Dimethyl-10b,10c-dihydropyrene-2,7-quinone, **17**, was prepared by Boekelheide and Phillips in 1963[3] as a key intermediate in the synthesis of *trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, **21**. The initial route[74, 75] to approach **21** via diene **36**, which is a valence isomer of **21**, was unsuccessful due to the inability to introduce unsaturation into the side chain of the [2.2]metacyclophane **37**, eq. 48. To overcome



21 36 37 eq. 48

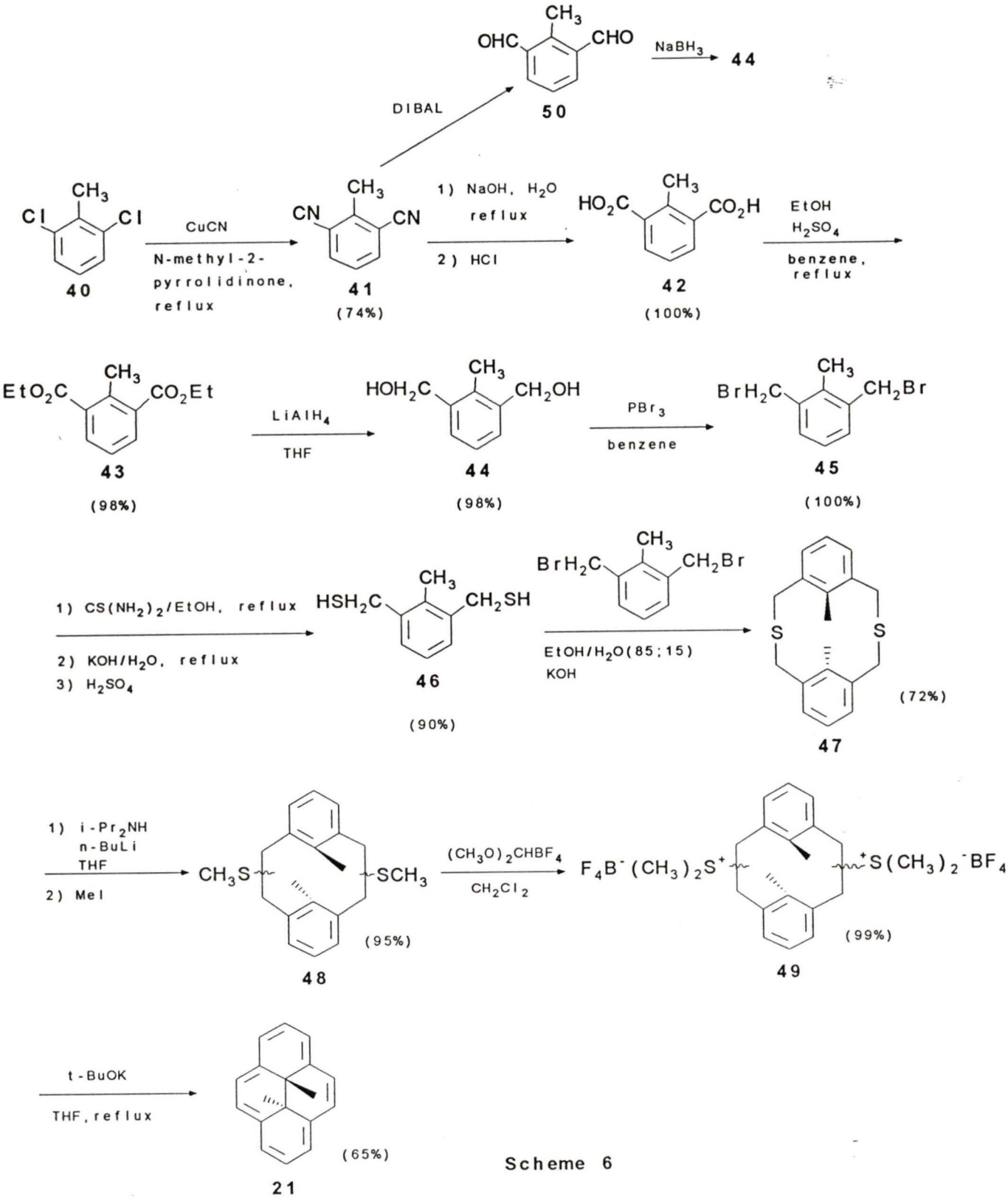
this problem, a phenolic oxidation-coupling-oxidation[76] type reaction of the dimethoxymetacyclophane **38** was used to give the bis-dienone **39**. This formed

the 10b,10c bond at an early stage. The bis-dienone **39** was then oxidized by air in alkaline solution or by NBS to give quinone **17**, which underwent reduction and dehydrogenation to yield DMDHP **21**, eq.49. The synthesis of

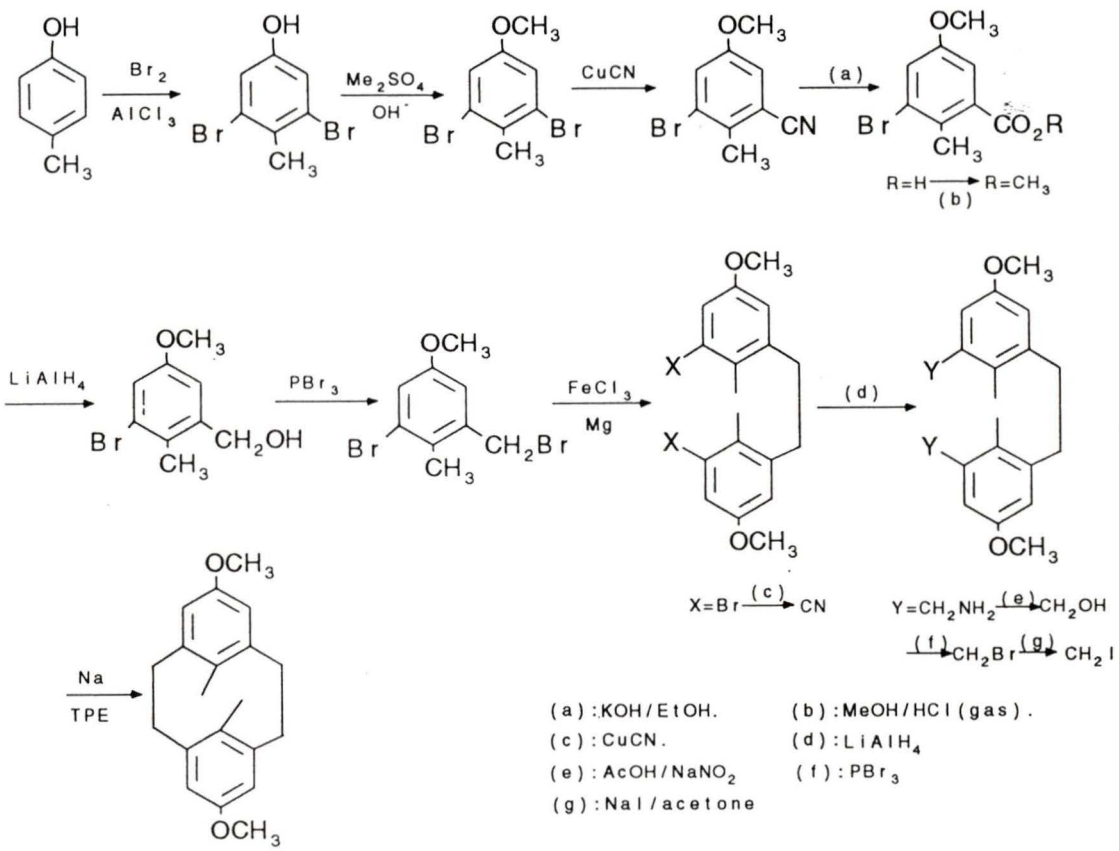


eq. 49

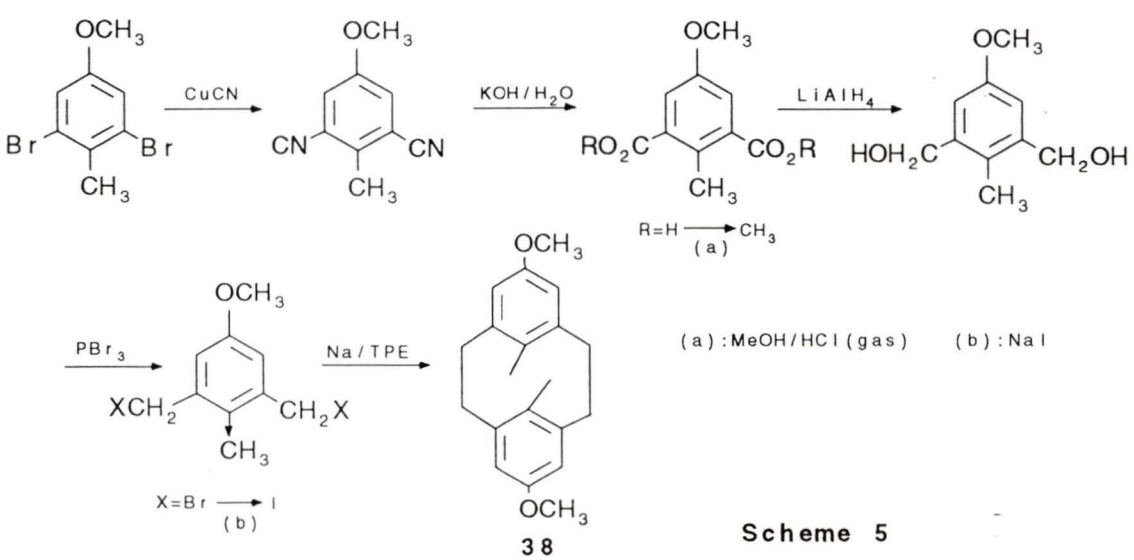
dimethoxymetacyclophane **38** started from *p*-cresol. The first route is outlined in Scheme 4. It involved 14 steps and the over-all yield of **38** was 1.9%. Further studies provided a shorter and more convenient route, Scheme 5, in which the over-all yield in this 10 step sequence was 5.1%. Even using the improved sequence in Scheme 5 and taking into account of the following two steps: the oxidation of **38** to bis-dieone **39** (94% yield) and the oxidation of **39** to quinone **17** (90.5%), the 12 step, 4.3% over-all yield sequence is not suitable to prepare reasonable quantities of quinone **17**.


CH3
OHC
CHO
NaBH3
44
50
DIBAL
CH3
Cl
Cl
CuCN
N-methyl-2-pyrrolidinone, reflux
CH3
CN
CN
1) NaOH, H2O
reflux
2) HCl
CH3
HO2C
CO2H
EtOH
H2SO4
benzene, reflux
40
41
(74%)
42
(100%)
CH3
EtO2C
CO2Et
LiAlH4
THF
CH3
HOH2C
CH2OH
PBr3
benzene
CH3
BrH2C
CH2Br
43
(98%)
44
(98%)
45
(100%)
1) CS(NH2)2/EtOH, reflux
2) KOH/H2O, reflux
3) H2SO4
CH3
HSH2C
CH2SH
CH3
BrH2C
CH2Br
EtOH/H2O(85;15)
KOH
S
S
46
(90%)
(72%)
47
1) i-Pr2NH
n-BuLi
THF
2) MeI
CH3S
SCH3
(95%)
48
(CH3O)2CHBF4
CH2Cl2
F4B-(CH3)2S+
+S(CH3)2-BF4
(99%)
49
t-BuOK
THF, reflux
(65%)
21

Scheme 6



Scheme 4



Scheme 5

2.1.2. A new synthesis of *trans*-10b,10c-dimethyl-10b,10c-dihydropyrene -2,7-quinone, 17

In the previous sections we have discussed the methods for the synthesis of quinones. Among these methods, the cyclization, the condensation and the annelation methods are not suitable for the preparation of quinone **17**, because they are not capable of achieving the right carbon skeleton which has the internal methyl groups in the *trans* configuration to each other. Thus the oxidation method seems to be the best option.

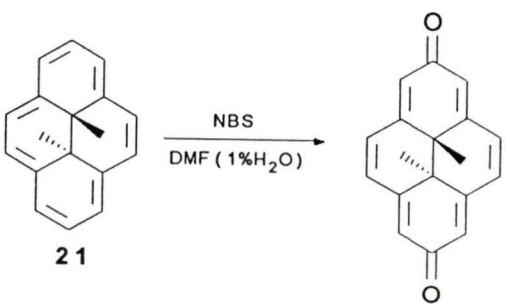
In the oxidation method, the starting materials normally are phenols, hydroquinols, aromatic amines or aromatic hydrocarbons. Aromatic hydrocarbons are relatively unfavourable substrates for preparing quinones by oxidation, but this is only true for the simple aromatic compounds. For the condensed polycyclic aromatic hydrocarbons, the oxidation is eased by the stabilization of the radical-cation intermediate with the charge extensively delocalized into the π-system. Thus many polycyclic aromatics have been oxidized to the corresponding quinones by different oxidants in good yields. DMDHP, **21**, is a macrocyclic aromatic compound. Its aromaticity has been demonstrated by the strong shielding of the internal methyl protons and the strong deshielding of the periphery protons. The X-ray structure data[77] also show that the bond alternation is absent in the π-system, which means the π-

electrons are highly delocalized. We thought that the oxidation of **21** could be a promising route to the quinone **17**, because DMDHP **21** is now available in gram quantities by the convenient synthetic route developed by Mitchell and Boekelheide[78], which involves a thiacyclophane. Thus the starting material, DMDHP **21**, was prepared by Mitchell's method. In the original sequence the dicyanide **41** was reduced to dialdehyde **50** by diisobutylaluminum hydride (DIBAL). We found that on the large scale, the DIBAL reduction of **41** did not go completely and the work-up of the reaction was not convenient. The modification shown in Scheme 6 was then used. Thus 2,6-dichlorotoluene, **40**, was converted into 2,6-dicyanotoluene, **41**, by cuprous cyanide in 74% yield. The hydrolysis of **41** in aq. NaOH followed by acidification gave diacid, **42**, in quantitative yield. The esterification of **42** with ethanol in refluxing benzene containing a catalytic amount of conc. sulphuric acid gave the diester, **43**, in 98% yield. $LiAlH_4$ reduction of the diester **43** gave the diol, **44**, in 98% yield. The diol was reacted with PBr_3 to give the dibromide, **45**, in quantitative yield. The dibromide **45** was further converted to dithiol, **46**, in 90% yield. A solution of dibromide **45** and dithiol **46** (molar ratio = 1:1) in benzene was added dropwise (5 sec/drop) to a well stirred solution of KOH in $EtOH/H_2O$ (85:15). Recrystallization of the reaction mixture of *anti* and *cis* isomers from benzene gave the pure *anti*-dithiacyclophane, **47**, in 72% yield. Wittig rearrangement of **47** gave a mixture of sulphide isomers, **48**, in 95% yield. Methylation of **48** with Borch's reagent[79] offered the bis-salt, **49**, in 99% yield. Finally DMDHP

21 was obtained in 65% yield by the Hofmann elimination of **49** with t-BuOK in refluxing THF. From 2,6-dichlorotoluene, DMDHP **21** was prepared in 10 steps in 28.2% over-all yield.

Many oxidants have been used to oxidize polycyclic aromatics to the corresponding quinones. 9,10-Anthraquinone is prepared by the oxidation of anthracene with nitric acid or chromic acid in industry. A good laboratory process employs sodium chlorate[80]. Periodic acid in DMF[14] is quite successful in oxidizing naphthacene, pentacene and benz[a]anthracene to their quinones, and with naphthalene also give 1,4-naphthoquinone in 76% yield[81]. Chromium trioxide in acetic acid, however, only gives 1,4-naphthoquinone in 35% yield, although with a phase-transfer catalyst, the yield can be improved to 50%[82]. Hydrogen peroxide in acid[83] has also been used to convert aromatic compounds to quinones. Other reagents like ceric ammonium sulphate in dilute sulphuric acid[84], manganese (III) sulphate in dilute sulphuric acid[85] also convert polycyclic aromatics into quinones in fair yield. Most of the oxidants mentioned above are used under acidic conditions, some in strong acid. Since under normal laboratory conditions, DMDHP, **21**, decomposes into unknown polar compounds when treated with strong acid[86], those oxidants employing acidic conditions will probably not be suitable for the oxidation of **21**. A trial oxidation of **21** by chromium trioxide in acetic acid was unsuccessful; no quinone could be isolated, and no **21** could be recovered. The incapabablity of **21** to survive in acidic conditions forced us to explore oxidants which could be

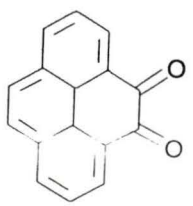
used under neutral or slightly basic conditions. In our early study on the NBS bromination of **21** in DMF to generate 2-bromo- and 2,7-dibromodimethyldihydropyrene, we found that if the DMF used in this reaction is not dried, (vacuum distilled from CaH_2), besides the bromination products, a small amount of quinone **17** (about 3% to 5% yield based on **21**) was formed. Use of NBS as a mild oxidation and dehydrogenation reagent has be reviewed by Filler[87]. The oxidation of allylic methylene groups to carbonyl groups[88] and oxidation of acetylenes and alkenes to α,β-diketones[89] have also been reported. So far, we have not found any report in the literature regarding the oxidation of aromatic rings by NBS. This may be due to the fact that NBS is not a strong oxidant. Further study on the reaction of NBS with **21** shows that DMF containing 1% of water gives the best yield of quinone **17**, eq 50. Thus, a solution of NBS in wet DMF was added



21 **17** eq. 50

to a solution of **21** in wet DMF at 0°C. After stirring for 5 hours the reaction was quenched with ice water. Chromatography of the crude product gave quinone **17** in 46% yield. The mechanism for this oxidation reaction is not known to us.

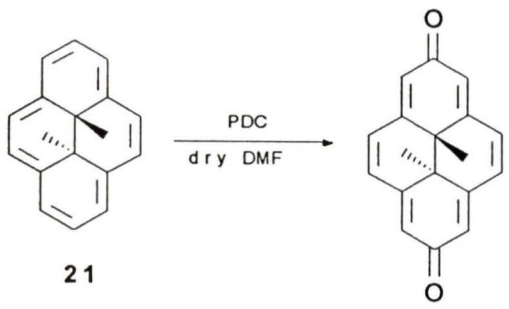
Although the oxidation of **21** by NBS gave a reasonable yield of quinone **17**, we hoped to do better. Pyridinium dichromate, PDC, is almost neutral[90] and is a good oxidizing agent for alcohols containing acid-sensitive functionalities. Since the first application of PDC in the oxidation of alcohols in aprotic media (DMF and CH_2Cl_2) by Corey and Schmidt[91], PDC has been widely used in organic synthesis where mild conditions are required and/or an acid-sensitive group is involved. In DMF, PDC oxidizes aldehydes and primary alcohols to carboxylic acids. Allylic primary and secondary alcohols are only oxidized to α,β-unsaturated carbonyl compounds. In CH_2Cl_2, primary alcohols can be oxidized to aldehydes and secondary alcohols to ketones. All of these oxidations proceed in high yield. In the oxidation of pyrene with sodium dichromate dihydrate in acetic acid and acetic anhydride (1:1), pyrene-4,5-quinone, **51**, was obtained in 29.5% yield[92]. When chromium trioxide in the



51

presence of pyridine and catalyzed by osmium tetroxide[93] was used, the yield of pyrene-4,5-quinone was increased to 80%. Although the orientation effect of the catalyst, osmium tetroxide, is important, the shift of reaction conditions from acidic to slightly basic also plays an important role. The oxidation of **21**

by PDC was first tried in CH_2Cl_2 at 0°C. The yield of quinone **17** was not good, probably due to the low solubility of PDC in CH_2Cl_2. In DMF using 4 equivalents of PDC the yield of quinone reached 54%. Further study showed that using freshly distilled DMF, controlling the addition speed of the DMDHP solution at 2 seconds/drop and the reaction temperature at -5 to 0°C, gave



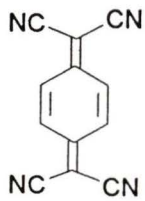
21 **17** eq. 51

quinone **17** in 67% yield, eq. 51. Thus a solution of DMDHP **21** in DMF was added dropwise to a solution of PDC in DMF cooled in ice-salt bath. The reaction apparatus was set in a cooling box with the temperature set at 4°C. During the addition and reaction time, no light was on. After the reaction, the mixture was quenched with ice-water and the aq. solution was extracted with dichloromethane. After evaporation of solvent, the solid residue was chromatographed on silica gel and gave quinone **17** as a yellow solid in 67% yield. The mp and the ^{1}H NMR data are consistent with those reported[3]. Since quinone **17** is a highly symmetric molecule, its ^{1}H NMR spectrum is quite simple. The two kinds of vinyl protons appeared as two singlets at δ 6.30 and δ 6.07; the internal methyl protons as a singlet at δ 1.87. The IR spectrum

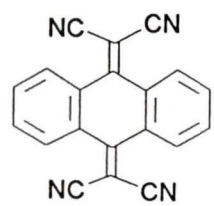
showed a strong adsorption at 1640 cm^{-1} indicating the present of a conjugated carbonyl group. The structure was also supported by the MS and ^{13}C NMR. Thus quinone **17** can now be prepared from the commercially available 2,6-dichlorotoluene in 12 steps in 19% over-all yield. This route provides a suitable quantity of quinone **17** for further study.

2.2. The condensation reaction of quinone 17 with malononitrile – the synthesis of tetracyano-*trans*-10b,10c-dimethyldihydropyrene-2,7-quinodimethane, 34, and the initial study of its ability to form a charge transfer complex

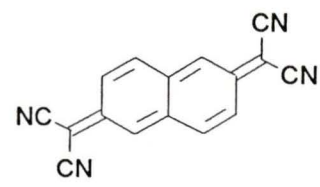
The synthesis of 7,7,8,8-tetracyanoquinodimethane (TCNQ), **52**, and the observation of electrical conductivity in certain anion radical salts of TCNQ by Acker and Hertler[94] have led to an extensively studied research area – organic conductors. Recently more attention has been paid to the synthesis of new



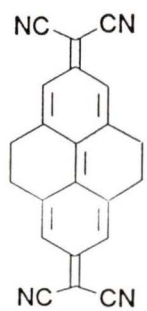
TCNQ
52



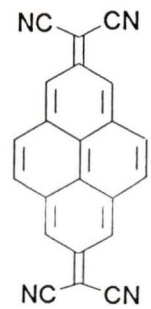
TCAQ
53



TNAP
54



TCNTP
55



TCNP
56

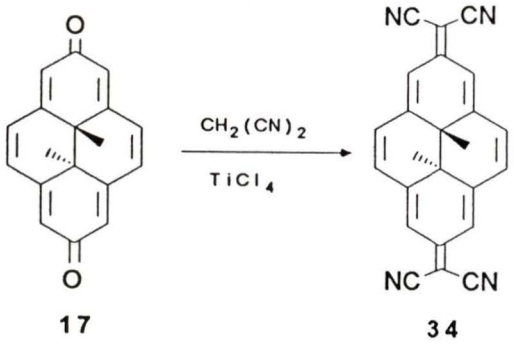
TCNQ type acceptors with extended π-system such as TCAQ[95] **53**, TNAP[96] **54**, TCNTP[97] **55**, and TCNP[97] **56**, which form anion radical salts with higher

conductivities. The desirable structural features for these acceptors are planarity, extensively conjugated π-molecular orbitals and high symmetry. The title compound **34** meets all the structural requirements. In addition its internal methyl groups may give it special behaviour in its electrochemistry and in the formation of charge transfer complexes.

The $TiCl_4$ catalyzed condensation[44,98] of a quinone with malononitrile has been used in the synthesis of many TCNQ type compounds. Our attempt to achieve the formation of **34** by this method was successful, eq.52. Thus the reaction of quinone **17** with malononitrile was carried out in dry $CHCl_3$ under reflux condition. The crude product **34** was precipitated as a red solid in 68% yield. After purification by Soxhlet extraction using CH_2Cl_2 as solvent and fractional recrystallisation from dry CH_2Cl_2, pure **34** forms dark purple metallic crystals, which decompose at 350°C. Like quinone **17**, its ^1H NMR spectrum is quite simple. The eight vinyl protons appear as two singlets at δ 6.84 and δ 6.56 and the internal methyl protons as a singlet at δ 1.40. A very strong absorption in its IR spectrum at 2215 cm^{-1} indicates the presence of a CN group. The structure of **34** was also supported by its HRMS.

The charge transfer complex of **34** and diethylamine can be formed by stirring a mixture of **34** and diethylamine in CH_2Cl_2 at room temperature or in CH_3CN at reflux temperature. The complex seems highly air sensitive and only exists in solution. Attempts at isolation were unsuccessful. The formation of complex can be confirmed by the color change of the solution from

red-orange to dark green and also by the red-shift in the electronic spectrum. The absorption at 450 nm disappears and a new absorption at 767 nm appears, Fig. 3 and Fig. 4. An attempt to form a complex with tetrathiafulvalene (TTF) was unsuccessful. The sample for study of the electrochemistry of **34** has been sent to specialists and the results will be reported in the future.



17 **34** eq. 52

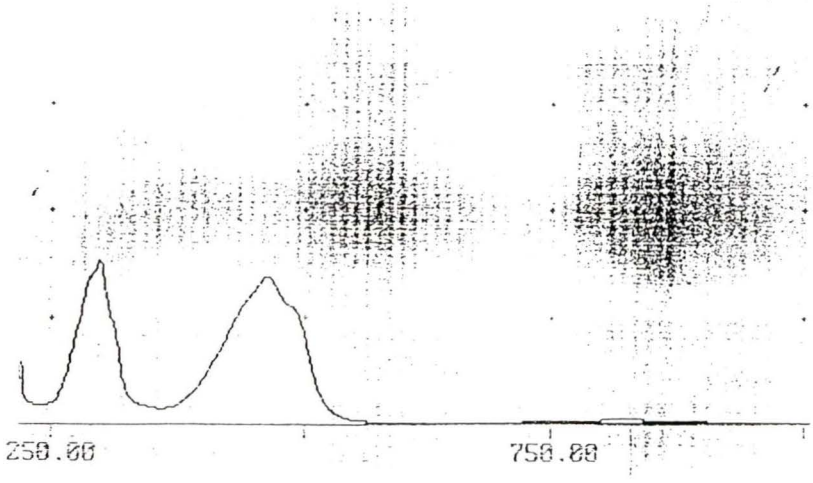


Fig. 3. The electronic spectrum of **34** in CH_2Cl_2

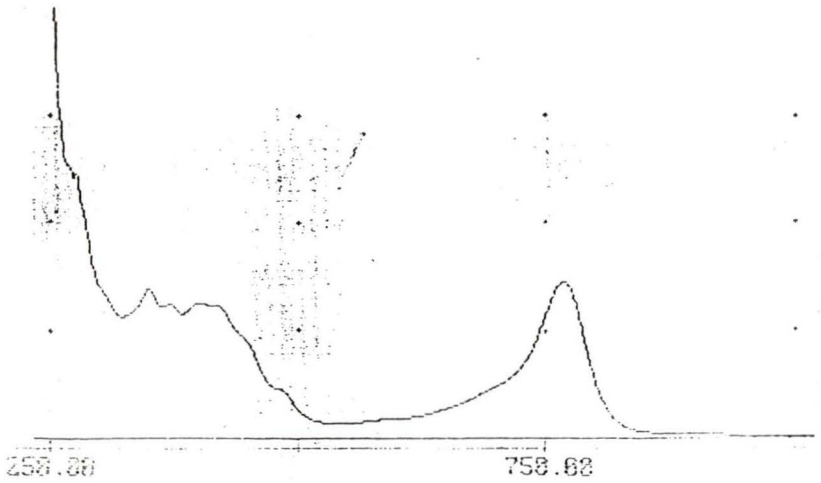
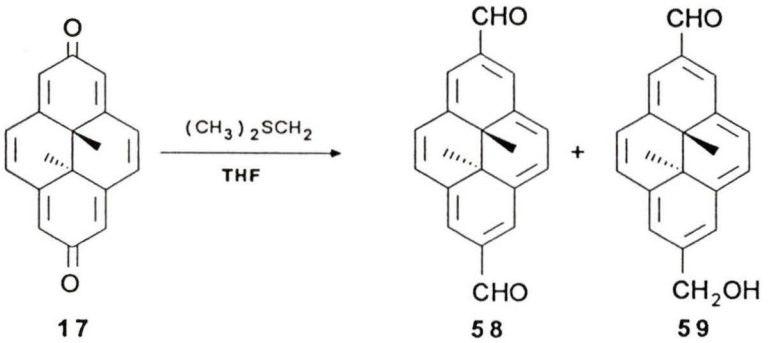


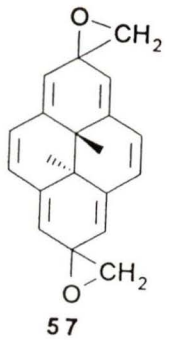
Fig. 4. The electronic spectrum of the $(C_2H_5)_2NH$-**34** complex in CH_2Cl_2

2.3. The addition reaction of dimethylsulfonium methylide to the oxygen-carbon double bond of quinone 17 and the synthesis of a macrocycle containing a DMDHP unit

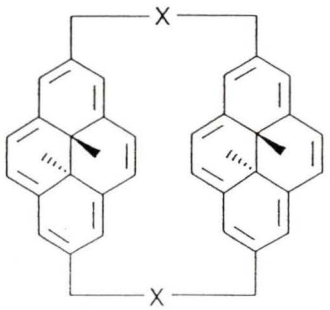
Dimethylsulfonium methylide reacts with α,β-unsaturated ketones to give exclusively oxirane derivatives[99]. In their attempt to introduce carbon at the 2- and 7-positions of DMDHP **21** via the reaction of dimethylsulfonium methylide with quinone **17**, Mitchell, Boekelheide et al[57] found that instead of the expected bisoxirane product **57**, 2,7-diformyl-*trans*-10b,10c-dimethyl-



17 **58** **59** eq. 53



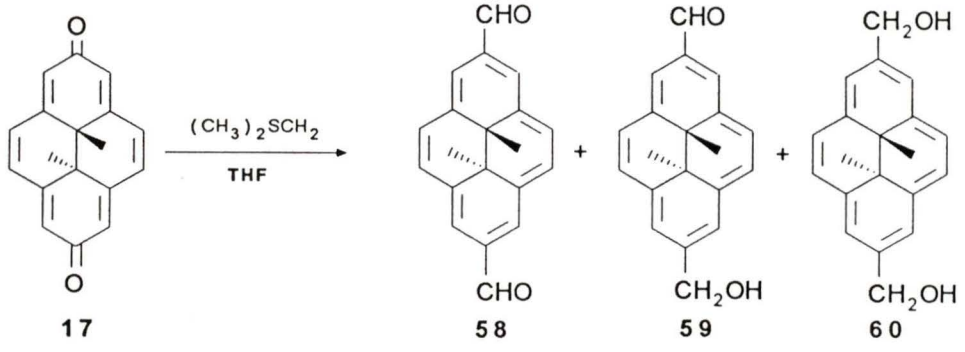
57



35

10b,10c-dihydropyrene, **58**, and 2-formyl-7-hydroxymethyl-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, **59**, were formed in 18% and 47% yields respectively, eq. 53. This reaction has the potential to provide a good method to a bifunctionalized dimethyldihydropyrene, which then could possibly be built into a cyclophane structure such as **35**.

We therefore reinvestigated the reaction of dimethylsulfonium methylide with quinone **17**. We found that besides the two products **58** and **59**, a third product, 2,7-bis(hydroxymethyl)-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, **60**, was isolated in 14% yield, eq. 54. A solution of dimethylsulfonium methylide prepared as described[100] was added to a solution of quinone **17** in

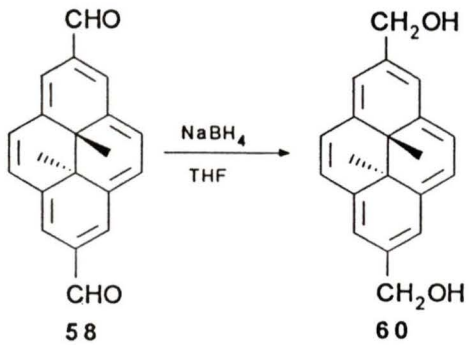


17 **58** **59** **60** eq. 54

THF at -78°C. After allowing the reaction mixture to slowly warm to room temperature, the reaction was quenched by adding ice. Chromatography of the crude products over silica gel gave **58** in 12% yield, **59** in 47% yield and **60** in 14% yield. **58** and **59** gave mp and ^{1}H NMR data consistent with those reported[57].

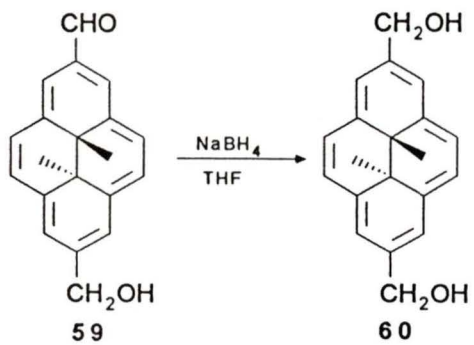
$NaBH_4$ reductions of **58** and **59** both gave dialcohol **60** in quantitative

yield, eq. 55 and 56. Thus for preparation of dialcohol **60**, the three products



58 60

eq. 55



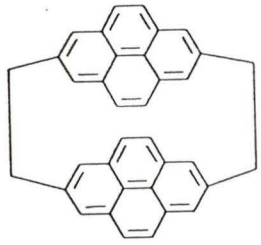
59 60

eq. 56

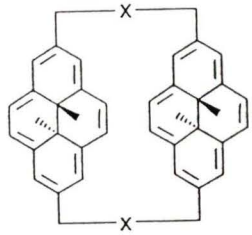
of the reaction (eq. 54) were not separated from each other, but the mixture was stirred in THF with $NaBH_4$ to form solely dialcohol **60**. The structure of dialcohol **60** was shown by its ^1H NMR spectrum. The eight aromatic protons appear as two singlets at δ 8.59 and δ 8.56; the internal methyl protons as a singlet at δ -4.11; the methylene protons as a doublet at δ 5.20 and the hydroxyl proton as a triplet at δ 4.67. The IR spectrum has a broad and strong absorption around 3280 cm^{-1} which confirms the presence of the hydroxyl group. The structure of dialcohol **60** also was supported by its MS and a correct elemental analysis.

Studies on paracyclophanes have shown that the benzene rings in these

molecules adopt boat conformations[101] and the aromatic protons in these molecules are less deshielded to different extents[102]. Possibly partly because of this and the fact that the rings are face to face such that one ring feels the shielding of the opposite ring, the external protons are less deshielded than in benzene. In a short bridged cyclophane such as [2,2](2,7)-pyrenophane, **61**, the



61



35

study of its electronic spectrum[103] has shown there is transannular π-electron interaction between the two pyrene units. A later study[104] indicated that the two pyrene rings were bent away from each other at the centre of the pyrene, see Fig. 5. We thought that if a DMDHP unit could be built into a cyclophane

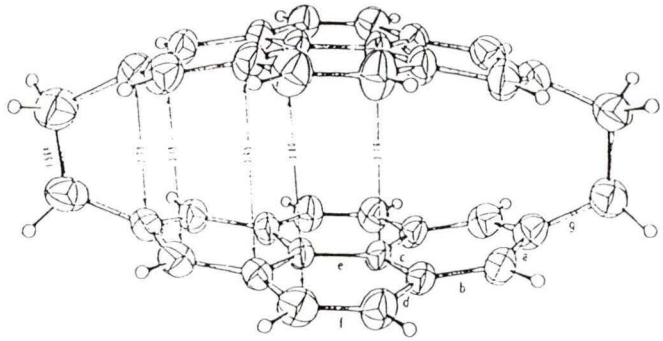
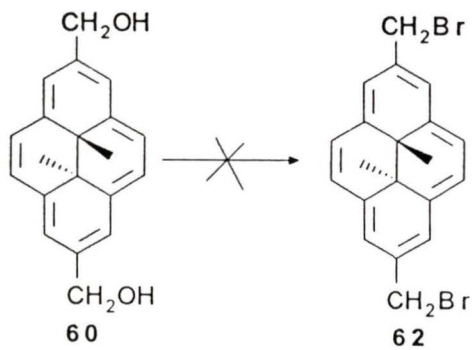


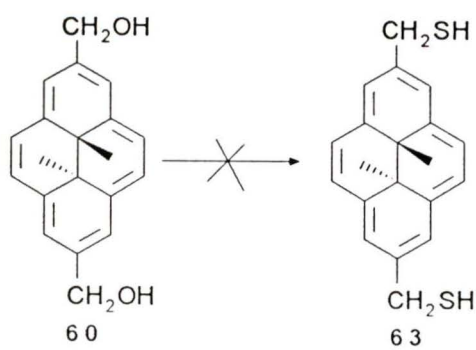
Fig. 5. The bent conformation of [2,2](2,7)-pyrenophane **61**

type molecule such as **35**, the effect of ring deformation on the chemical shift of the internal methyl protons of the DMDHP unit, the transannular interaction between the π-systems of the two DMDHP rings and the interaction of the two internal methyl groups located inside the cyclophane, plus the changes in these effects with the change of the length of the bridge, would be a very interesting project to study.

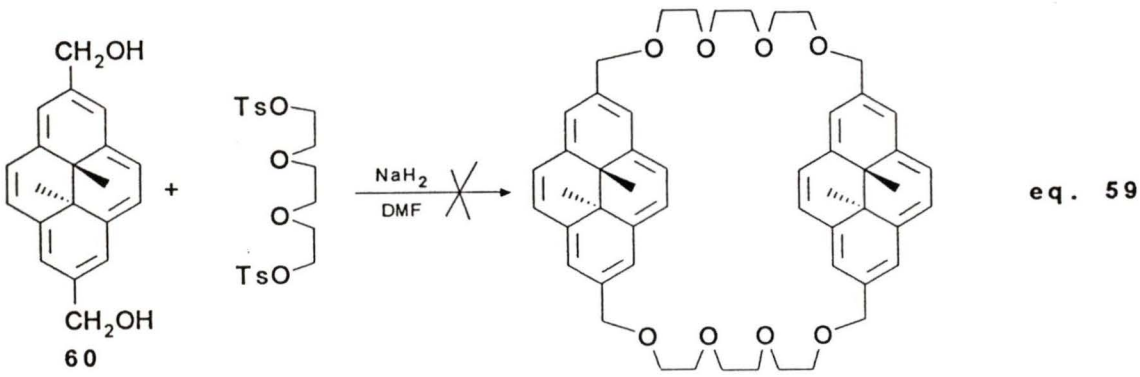
So far we have not been successful in converting the dialcohol **60** to the dibromide **61**, eq. 57 and in conversion of the dialcohol **60** to the dithiol **62**, eq.58. The coupling reaction of dialcohol **60** with distosylate shown in eq. 59 also failed. This was very disappointing, but it appear that DMDHP's



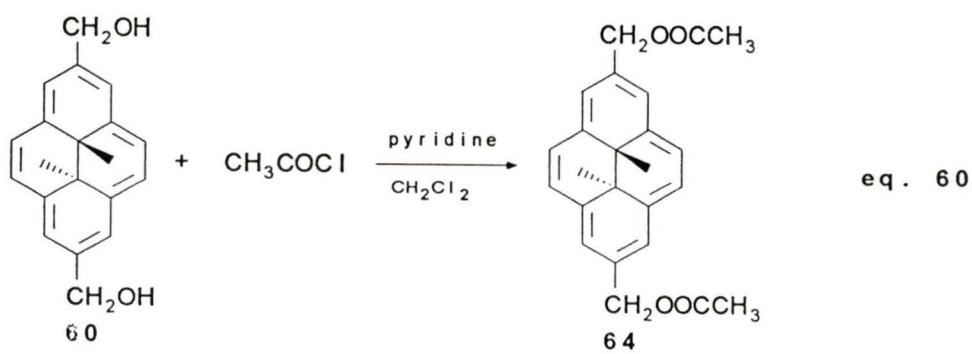
eq. 57



eq. 58

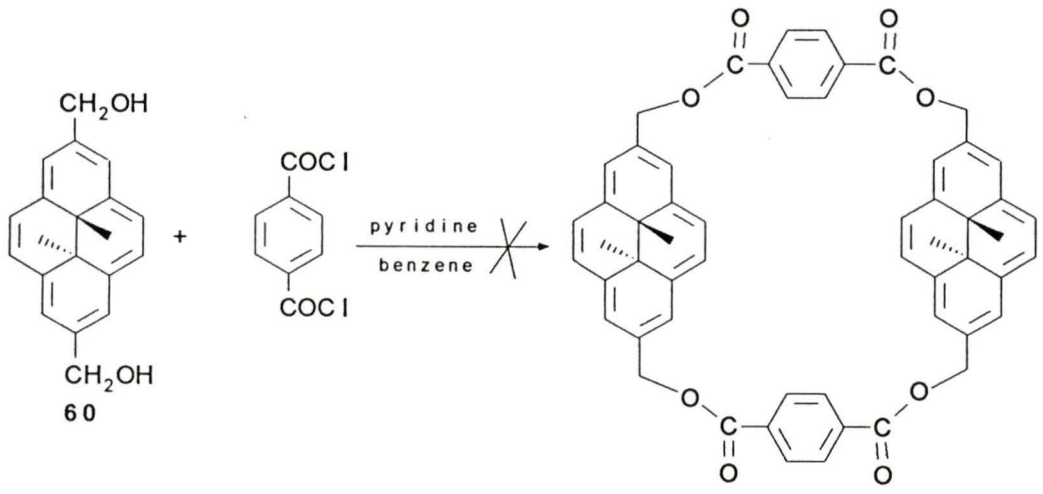


containing the group $-CH_2X$ where X is a reasonable leaving group, eg. $-CH_2Br$, are not very stable and do not make useful reaction intermediates. We thus considered next whether ester would be sufficiently stable. The model reaction of dialcohol **60** with acetyl chloride, eq 60, gave an 88% yield of diester **64**.



Terephthaloyl chloride was chosen as the first diacid halide to react with dialcohol **60.** This should give the very interesting molecule **65** with a

hydrophobic cavity located in its centre. Unfortunately, after the reaction, no coupling product **65** could be isolated and no starting dialcohol **60** could be recovered, eq 61. Presumably the reactivity of terephthaloyl chloride

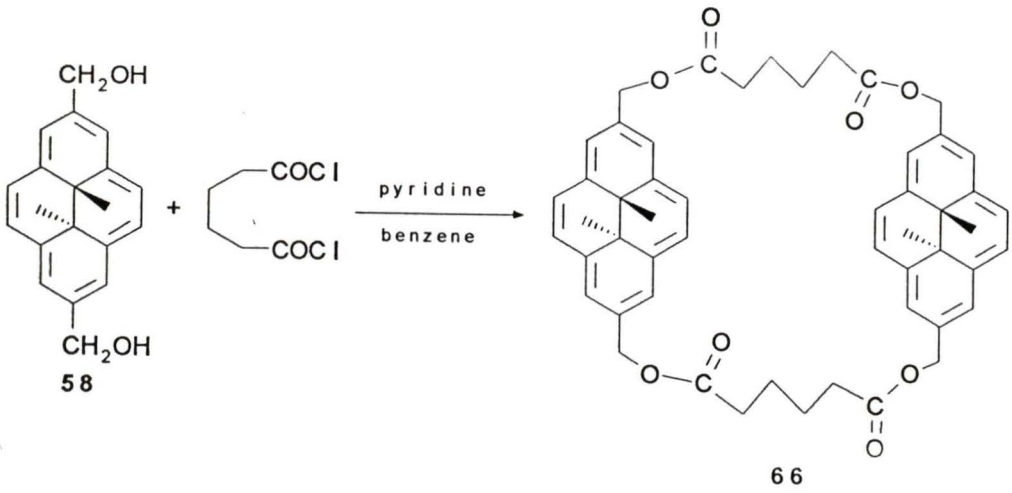


eq. 61

was not high enough, the reaction rate of the chloride and the alcohol being slow. Since in high dilution techniques, the faster the reaction, the lower the chance to form polymer, we believe that the product of the coupling reaction of alcohol **60** and terephthaloyl chloride was a poly-ester. The fact that there was a green band at the top part of silica gel column that could not be eluted even by methanol, suggested the formation of a polymer.

We thought that using an alkyl diacid chloride which has a relatively high reactivity might reduce the amount of polymerization. Thus the coupling reaction of dialcohol **60** with adipoyl chloride was carried out in benzene in the presence of pyridine and gave **66**, in 10% yield, eq. 62 In its ^{1}H NMR

spectrum, the two types of aromatic proton each appear as singlets at δ 8.43



eq. 62

and δ 8.39 and the 12 internal methyl protons also appear as a singlet at δ -4.31 indicating a symmetrical environment. The eight methylene-oxy protons appear as a singlet at δ 5.72 and the eight protons of the methylene groups α to the carbonyl carbon and the eight protons of methylene groups β to the carbonyl carbon appear as two multiplets at δ 2.47-2.42 and δ 1.78-1.74 respectively. The overall structure of **66** was also supported by its ^{13}C NMR, IR and HRMS spectra.

It was a surprise to us that the ^{1}H-NOESY NMR experiment of **66** indicated not only the expected interactions between the aromatic protons and the methylene-oxy protons, but also a medium strong interaction between the aromatic protons and internal methyl protons, Fig. 5. The same interaction

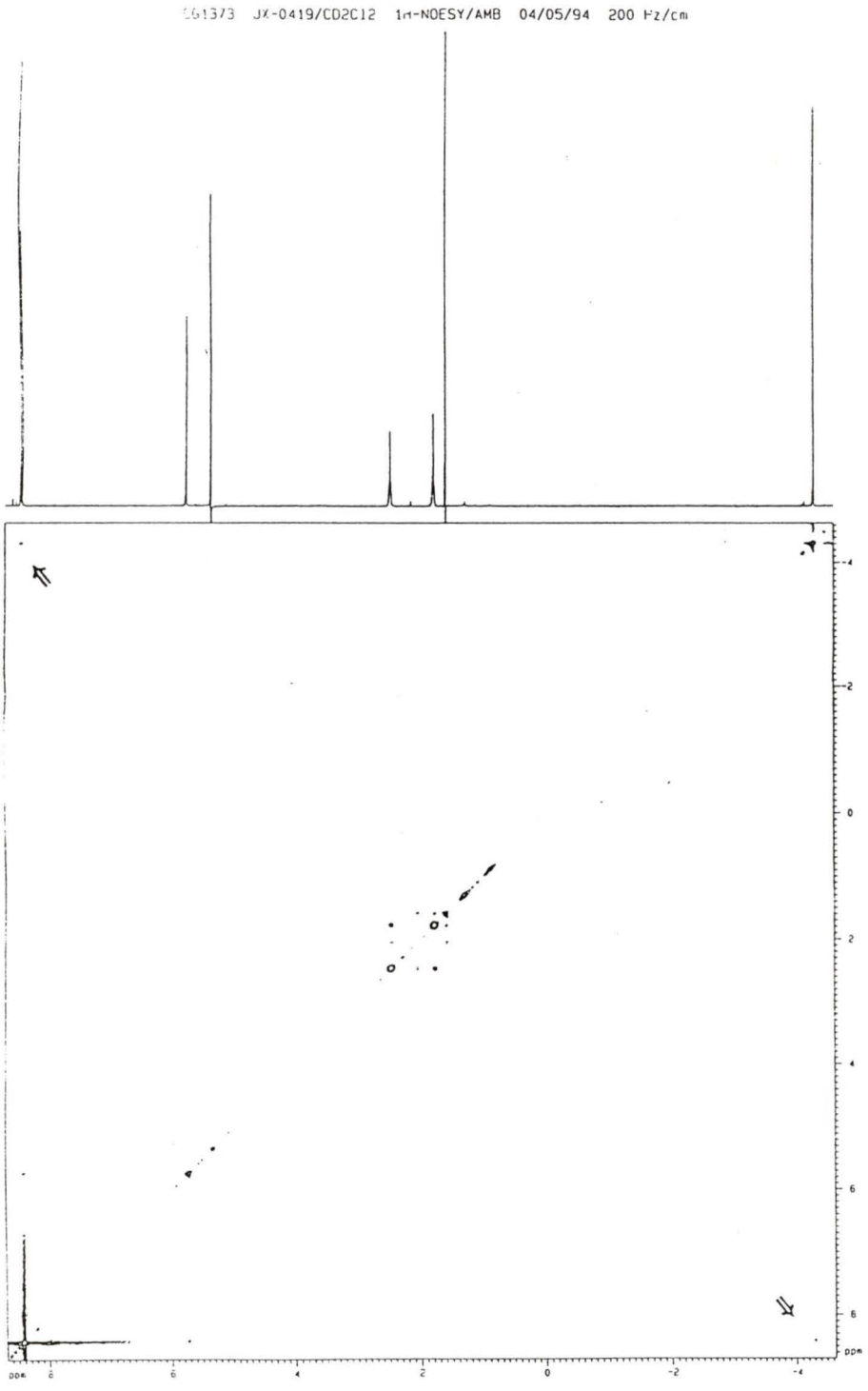


Fig. 6. ^{1}H-NOESY spectrum of **66**

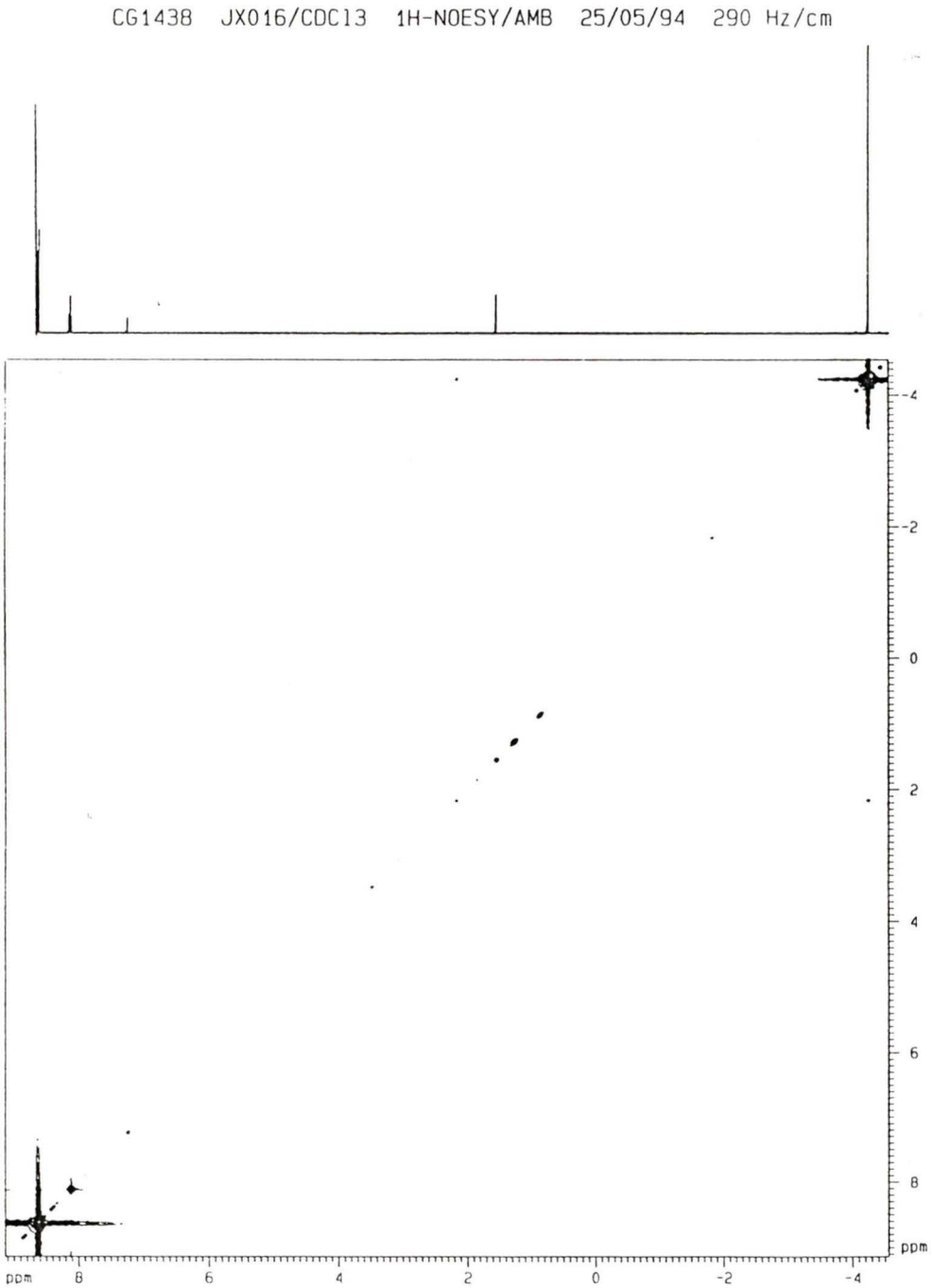


Fig. 7. The ^{1}H-NOESY spectrum of **21**

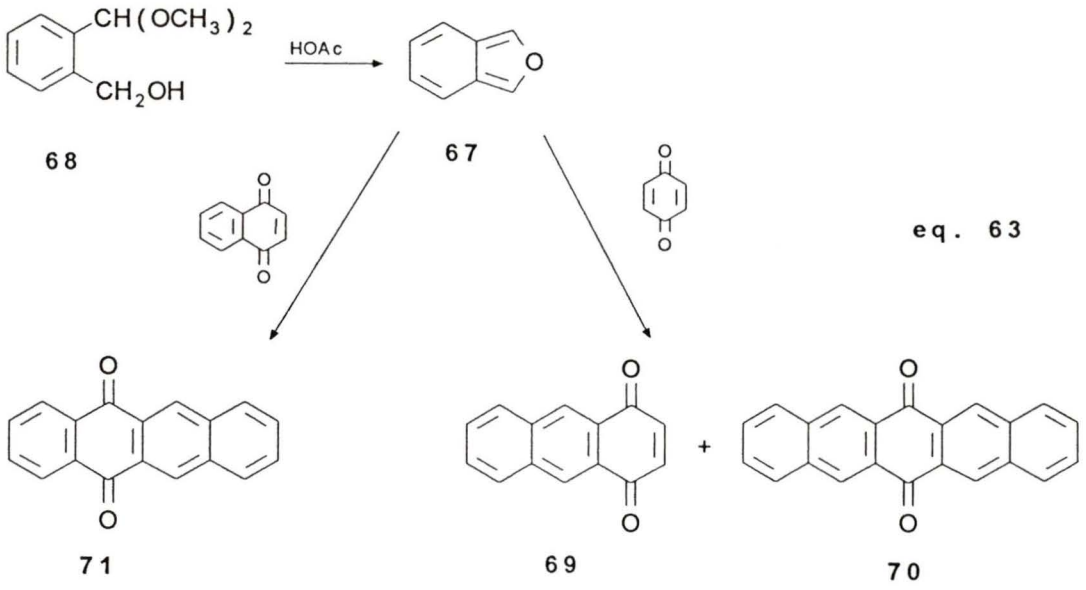
was not found in the ^{1}H-NOESY NMR experiment of DMDHP **21** itself, Fig. 6, indicating that the interaction must be intermolecular. These results suggest that the two DMDHP rings in **66** are not in the face to face conformation, at least in solution. This may also account for the absence of a red-shifted absorption in its electronic spectrum.

2.4. Attempted Diels-Alder cycloaddition reactions of quinone 17

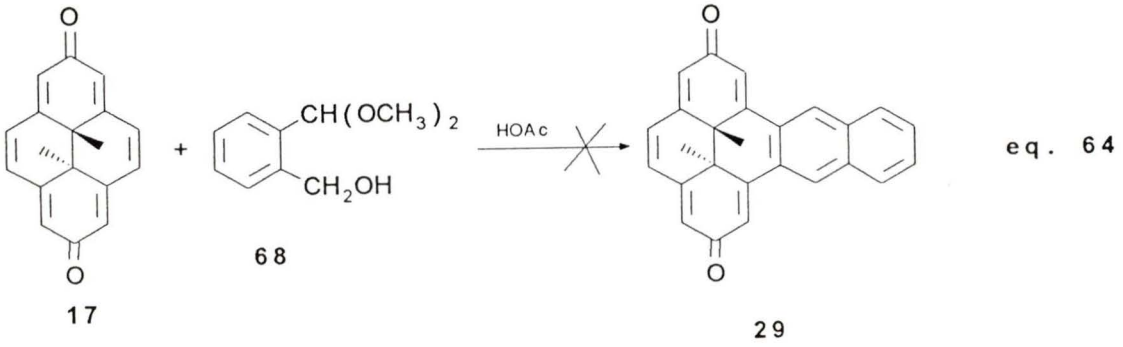
We wanted to study the possibility of quinone **17** acting as a dienophile in the Diels-Alder cycloaddition reaction in order to prepare [e]-fused derivatives of **21**. Isobenzofuran type and *o*-xylylene type dienes are of particular interest to us, since the adducts formed by these dienes and quinone **17** might be conveniently converted to the [e]-fused derivatives of **21** by deoxygenation or dehydrogenation.

The first diene chosen for study was isobenzofuran, **67**. The chemistry of isobenzofurans has been well documented. In their reviews, Rodrigo[105] and Friedrichsen[106] give comprehensive discussion of the synthesis, spectroscopic properties and reactions of isobenzofurans and of their application to the synthesis of natural products and polyaromatic hydrocarbons. Because of the high reactivity of isobenzofuran, normally after generation it is immediately intercepted *in situ* by the added dienophile. The base-induced elimination reaction of 1-alkoxyphthalans[107] is a convenient and efficient method to generate isobenzofurans. This has been successfully applied to trap the aryne derivative of **21** by Mitchell and Zhou[69]. However, probably due to the strongly basic conditions involved in this method, so far no report on the application of this method to generate isobenzofurans to react with quinones has been seen. Thus we first studied the reaction of quinone **17** with strong base (t-BuOK) in

THF. Quenching with water, returned no quinone **17**. Thus we prefered to avoid strong basic conditions. Recently it was found[108] that alcohol **68** on treatment with acetic acid was a satisfactory route to isobenzofuran. Treating **68** in hot acetic acid with benzoquinone or 1,4-naphthoquinone gave the expected Diels-Alder adducts of isobenzofuran, namely **69** and **70**, and **71**

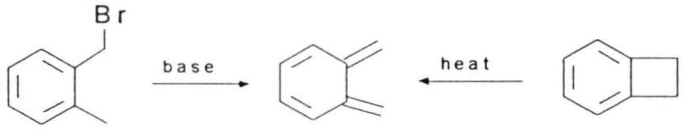


(eq.63). Unfortunately after treatment of **68** with quinone **17** in acetic acid at 100°C for 10 hours, no Diels-Alder adducts could be isolated, eq. 64.



Repeating the same reaction at different temperatures also was unsuccessful. At temperatures below 50°C quinone **17** was recovered; while at reflux temperature no Diels-Alder adducts could isolated nor quinone **17** could be recovered. TLC of the high temperature reaction mixture showed a long fluorescent tail but no products could be recognized. Heating quinone **17** by itself both in acetic acid and in diphenyl ether above 100°C for several hours also gave the same result on TLC. This indicated that quinone **17** changed to unknown highly fluorescent compounds after heating above 100°C for more than 3 hours.

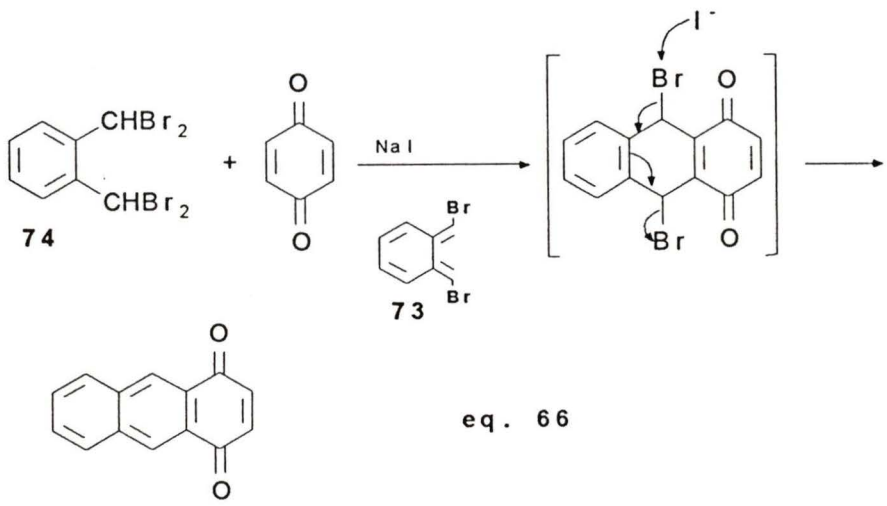
We also studied the highly reactive diene *o*-xylylene, which is also known as *o*-quinodimethane, **72**. The Diels-Alder reactions of **72** have been widely applied, both intramolecularly[109] and intermolecularly[110], in organic synthesis, especially in natural product synthesis. Diels-Alder reactions with quinones are also well cited[111]. In these reactions *o*-xylylenes were generated in most cases[111a-d] by 1,4-elimination of HBr from α-bromo-*o*-xylene using NaI as the base, also by the thermal ring opening of substituted benzocyclobutenes[111e-f], eq. 65. Since the latter requires a high temperature,



72

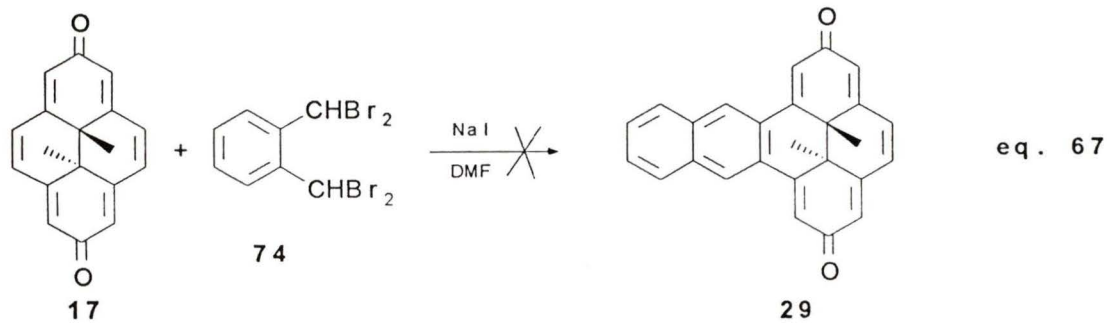
eq. 65

it will not be suitable for our purpose. The adduct formed from tetrabromide **74** with benzoquinone in the presence of NaI undergoes elimination of Br_2 to aromatize the six member ring formed in D-A reaction *in situ*, eq. 66[111a]. Thus

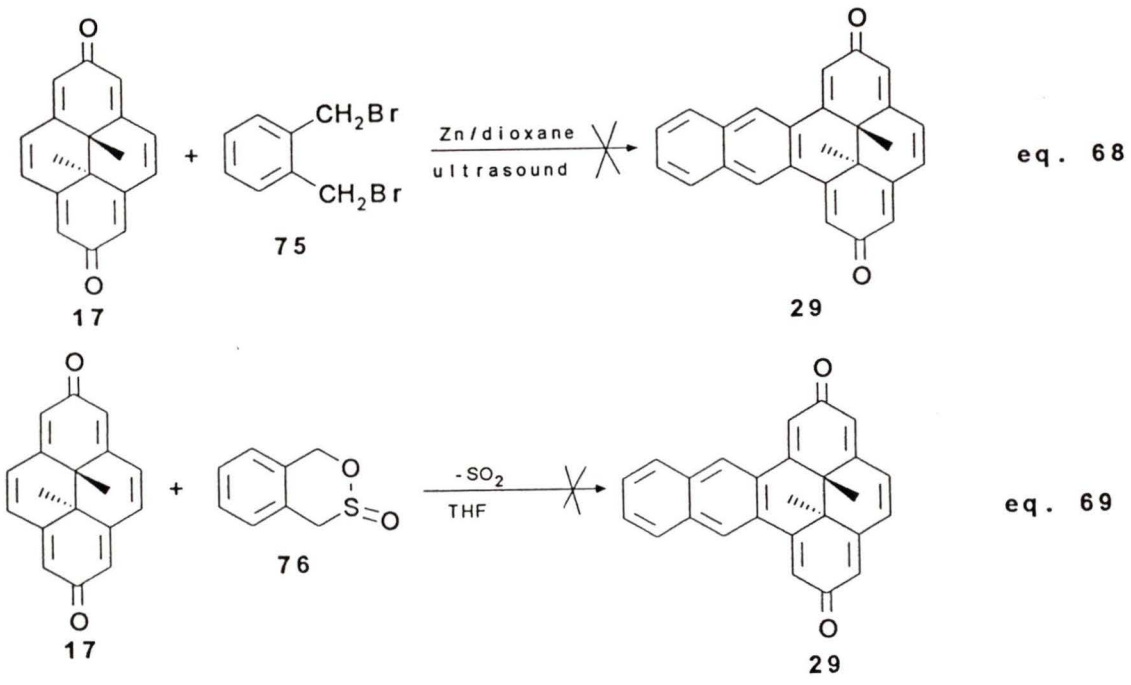


eq. 66

using the reported procedure, commercially available α,α,α',α'-tetrabromo-*o*-xylene **74** was added to a mixture of NaI and quinone **17** in dry DMF and stirred at 60°C for 24 hours, eq. 67. No Diels-Alder product could be isolated. Several further efforts were made, e.g. by using ultrasound-promoted reaction[112] of zinc and α,α'-dibromo-*o*-xylene, **73**, eq.68, and using the low



eq. 67



temperature thermal elimination of SO_2 from **76**[113], eq. 69. Thses were all unsuccessful and in both cases quinone **17** was recovered.

This suggests that either the quinone **17** is not reactive enough in the D-A reaction or the stereo effect of the internal methyl groups of quinone **17** with dienes is too large to form either the *endo*- or the *exo*-transition states. If the reason is the latter, probably we could do nothing, but if the reason is the former, Lewis acid catalysis may change the situation. Quinones are electron-deficient dienophiles, and the formation of a Lewis acid complex should further enhance the electron-deficiency of the quinone, and hence increases its reactivity in its Diels-Alder reaction. We tried $AlCl_3$ as Lews acid

catalyst in the reaction shown in eq. 69. Thus, a solution of **76** (which was prepared by the method reported[113]) in THF was added to a mixture of quinone **17** and $AlCl_3$ in THF at room temperature and then was heated to reflux for 6 hours. After quenching with ice, no cycloaddition product could be isolated and 83% of the quinone **17** was recovered.

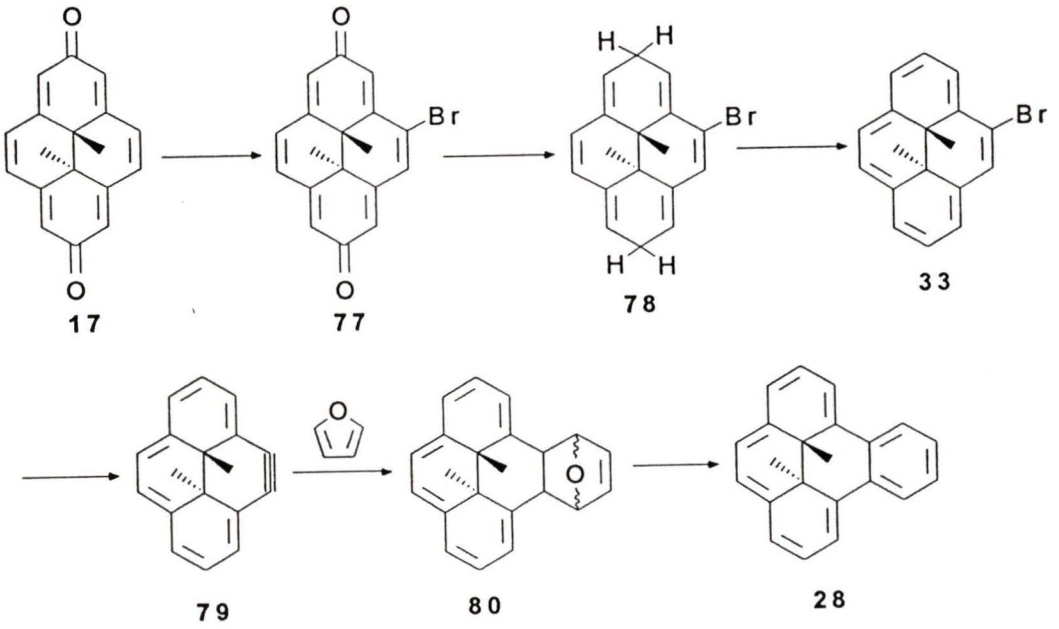
Clearly these initial results suggested that quinone **17** is not a useful D-A dienophile.

2.5. Bromination of quinone 17 and a possible route leading to a regioselective synthesis of the dibenzannelated [*a,h*]- and [*a,i*]-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, 95 and 97

2.5.1. Bromination of quinone 17

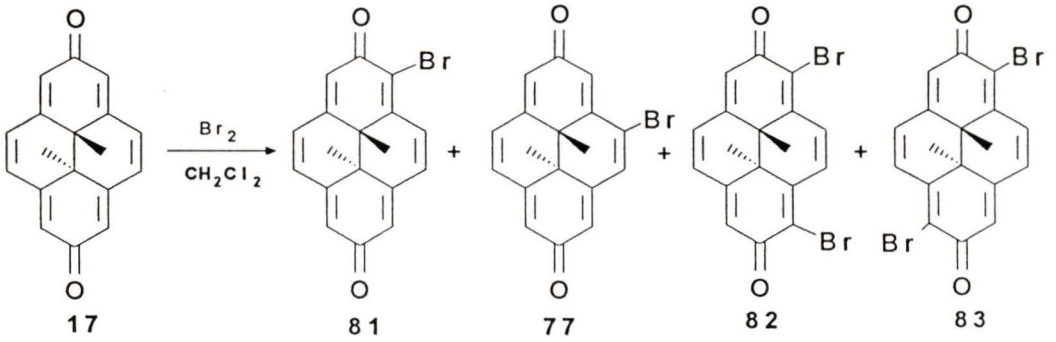
Quinones can be halogenated by chlorine and bromine. This process involves two steps: the *trans* addition of halogen to the quinone's carbon double bond, and then elimination of one molecule of hydrogen chloride (hydrogen bromide) from the dichloride (dibromide) to form the halogen substituted quinones, see eq. 39. In some cases a second molecule of halogen can be added to the halogen substituted quinone to form a disubstituted quinone[115]. The lack of success in the Diels-Alder reaction of quinone **17** led us to think that if bromination of quinone **17** could introduce bromine at the 4-carbon of quinone **17**, to give **77**, then reduction and dehydrogenation of **77** should give the 4-bromo-DMDHP **33**, which is a precursor to the aryne derivative **79**. The Diels-Alder reaction of the aryne derivative **79** with dienes might then provide us an alternative route to the [e]-fused derivatives of **21**, Scheme 7.

Bromination of quinones with bromine is normally carried out in acetic acid or carbon tetrachloride[116]. In some cases[117] pyridine is also used as the solvent. Due to the poor solubility of quinone **17** in carbon tetrachloride, we



Scheme 7

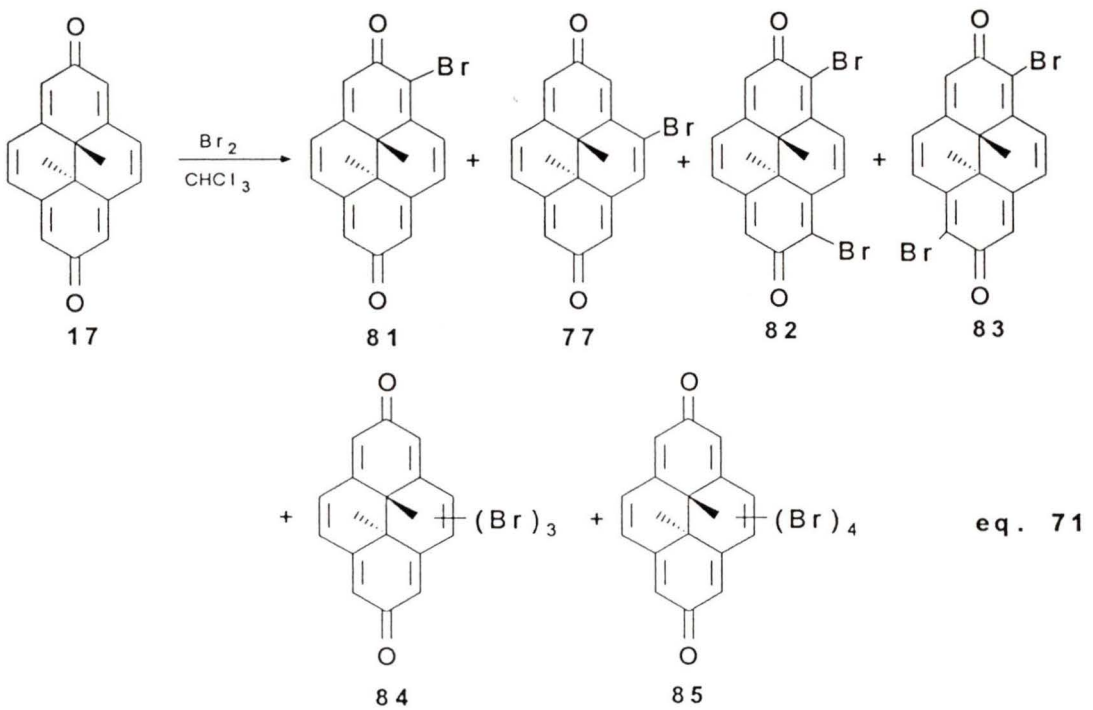
first chose dichloromethane as reaction solvent. After a solution of **17** and bromine (molar ratio = 1:2) in dichloromethane was refluxed over night, only about 40% of quinone **17** was reacted. Refluxing for longer times did not



eq. 70

extend the reaction further. The product contained four bromides, eq. 70, namely two dibromides, 1,8-dibromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, **82**, 1,6-dibromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, **83**, and two monobromides, 1-bromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, **81**, 4-bromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, **77**. The dibromides were present only in very small amount and could only be recognized by TLC comparison (see below). The two monobromide isomers were obtained in the ratio of **81** : **77** = 5 : 1. The yield for **81** was 31% and for **77** was 6%.

To increase the conversion of **17** in its bromination reaction, chloroform which has a higher b.p. than dichloromethane, was next used, eq 71. Although



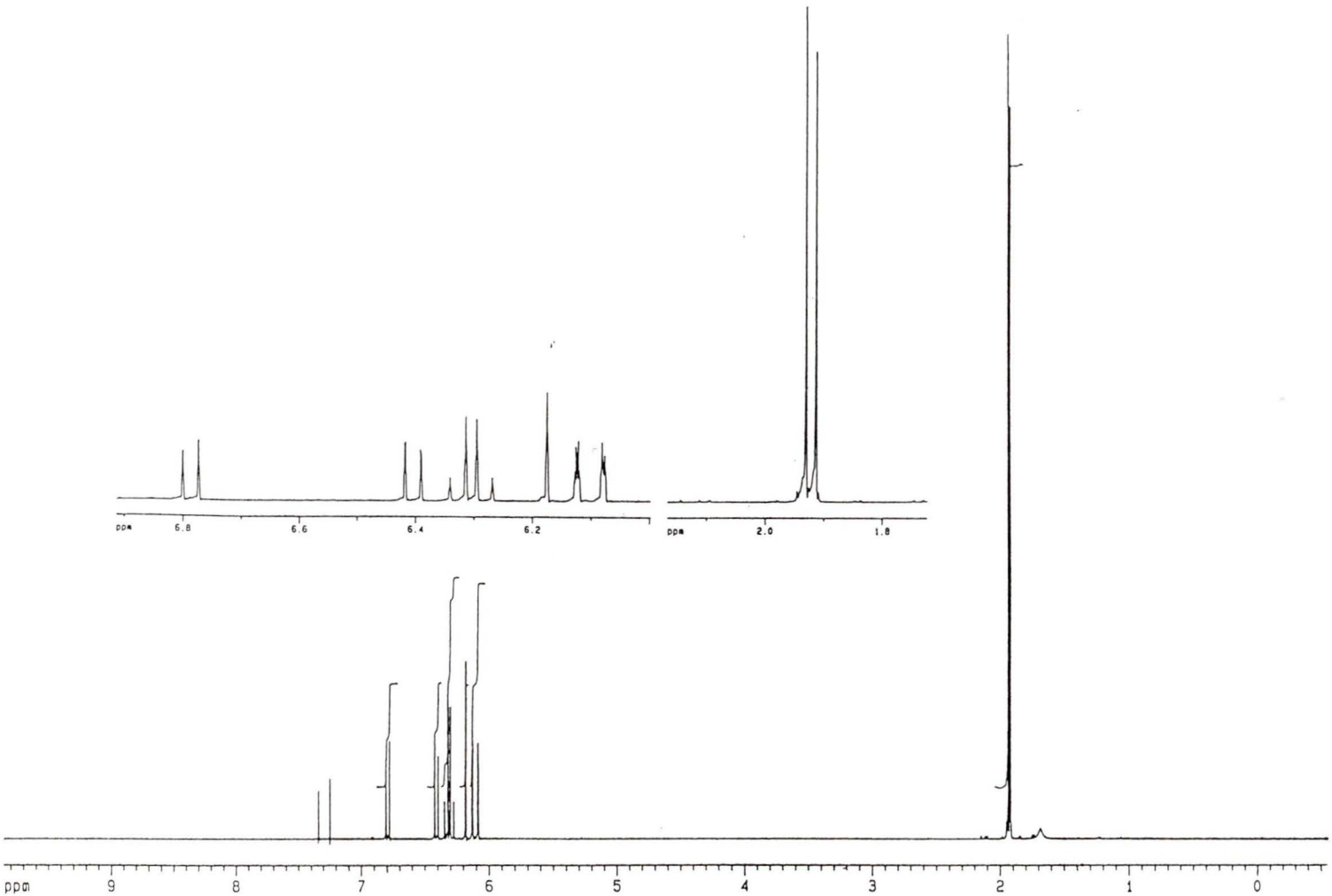
eq. 71

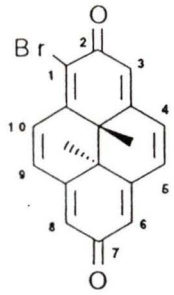
almost 70% of quinone **17** reacted, the product mixture was more complicated. Besides a small amount of tetrabromides **84** and tribromides **85**, the mixture contained 34% of **82**, 37% of **83**, 22% of **81** and 6.8% of **77**. The yield for **82** is 25%, for **83** is 27%, for **81** is 16% and for **77** is 5.0%. An attempt to push the reaction to completion by reacting the HBr formed with pyridine or diethylamine[118] did not improve the yield of the reaction.

The characterization of dibromides **82** and **83** and monobromides **81**, **77** was based on their ^{1}H NMR, COSY and NOESY and ^{13}C NMR spectra and was also supported by their MS and IR spectra and correct elemental analyses. The assignment of vinyl protons was made using ^{1}H NMR, COSY and NOESY spectra

The three ^{1}H NMR spectra of monobromide **81** are shown in Fig. 8, Fig. 9 and Fig. 10. In the COSY spectrum, the strong coupling between H10 and H9, H5 and H4 are indicated by the strong intensity of the cross-peaks corresponding to these protons; the weak couplings between H10 and H8, H9 and H8, H8 and H6, H6 and H5, H5 and H3, H4 and H3 are indicated by their low intensity cross-peaks. The assignment of vinyl protons was also supported by the NOESY spectra. The relative positions of H10, H9 and H8 are confirmed by the weak interaction between H9 and H8 and the absence of interaction between H10 and H8. The position of H6 is confirmed by the weak coupling with H8, the weak interaction with H5 and the absence of interaction with H4. This also shows the relative positions of H8, H6, H5 and H4.

Fig. 8. The ^{1}H-NMR spectrum of **81**





81

Fig. 9. The ^{1}H-COSY spectrum of **81**

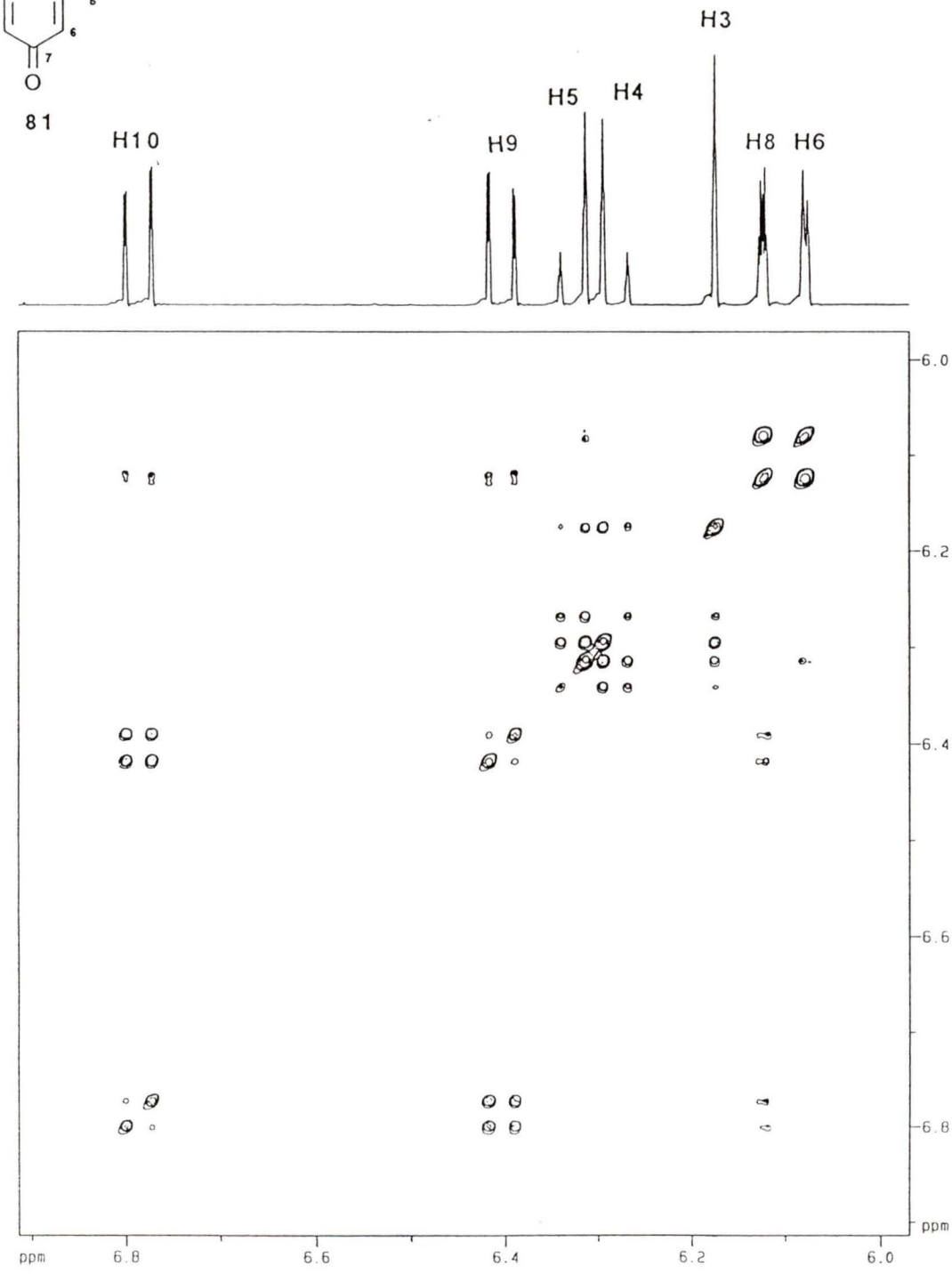
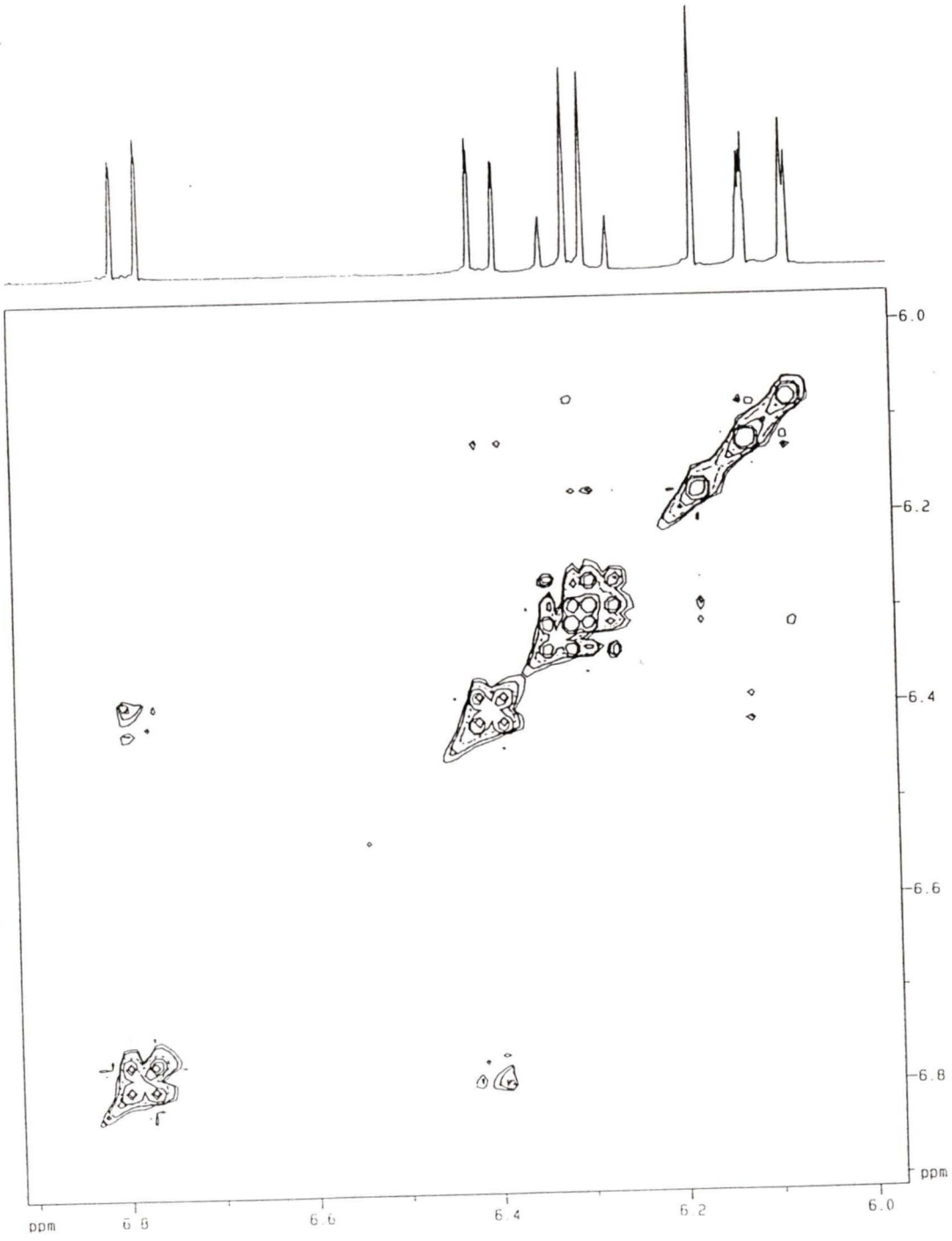


Fig. 10. The ^{1}H-NOESY spectrum of **81**

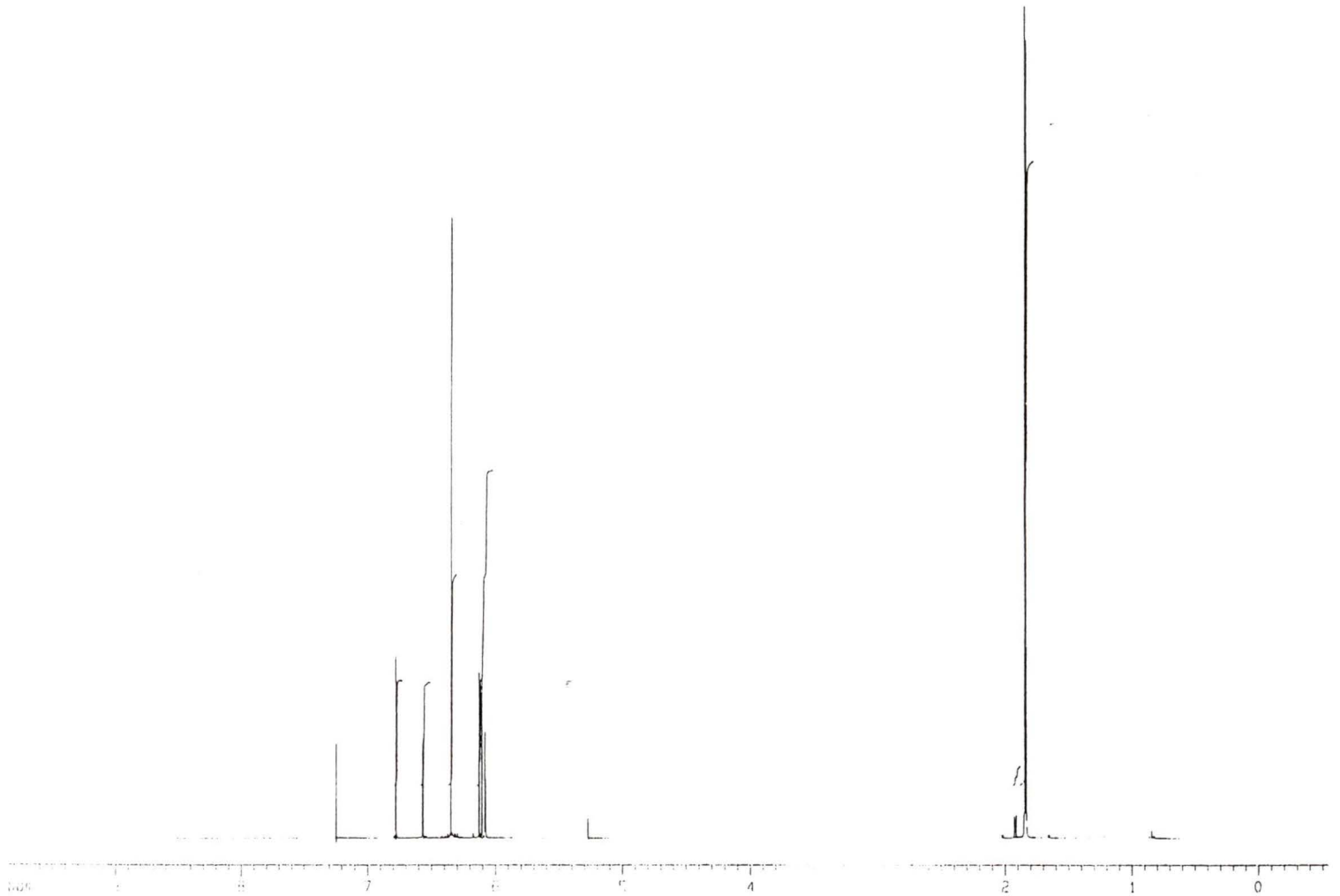


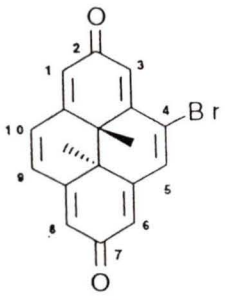
Similarly, the position of H3 relative to H4 and H5 is revealed by a weak interaction between H4 and H3 and a weaker coupling between H5 and H3. The protons of the two internal methyl groups appears as two singlets in ^{1}H NMR spectrum due to the different distances from the bromine substituent.

The ^{1}H NMR, COSY and NOESY spectra for monobromide **77** are shown in Fig. 11, Fig. 12 and Fig. 13. The protons H10 and H9 appear as a singlet due to a low value of $\Delta\delta/J$. The COSY spectrum shows the weak couplings between H8 and H6, H6 and H5, H5 and H3, H3 and H1. The NOESY spectrum shows that H10 and H9 are weakly interacted with H1 and H8 respectively. H6 is weakly coupled with H8 and interacts with H5. H3 is weakly coupled with H1. The internal methyl protons also appear as two singlets due to the different distances from the bromine substituent.

For dibromide **83**, its three NMR spectra are shown in Fig. 14, Fig. 15 and Fig. 16. A strong coupling is observed between H4 (or H9) and H5 (or H10). There are weak couplings between H3 (or H8) and H4 (or H9) and between H3 (or H8) and H5 (or H10). The assignment of H5 or (H10), H4 (or H9) and H3 (or H8) are also supported by comparing their chemical shifts with those of H8, H9 and H10 of monobromide **81**, see Table. 3. The internal methyl protons appear as one singlet since they are in the same chemical environment.

Fig. 11. The ^{1}H-NMR spectrum of **77**





77

Fig. 12. The ^{1}H-COSY spectrum of **77**

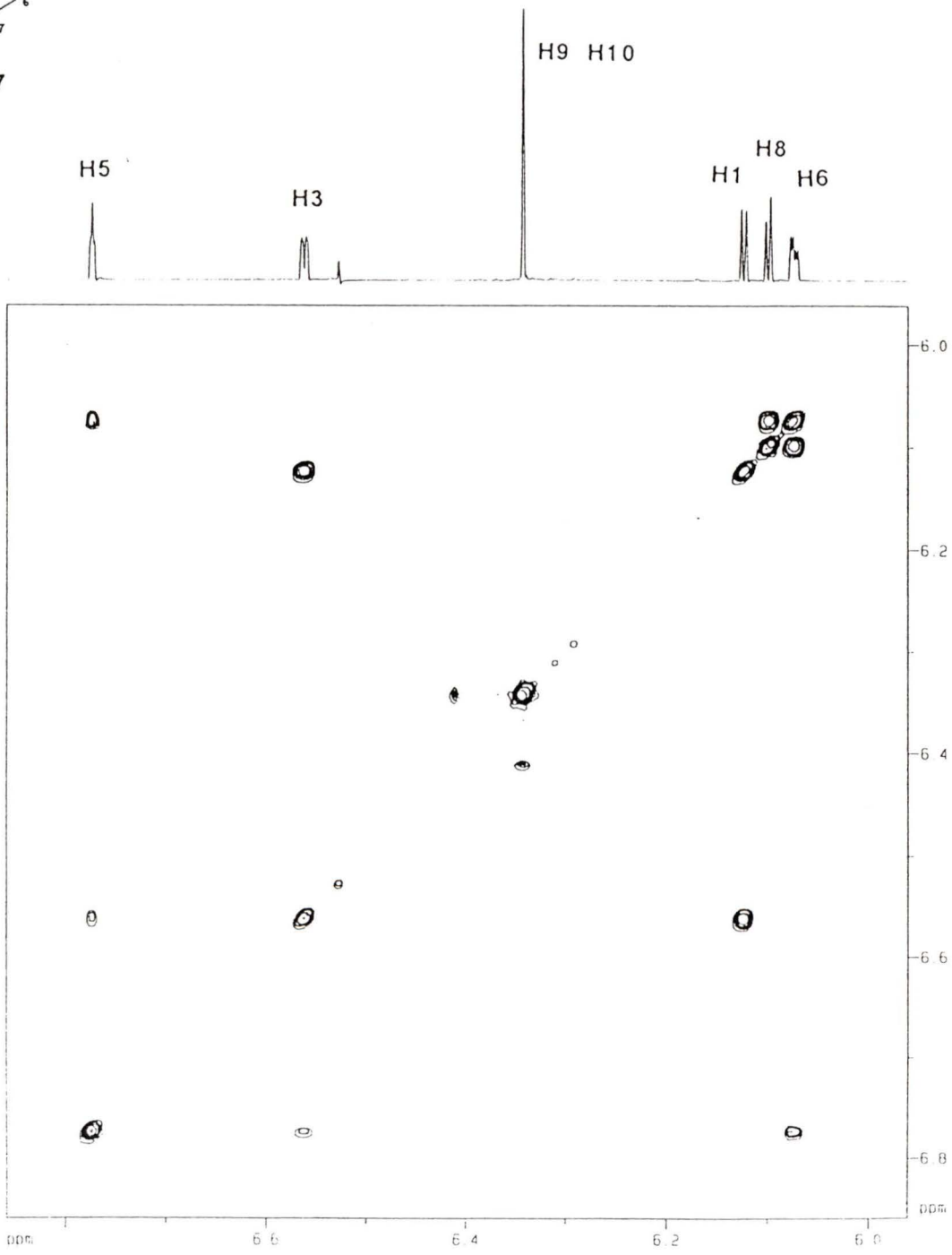


Fig. 13. The ^{1}H-NOESY spectrum of **77**

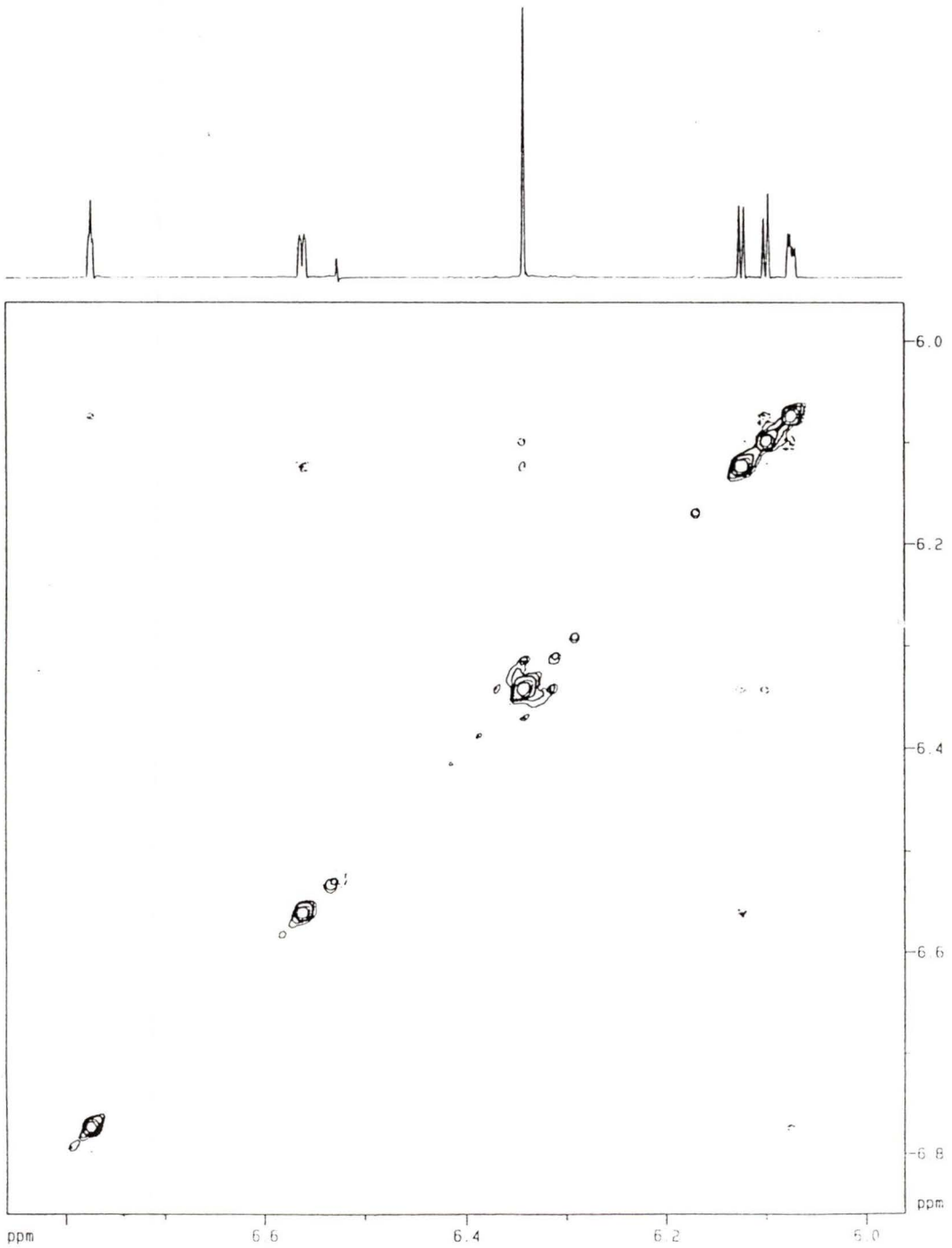
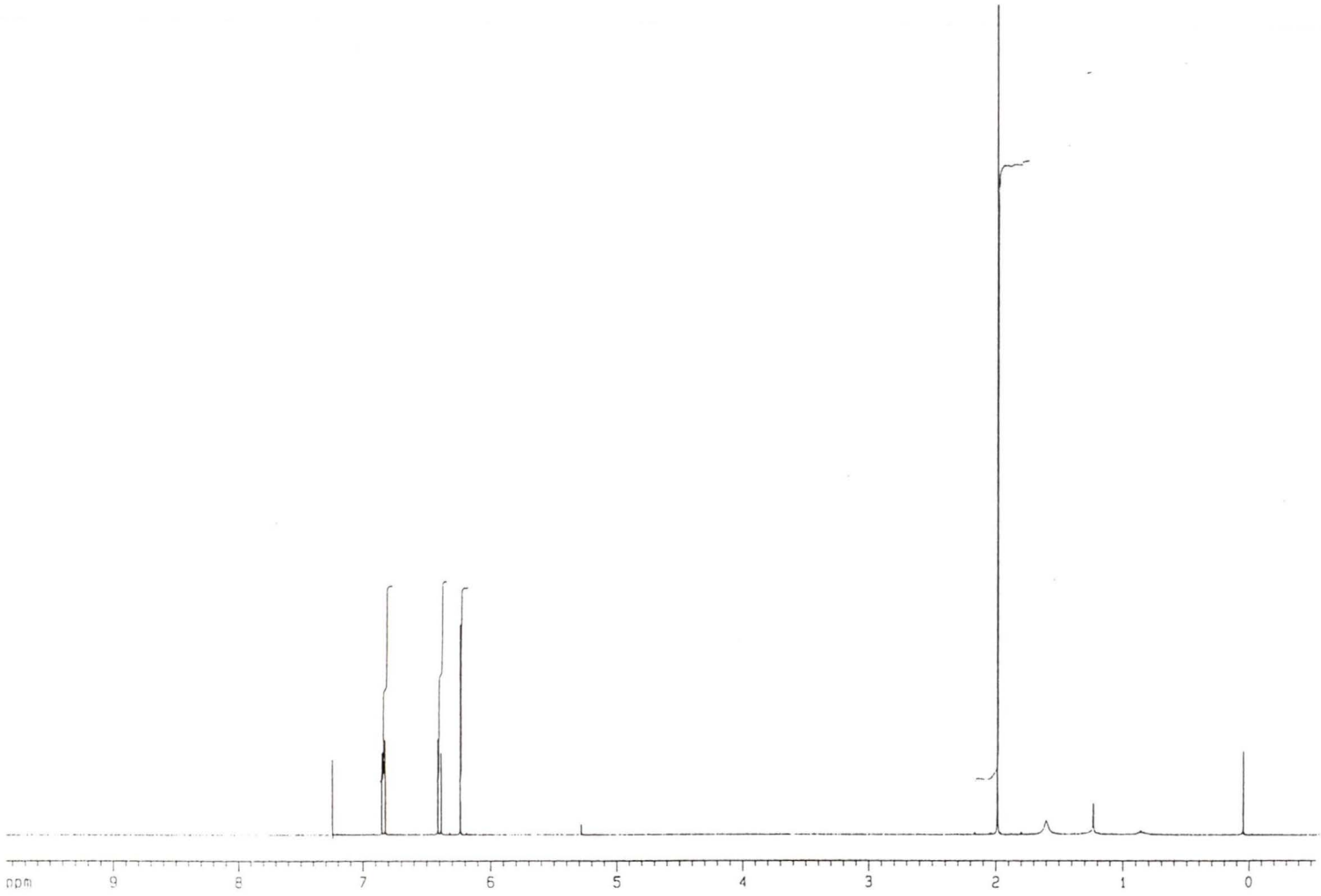
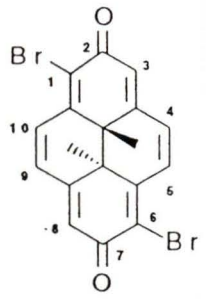


Fig. 14. The ^{1}H-NMR spectrum of **83**





83

Fig. 15. The ^{1}H-COSY spectrum of **83**

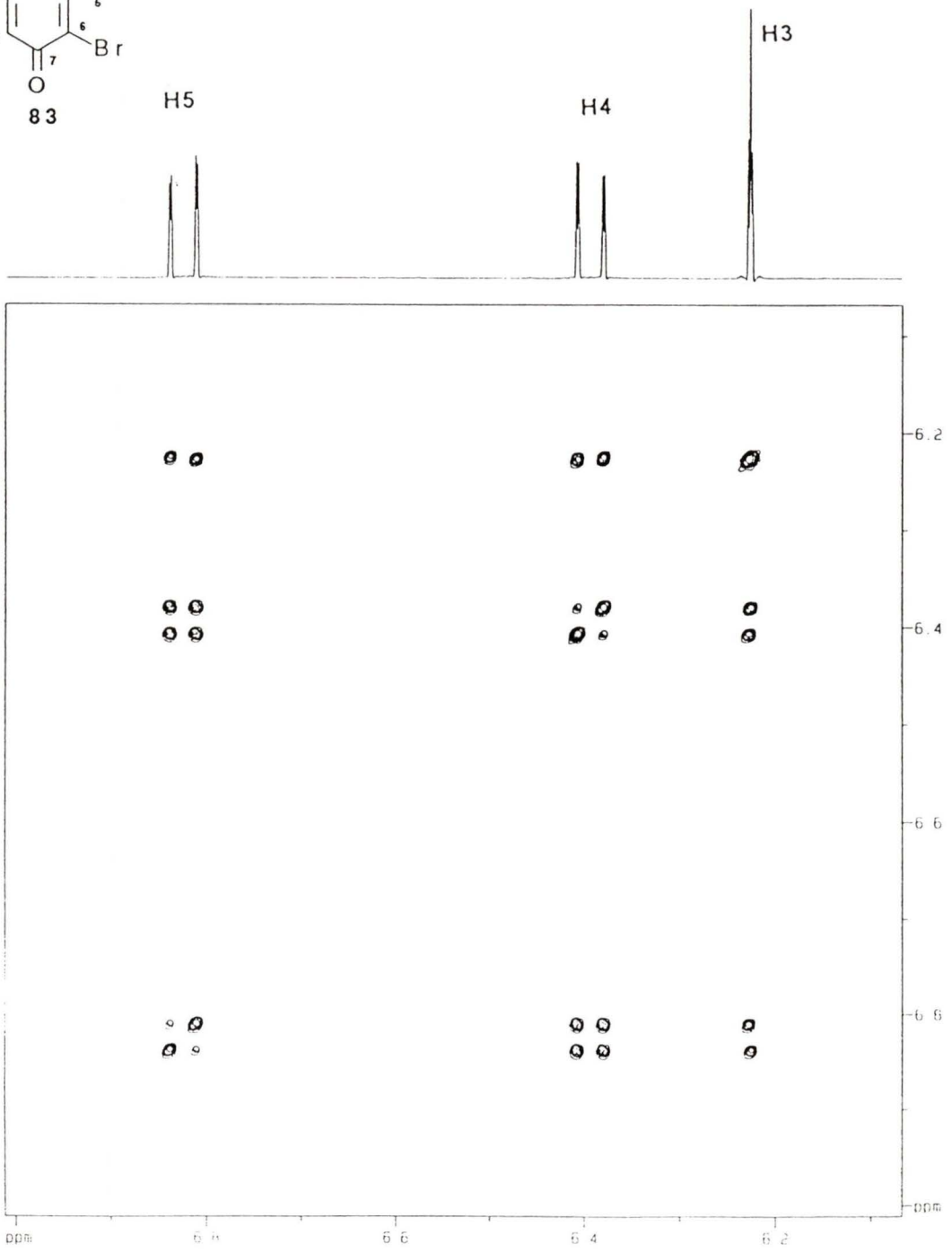


Fig. 16. The ^{1}H-NOESY spectrum of **83**

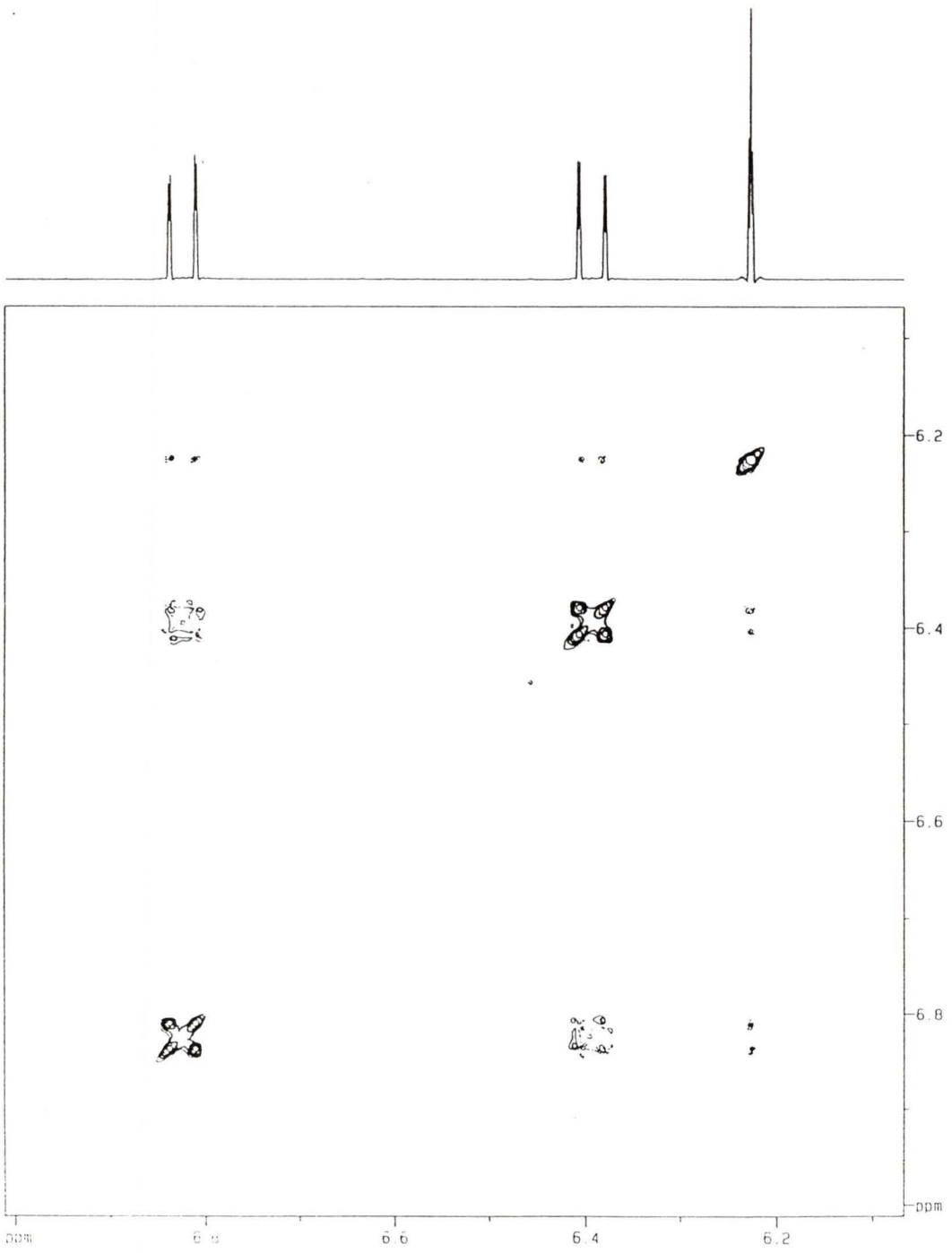
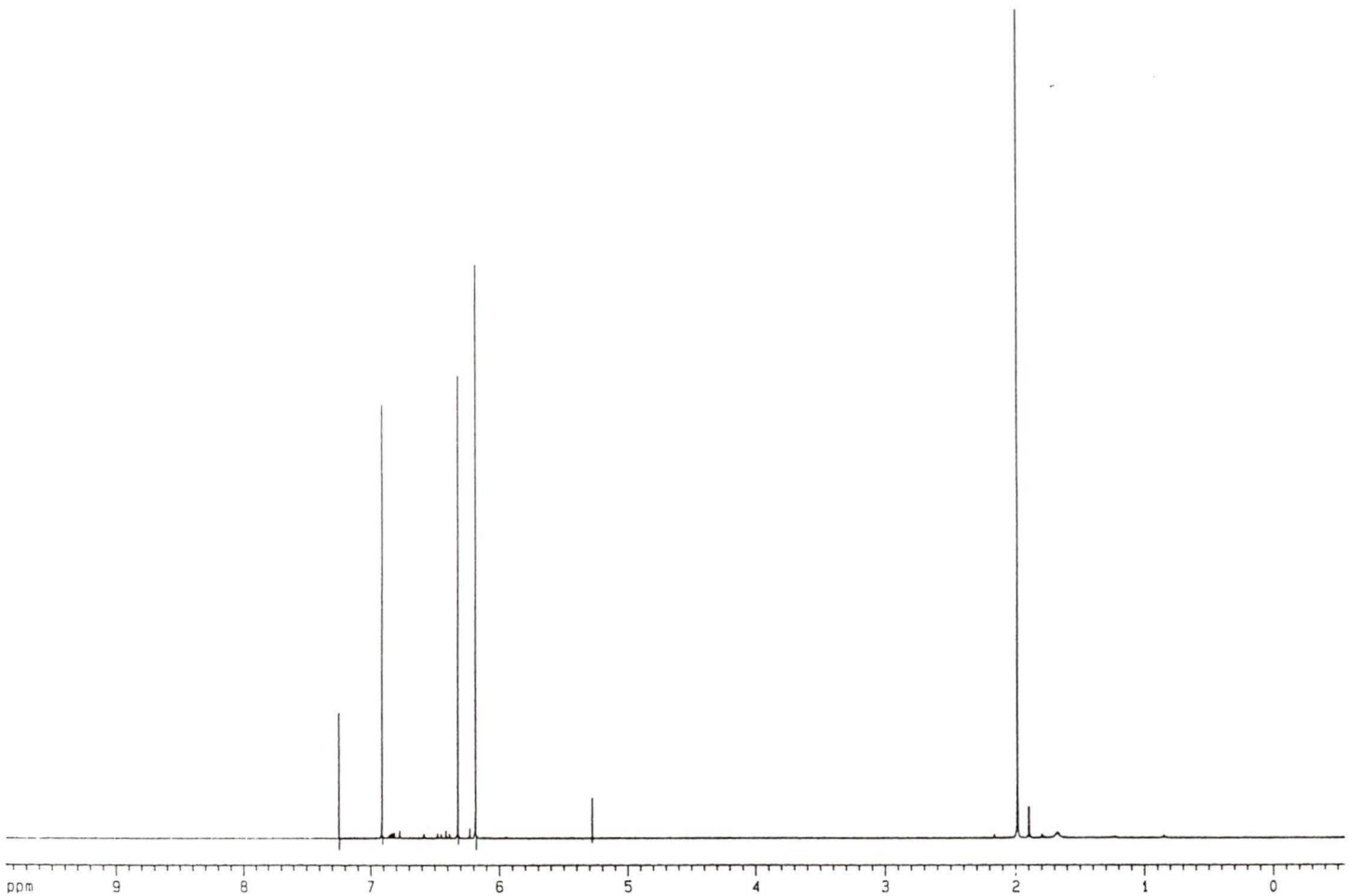


Fig. 17. The ^{1}H-NMR spectrum of **82**



The ^{1}H NMR spectrum of dibromide **82** is shown in Fig. 17. Thus, due to the symmetry of **82**, H10 (H9) appear as a singlet at δ 6.91 ; H6 (H3) as a singlet at δ 6.18; H5 (H4) appear as a singlet at δ 6.31. The assignment of the these protons is supported by comparing their chemical shifts with those of H10, H4 and H3 of monobromide **81**, Table 4.

The exclusion of the possible isomer **86** was based on the absence of a similar long distance coupling between H 3 and H1 as shown in the COSY of

Table 3. The chemical shifts of aromatic protons of **81** and **83**

81	proton	H10	H9	H8
	δ	6.78	6.40	6.12
83	proton	H10	H9	H8
	δ	6.82	6.38	6.22

Table 4. The chemical shifts of aromatic protons of **81** and **82**

81	proton	H10	H4	H3
	δ	6.78	6.28	6.18
82	proton	H10	H4	H3
	δ	6.91	6.31	6.18

77. As well, isomer **86** would have H3 appear around δ 6.5, H1 around δ 6.1, H10 around δ 6.3 (estimated form the chemical shifts of protons in **77**). These do not coordinate with the chemical shifts in the ^{1}H NMR spectrum of **82**, see Table 5. The possible isomer **87** was excluded by the absence of long distance couplings between H3 and H1, H10 and H1, H5 and H3, which was shown in the COSY spectrum of **77** and by the comparison of the chemical shifts in the

Table 5. The chemical shifts of aromatic protons of **82** and **86**

86	proton	H3	H10	H1
	δ*	6.5	6.3	6.1
82	proton	H10	H4	H3
	δ	6.91	6.31	6.18

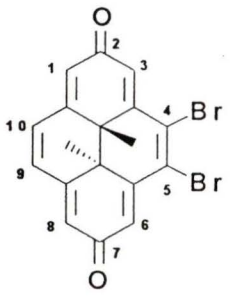
* estimated from the δ of the similar proton in **75**

Table 6. The chemical shifts of aromatic protons of **82** and **87**

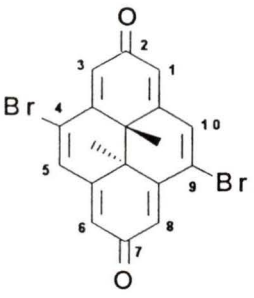
87	proton	H10	H1	H8
	δ*	6.8	6.6	6.1
82	proton	H10	H4	H3
	δ	6.91	6.31	6.18

* estimated from the δ of the similar protons in **75**

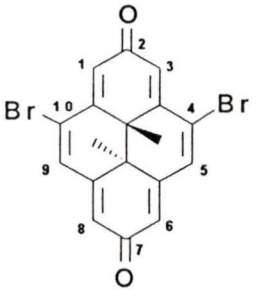
^{1}H NMR spectrum of **82** with those estimated for isomer **87**, see Table 6. For the possible isomer **88**, because the two internal methyl groups are at different distances from the two bromine substituents, there should be two singlets around δ 1.9. The one singlet corresponding to 6 protons at δ 1.99 in the ^{1}H NMR spectrum of **82** clearly indicated that the product is not isomer **88**. Similarly the other isomers : **89**, **90, 91, 92** and **93** can be excluded by the fact that there is only one singlet observed for the internal methyl protons both in the ^{1}H NMR spectrum of **82** and in the ^{1}H NMR spectrum of **83**. More than that, due to the symmetry of **82** and **83** their ^{13}C NMR spectra show 9 different kinds of carbons, while for the isomers **89** - **93**, their ^{13}C NMR spectra should show 12 different carbons for **89** and 18 diferent carbons for the rest of the isomers.



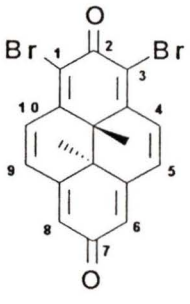
86



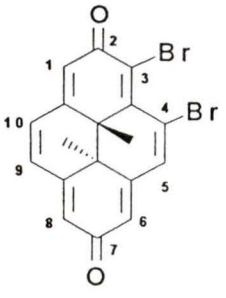
87



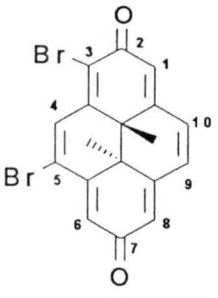
88



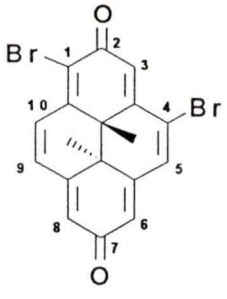
89



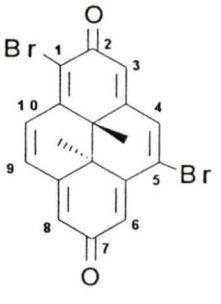
90



91



92

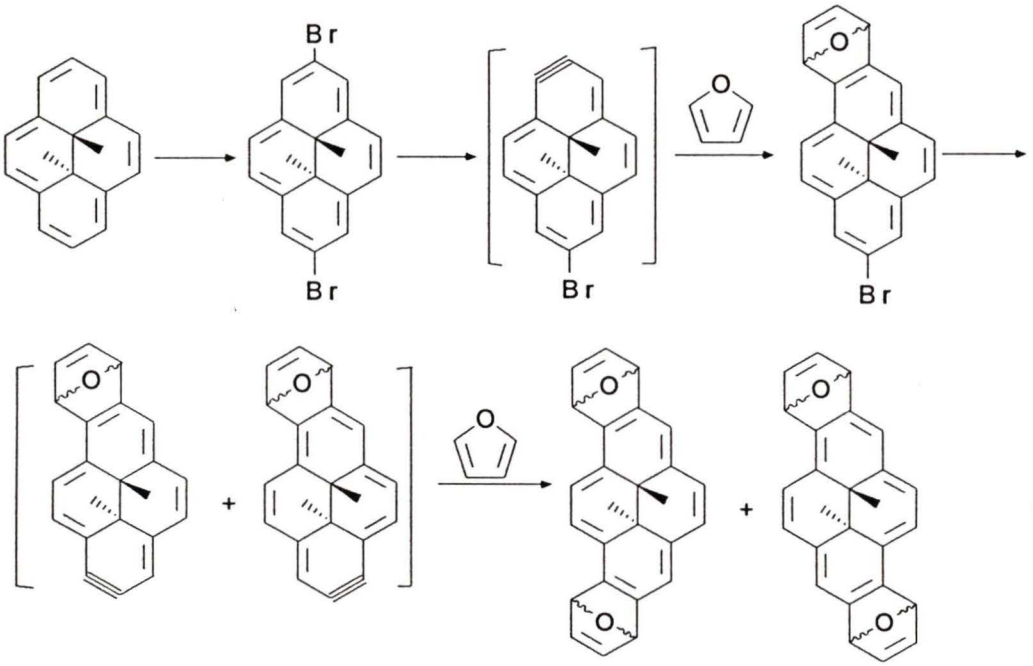


93

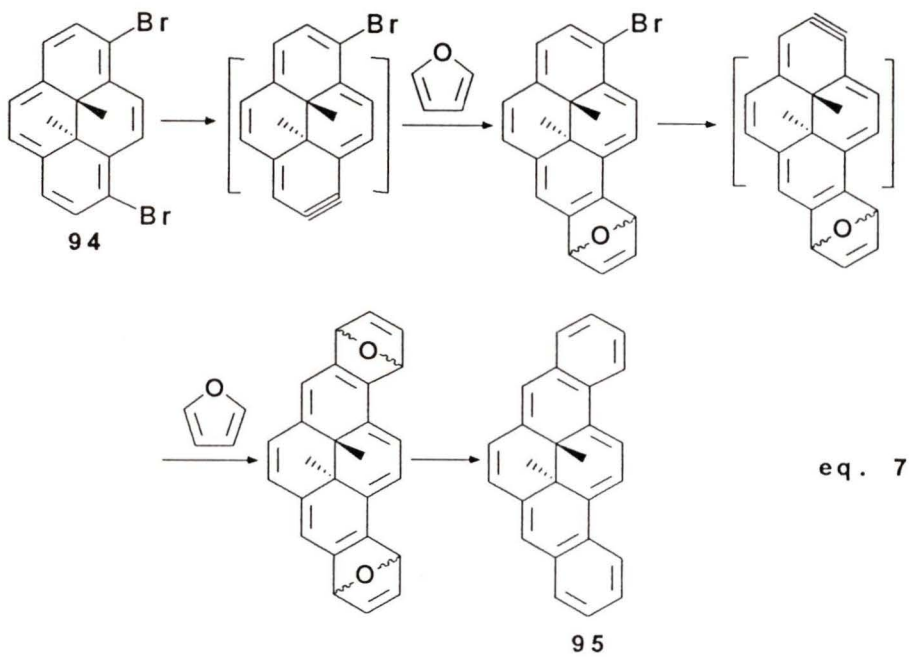
2.5.2. A possible route leading to a regioselective synthesis of the dibenzannelated [*a,h*]- and [*a,i*]-DMDHP, 95 and 97

Although bromine could be introduced to the 4 position of quinone **17**, the selectivity of the reaction was not good and the yield of **77** was quite poor (7%). So far we have not accumulated enough of **77** to test the sequence from **77** through **33** to **79** and then to **28**, Scheme 7. On the other hand, even if the sequence shown in Scheme 7 is successful, the poor yield of **75** will make this route not very practical.

Although the bromination of quinone **17** gave us the desired product **77** in low yield, it did give the dibromides in fairly good yield (almost 60% yield for two isomers, **82** and **83**, which can be quite easily separated by column chromatography). As the major products of the bromination reaction, we thought they may be useful in the synthesis of the interesting molecules: dibenzannelated [*a,h*]- and [*a,i*]-DMDHP, **95** and **97**, especially since **97** has shown special properties in its NMR spectrum and has biradical character[119]. Zhou[120] has shown that the bis-aryne derived from 2,7-dibromo-DMDHP can be trapped by furan to give the Diels-Alder adducts. The product was a mixture of regio isomers, eq 72. If we can convert **82** and **83** to the corresponding DMDHP **94** and **96**, then elimination of 2 molecules of HBr and trapping of the arynes by furan will give us two pure regio isomers of the



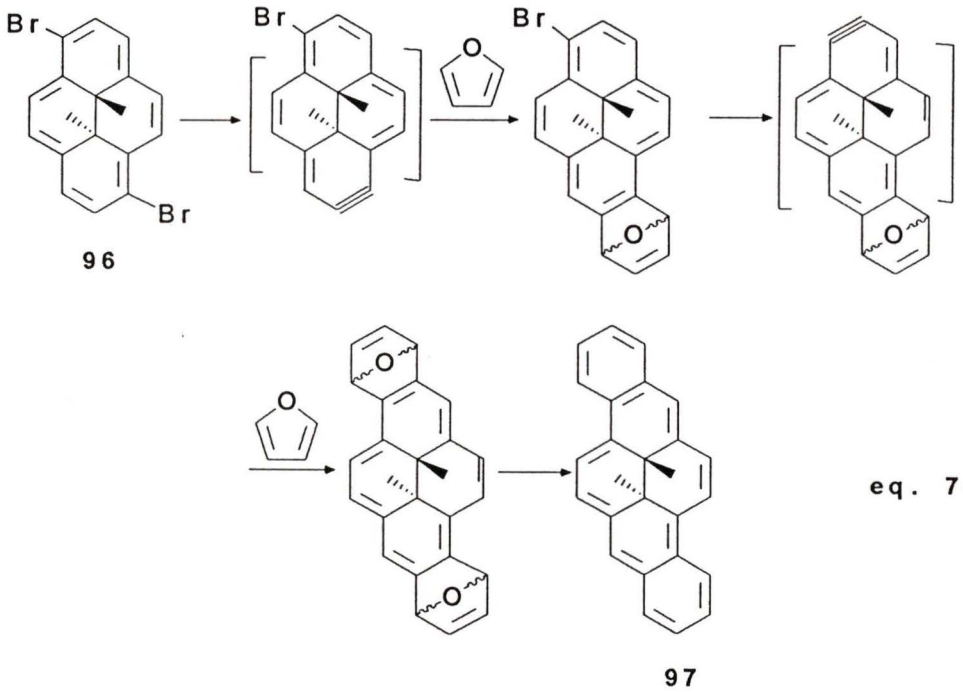
eq. 72



94

95

eq. 73



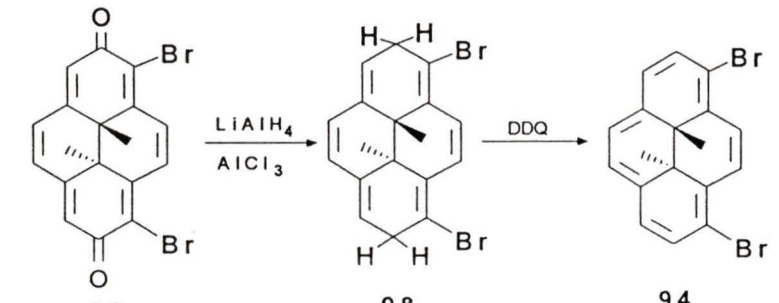
96

97

eq. 74

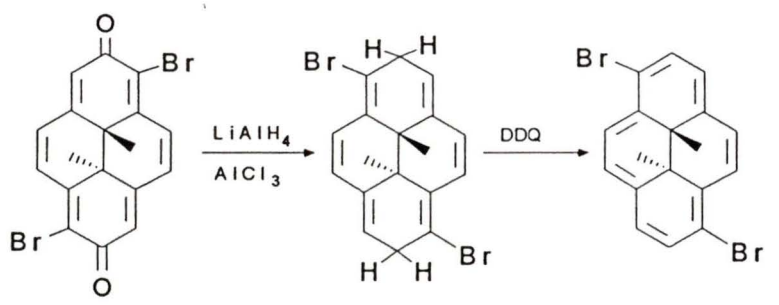
adducts, eq. 73 and 74. As well, conversion of these two isomers, **82** and **83**, to **94** and **96** will also be a model study to test the feasibility to convert **77** to **33** by reduction and dehydrogenation, since we are not sure whether or not the bromine substituent can survive the harsh conditions of the reduction step.

Thus each of **82** and **83** were reacted with a mixture of $LiAlH_4$ and $AlCl_3$ under the same conditions reported for converting **17** to **22**[4]. Both gave a mixture of the corresponding dihydropyrenes (**94** and **96**) and tetrahydropyrenes (**98** and **99**) respectively. The mixtures were dehydrogenated by DDQ to convert the tetrahydropyrenes to dihydropyrenes, eq. 75 and eq. 76. From **82**, **94** was obtained in 83% yield and from **83**, **96**



82 98 94

eq. 75



83 99 96

eq. 76

was obtained in 86% yield. **94** was characterized by its ^{1}H and ^{13}C NMR, MS and IR spectrum. In its ^{1}H NMR spectrum, Fig. 18, H2(H7) appears as a doublet at δ 8.41, H3(H6) as a doublet at δ 8.31, H9(H10) as a singlet at δ 8.96 and H4(H5) as a singlet at δ 8.62. **96** was characterized by its ^{1}H and ^{13}C NMR, MS and IR spectrum and a correct elemental analysis. Its ^{1}H NMR spectrum is shown in Fig. 19. The aromatic protons were assigned as H2(H7) as a doublet at δ 8.46; H3(H8) as a doublet at δ 8.31; H4(H9) as doublet at δ 8.66; H5(H10) as doublet at δ 8.92.

Due to limited time, we have not tried the subsequent steps in eq. 73 and eq. 74. The study of these reactions will be part of future work of the group.

Fig. 18. ^{1}H-NMR spectrum of **94**

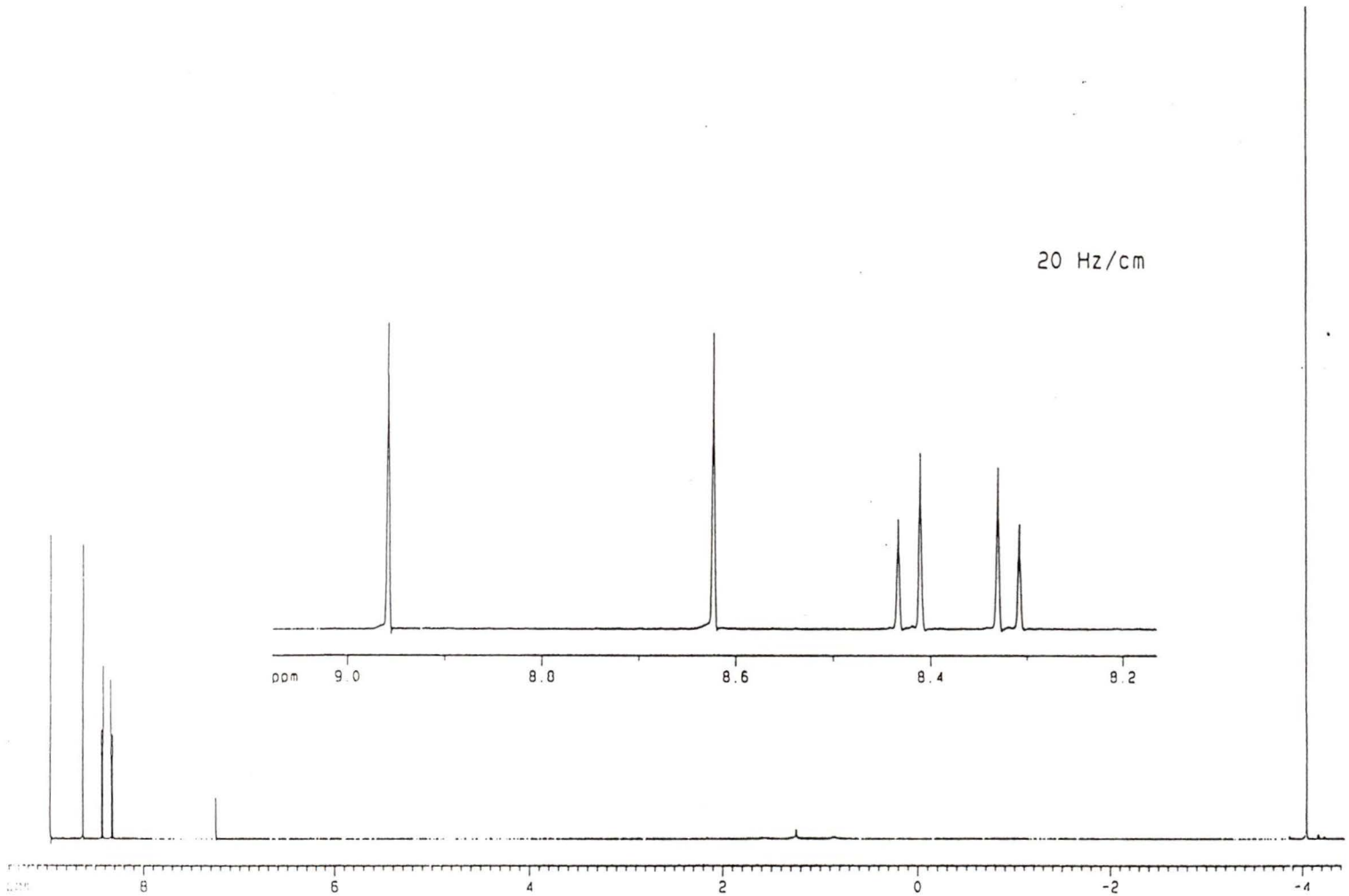
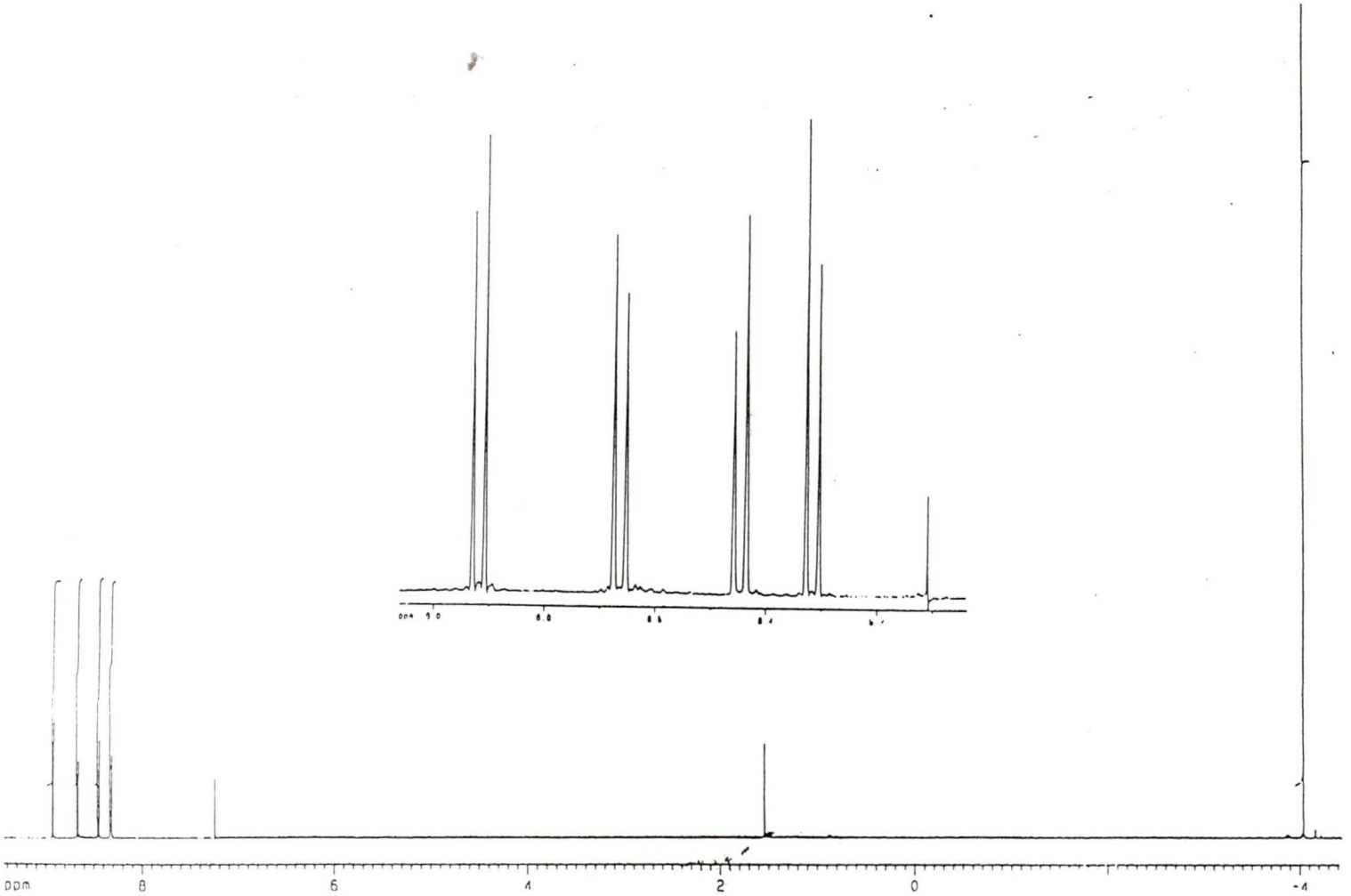


Fig. 19. ^{1}H-NMR spectrum of **96**

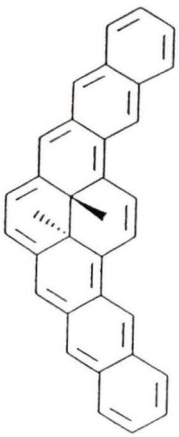


CHAPTER THREE

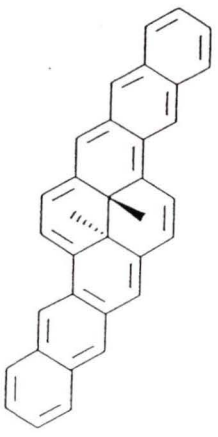
FUTURE WORK

3.1. The continuation of the regio-selective synthesis of dibenzannelated [a,h] and [a,i]-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrenes, 95 and 97

With the two dibromo DMDHP, **94** and **96**, in hand, the next step to be tried is the generation of the aryne intermediate and trapping with furan, followed by deoxygenation to form **95** and **97** (see eq. 73 and eq. 74). If that works, using isobenzofuran as the trapping reagent in eq. 73 and 74 should lead to the synthesis of dinaphthannelated [a.h]- and [a,i]-trans-10b,10c-dimethyl-10b,10c-dihydropyrenes, **100** and **101**. NMR and ESR studies should give us information on whether or not **101** has biradical properties.



100

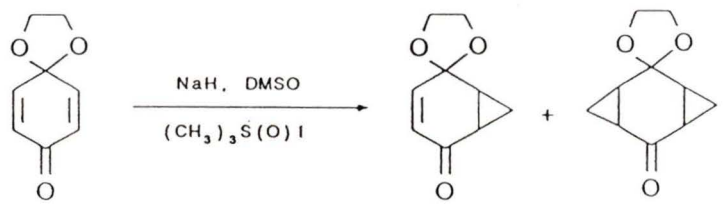


101

3.2. The reaction of dimethylsulfoxonium methylide and quinone 17

Both dimethylsulfonium methylide and dimethylsulfoxonium methylide react with carbonyl compounds to from oxiranes. However, for α,β-unsaturated carbonyl compounds, dimethylsulfonium methylide gives oxiranes while dimethylsulfoxonium methylide gives addition of methylene to the α,β double bond[121].

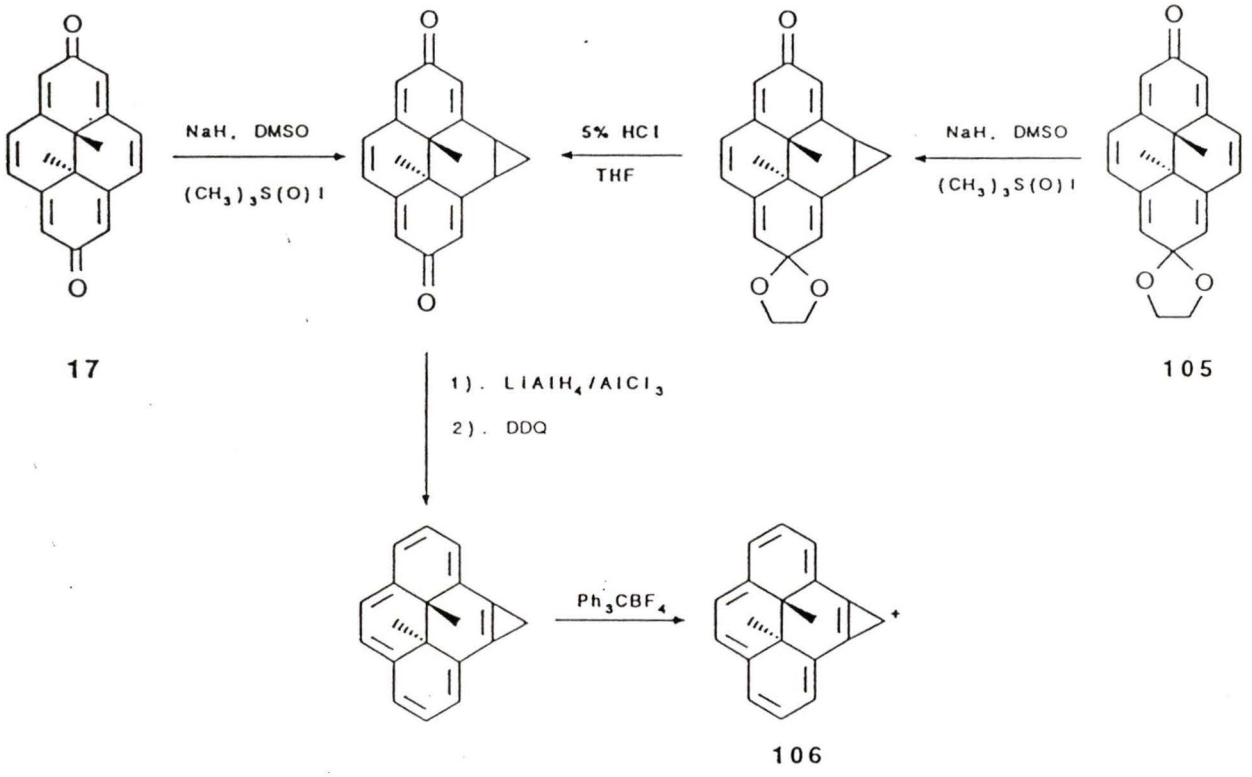
So far we have not found any report of the addition reaction of dimethylsulfoxonium methylide to the carbon double bond of quinones. The only similar case is the addition of sulfoxonium methylide to the α,β double bond of **102** to form the cyclopropane derivatives **103**, **104**, eq. 77[122]. We think



102 103 104 eq. 77

it is worthwhile to investigate the addition reaction of dimethylsulfoxonium methylide to quinone **17** or the ketal protected form **105**. As shown in Scheme 8, the resulting cyclopropane derivatives of **17** might be converted to the

corresponding [e]-fused cyclopropane derivatives of DMDHP **21**. Abstracting[123] one of the methylene hydrogens on the cyclopropane ring may generate the



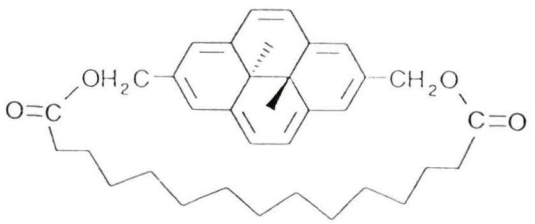
Scheme 8

carbon cation, **106**, in which the three membered ring is aromatic (4n+2=2, n=0). The NMR study of **106** may offer us a measure of the aromaticity of the cyclopropane cation versus that of benzene by comparing the internal methyl protons' chemical shifts of **106** and **28**.

3.3. The reaction of dialcohol 59 and diacid halides with different lengths of alkyl chain

The success of the coupling reaction of the dialcohol **60** with adipoyl chloride and the special NMR properties of the macrocyclophane **66** encourage us to think that reducing the length of alkyl chain of the diacid halide used in the coupling reaction may change the conformation of the DMDHP unit in the resultant macrocyclophane. Thus the transannular π-electron interaction and the interaction of the two internal methyl groups inside the macrocyclophane cavity versus the change in the length of the two bridge chains will be a very interesting project.

On the other hand, increasing the length of the alkyl chain of the diacid halide used in the coupling reaction, may offer us a route to the basket-shaped macrocyclic molecules with one DMDHP unit connected by a long alkyl chain at both sides, **107**. The NMR study of the chemical shift of the methylene protons on the chain may give us some information about how the strength of the induced magnetic field varies across the face of the molecule.



107

CHAPTER FOUR

CONCLUSION

A new synthesis of trans-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone **17** has been achieved through the oxidition of DMDHP **21** by both NBS and PDC. Although the synthetic sequence to quinone **17** has been shortened by only 4 steps from the original 16 steps to now 12 steps, the over-all yield of quinone **17** has been increased from 1.6% to 19%. By the new sequence, quinone **17** can be obtained in a suitable amount so that a study of its reactions can be performed.

Although our original attempt to develop an efficient and convienient synthetic route leading to various [e]-fused DMDHPs by empolying the quinone **17** as a dienophile in Diels-Alder reaction ended up without success, the synthetic value of quinone **17** has been demonstrated by studies of its other reactions.

The success of the condensation reaction of quinone **17** and malononitrile has lead to the synthesis of the TCNQ analogue, **34**, which has some potential as an organic conductor. The initial electronic spectrum study has shown the formation of charge transfer complex of **34** and N,N-diethylamine. The further study on the electrochemistry of **34** is being carried out in Professor Fry's group and the result will be reported in the future.

The study on the bromination reaction of quinone **17** and the reduction and dehydrogenation of two of the bromination products has offered us two

pure regio isomers of dibromo substituted DMDHP, **94** and **96**. From these two isomers a regio-selective synthesis of dibenzannelated [*a,h*]- and [*a,i*]-10b,10c-dimethyl-10b,10c-dihydropyrene, **95** and **97** will be a very promising project for future work in the group.

The re-study of the addition reaction of dimethylsulfonium methylide to the oxygen-carbon double bond of quinone **17** lead to the finding of the third product of this reaction, the diol **58**. Thus **21** can be bifunctionalized at the 2 and the 7 positions with carbon functional groups (formyl group or hydroxymethyl group). The first macrocyclophane with a DMDHP unit has been synthesised by the coupling reaction of diol **58** and adipoyl chloride. Its dynamic NMR study (τ_1 and τ_2 experiments) is currently being carried out by us and the results will be reported in the near future.

CHAPTER FIVE

EXPERIMENTAL

5.1 Instrumentation

Melting points were determined on a Reichert 7905 melting point apparatus, integrated to a chrome-alumel thermocouple. Infrared spectra, major peaks only, calibrated with polystyrene, were recorded on a Bruker IFS25 FT-IR or on a Perkin-Elmer 283 spectrometer as KBr discs (unless otherwise stated). Ultraviolet-visible spectra were recorded on a Cary 5 or a Perkin-Elmer Lambda-4B spectrometer in dichloromethane (unless otherwise specified). Proton NMR spectra were recorded either at 90 MHz on a Perkin-Elmer R-32 using $CDCl_3$ (unless otherwise specified) as solvent and either TMS or the $CHCl_3$ peak at 7.24 ppm as internal standard (unless otherwise specified), or at 250 MHz on a Bruker WM 250 or at 360 MHz on a Bruker AMX 360 using $CDCl_3$ as solvent (unless otherwise specified) and the solvent deuterium signal for calibration. Carbon NMR spectra were recorded in $CDCl_3$ (unless otherwise specified) on a Bruker WM 250 spectrometer at 62.9 MHz or on a Bruker AMX 360 spectrometer at 90.6 MHz using the solvent peak for calibration. Mass spectra were recorded on a Finigan 3300 gas chromatography-mass spectrometer using methane gas for chemical ionization (CI) or electron impact (EI) at 70 eV. Exact mass measurements used a Perkin-Hitachi RMU-6E or a Kratos Concept-H instrument with perfluorokerosene as calibrant. Elemental analyses were carried out by

Canadian Microanalytical Services Ltd, Vancouver, B.C.. The reactions requiring anhydrous conditions were carried out under an atmosphere of argon and in oven dried glassware. The solvents were distilled over sodium-benzophenone (benzene, diethyl ether and tetrahydrofuran), over calcium hydride (dichloromethane, carbon tetrachloride, pyridine, dimethylsulfoxide under reduced pressure and dimethylformamide under reduced pressure) or over P_2O_5 (chloroform). All evaporation were carried out under reduced pressure on a rotary evaporator. Silica gel and alumina used for flash column chromatography were E. Merck, Silica Gel 60, 70-230 mesh and Aldrich, Aluminum oxide, activated, neutral, Brockmann I, ~150 mesh respectively.

5.2 Experimental procedures

2-Methyl-*iso*-phthalic Acid, 42

The dinitrile **41**[78] (14 g, 0.1 mol) was added to a solution of NaOH (16 g, 0.4 mol) in H_2O (80 mL) and refluxed for 24 hours. After cooling to 0°C, HCl (20%) was added to the stirred mixture till the pH was about 1. The white precipitate was filtered and washed well with water. After vacuum drying, 18 g (100% yield) of diacid **42** was obtained as a white powder, **mp** 240-242°C (mp 228-229°C[124]). **^{1}H NMR** (250MHz) δ 7.53 (d, 2H), 6.98 (t, 1H), and 2.30 (s, 3H). **IR**: 3300-2800 (s, broad), 1690 (s), 1580 (w), 1473 (w), 1304 (w), 1256 (m), 1085 (w), 952 (w), 910 (w).

Diethyl 2-methyl-*iso*-phthalate[124], 43

A mixture of diacid **42** (18 g, 0.1 mol), ethanol (80 mL) and H_2SO_4 (10 mL) in benzene (250 mL) was refluxed with a Dean-Stark water separator for 24 hours. After cooling to room temperature, the mixture was poured into ice water and extracted with diethyl ether. The organic layers was combined and washed well with aq. $NaHCO_3$ and water and then dried over $MgSO_4$. After evaporating the solvent, 23 g (98% yield) of diester **43** was obtained as a colourless oil. **^{1}H NMR** (250MHz) δ 7.78 (d, 2H), 7.25 (t, 1H), 4.30 (q, 4H), 2.63

(s, 3H), 1.30 (t, 6H). **IR** (neat): 2973 (m), 1731 (s), 1454 (m), 1371 (w), 1304 (m), 1218 (s), 1114 (w), 1053 (s), 914 (w), 751 (m).

2,6-Bis(hydroxymethyl)toluene, 44

A solution of diester **43** (23.6 g, 0.1 mol) in dry THF (100 mL) was added dropwise to a solution of $LiAlH_4$ (10 g, 0.25 mol) in dry THF (200 mL). The addition speed was controled to maintain a gentle reflux. After addition, the mixture was refluxed for 5 hours and then cooled to 0°C. The work-up used the following procedure[125]. Thus at 0°C and with good stirring, H_2O (10 mL) followed by 15% aq. NaOH (10 mL) and H_2O (30 mL) was added dropwise to the reaction mixture above. The granular precipitate was filtered and washed well with hot THF. The total THF solution was combined and dried over $MgSO_4$. After evaporating the solvent, 14.6 g (98% yield) of dialcohol **44** was obtained as a white solid which is essentially pure. Recrystallization from water gave white needles, **mp** 121-123°C (mp 123-124°C[124]).

Conversions from compound **44** to DMDHP **21** followed the procedures reported[78].

trans-10b,10c-Dimethyl-10b,10c-dihydropyrene-2,7-quinone, 17

a. Oxidation with NBS

NBS (356 mg, 2.0 mmol) in DMF (20 mL) was added dropwise to a stirred solution of DMDHP **21** (116 mg, 0.50 mmol) in DMF (20 mL, containing 0.5% water) at 0°C. After stirring over night at 0°C, the mixture was poured into ice water and extracted with dichloromethane. The organic layers were combined, washed thoroughly with water and dried over anhydrous $MgSO_4$. The solvent was evaporated under reduced pressure. The residue was dissolved in dichloromethane, chromatographed on silica gel using dichloromethane and diethyl ether (7:3) as eluent to give the quinone **17** as (a yellow solid, 62 mg, (46%). A sample was recrystallized from benzene as yellow crystals, **mp** 267-269°C (mp 252°C decompose[65]); **^{1}H NMR** (360MHz) δ 6.30 (s, 4H, H4,5,9,10), 6.07 (s, 4H, H1,3,6,8), 1.87 (s, 6H, H of internal methyl). The **^{1}H NMR** was consistent with that reported[65]. **^{13}C NMR** (360MHz) δ 186.2, 157.1, 131.6, 128.4, 47.4, 28.5. **MS** (CI), *m/z* (%): 303 (5.2, M+41), 291 (15.2, M+29), 263 (100.0, MH^+), 262 (4.1, $M^{+\cdot}$). **IR**: 3049 (w), 2973 (w), 1640 (s), 1605 (s), 1555 (m), 1442 (m) 1367 (s), 1291 (s) 1191 (w), 965 (w), 930 (s), 915 (s), 905 (m). **UV** λ_{max} nm (ε_{max}): 273 (57,900), 317 (20,400, shoulder), 333 (24,600), 348 (17,800, shoulder), 399 (9000).

b. Oxidation with PDC

DMDHP (531 mg, 2.3 mmol) in dry DMF (40 mL) was added slowly through a Hershburg dropping funnel to a solution of PDC (4.30 g, 11.4 mmol) in dry DMF (50 mL) at -5°C. The addition took about five hours and the reaction mixture was left stirring in a cold room (0°C) for another three hours. After addition of dichloromethane (200 mL), the reaction mixture was poured into ice water and stirred for 30 minutes. The resultant dark brown precipitate was filtered and washed well with acetone and dichloromethane. The filtrate was separated and the aqueous layer was extracted with dichloromethane. The organic layers were combined, washed with water, dried over anhydrous $MgSO_4$ and concentrated under reduced pressure. The solid residue was dissolved in dichloromethane and chromatographed on silica gel using dichloromethane and diethyl ether (7:3) as eluent to give 455 mg crude product. Recrystallisation from dichloromethane-hexane gave 405 mg (67%) yellow needles , **mp** 267-269°C and identical NMR spectrum to that above.

α,α,α',α'-Tetracyano-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinodimethane, 34

$TiCl_4$ (0.2 mL, 2 mmol) was added dropwise to a well stirred solution of quinone **17** (131 mg, 0.5 mmol) in dry $CHCl_3$ (20 mL) at 0°C. The resultant brown suspension was stirred for 10 minutes without further cooling. A

solution of malononitrile (0.6 mL, 5 mmol) and pyridine (0.8 mL, 10 mmol) in dry $CHCl_3$ (5 mL) was added. After 12 hrs of reflux, the reaction mixture was cooled to room temperature. The reddish precipitate was filtered, washed well with water and dried under vacuum. This gave 103 mg (68%) of crude **34**. The purification of **34** was carried out by Soxhlet extraction using dichloromethane as solvent followed by fractional recrystallization from dichloromethane. The purified **34** was metallic purple crystals, mp > 350°C (dec.). **^{1}H NMR** (360 MHz, CD_2Cl_2) δ 6.84 (s, 4H, H4,5,9,10), 6.56 (s, 4H, H1,3,6,8), 1.40 (s, 6H, H of internal methyl). **^{13}C NMR** (not available due to the poor solubility of **34**). **MS** (CI), *m/z* (%): 359 (100, MH^+), 243 (10.2), 241 (41.9), 85 (19.4), 67 (23.8). **IR**: 3052 (w), 2215 (v), 1626 (v), 1509 (v), 1400 (m), 1350 (m), 981 (m), 915 (s). **UV** λ_{max} nm (ε_{max}):289 (43,800, shoulder), 296 (47,700), 443 (35,300, shoulder), 460 (41,000), 485 (32,900, shoulder), Fig. 3, page 52.

HRMS calculated for $C_{24}H_{14}N_4$: 358.1218, Found: 358.1236

Anal.	Calculated for $C_{24}H_{14}N_4$:	C 80.43,	H 3.94
	Found:	C 79.51	H 3.96

Complexation of 34 with N,N-diethyl amine

34 (3.5 mg, 0.01 mmol) was dissolved in dry CH_2Cl_2(30 mL) and freshly distilled diethylamine (0.7 mg, 0.01 mmol) was added. The mixture was

stirred under N_2 for 8 hours. The colour of the solution changed from orange to dark green. An effort to isolate the complex by evaporation the solvent caused decomposation of the complex(disappearence of the dark green colour). The electronic spectrum of the dark green solution is shown in Fig. 4 on page 54, λ_{max} nm (ε_{max}): 350 (44,500), 370 (40,700, shoulder), 407 (38,900), 475 (14,800, shoulder), 770 (48,400). The absorption at 770 nm indicates formation of the complex.

2,7-Diformyl-*trans*-10b,10c-Dimethyl-10b,10c-dihydropyrene 58 and 2-Formyl-7-hydroxymethyl-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, 59 and 2,7-bis(hydroxymethyl)-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, 60

NaH (52% dispersion in mineral oil) (1.0 g, 20 mmol) was washed with dry hexane (5 mL) three times. Dry DMSO (20 mL) was added under N_2 and the mixture was heated at 60°C in a water bath for 45 minutes (until no more H_2 was evolved). The clear grey coloured solution was cooled to room temperature, diluted with dry THF (50 mL) and cooled to -20°C. A solution of trimethylsulfonium iodide (4.08 g, 20 mmol) in dry DMF (40 mL) was added to the solution above. After addition the mixture was stirred at -20°C for 15 minutes and then cooled to -78°C. Under N_2 and with good stirring a solution of quinone **17** (0.524 g, 2.0 mmol) in dry THF (20 mL) was added dropwise to

the mixture above. After the addition the reaction was kept at -78°C for 30 minutes then the cooling bath was removed. The resultant dark purple mixture was slowly warmed to 0°C and poured into a mixture of ice water and dichloromethane. The aqueous layer was separated and extracted with dichloromethane. The organic layers was combined and washed well with water, dried over $MgSO_4$ and concentrated under reduced pressure. The residue was dissolved in dichloromethane and chromatographed on silica gel (5 % water deactivated) using dichloromethane then dichloromethane-diethyl ether (8:2) as eluent. The first purple band gave 34 mg (12%) of dialdehyde **58** as dark purple crystals, **mp** 187-189°C (mp 187-190°C[57]) and **^{1}H NMR** (360 MHz,) δ 10.59 (s, 2H, -CHO), 8.96 (s, 4H, H-1, 3, 6, 8), 8.77 (s, 4H, H-4, 5, 9, 10), -3.61 (s, 6H, H of internal methyl) which was consistent with that reported.[57] **^{13}C NMR** (360MHz) δ 193.26, 139.57, 131.53, 128.92, 125.17, 32.58, 15.95. The second deep purple band gave 322 mg (47%) of **59** as black purple crystals, **mp** 199-201°C (mp 198-200°C[57]). **^{1}H NMR** (360 MHz) δ 10.54 (s, 1H, -CHO), 8.98 (s, 4H, H4, 5, 9,10), 8.78(d, J= 8 Hz, 2H, H1, 3), 8.53 (t, J= 5 Hz, 3 Hz, 2H, H6, 8), 5.35 (d, J= 6 Hz, 2H, -C**H**$_2$OH), 2.21 (t, J= 6 Hz, 1H, -OH), -3.81 (s, 3H, internal -CH_3), -3.82(s, 3H, internal -CH_3). **^{13}C NMR** (360MHz) δ 193.48, 141.54, 139.89, 135.35, 129.26, 128.82, 125.18, 124.03, 122.36, 66.46, 31.72, 31.39, 15.95, 14.61. The green band was then eluted with dichloromethane-diethyl ether (8:2) gave 81 mg (14%) of green crystals of 2,7-bis(hydroxymethyl)-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene **60** (see

below).

2,7-Bis(hydroxymethyl)-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, 60

A mixture of the dialdehyde **58** (288 mg, 1.0 mmol) and $NaBH_4$ (40 mg, 1 mmol) in THF (30 mL) was stirred at room temperature overnight. Dichloromethane (100 mL) was added and the green mixture was poured into ice water. The aqueous layer was separated and extracted with dichloromethane. The organic layers were combined and washed well with water, dried over $MgSO_4$ and concentrated under reduced pressure. The residue was dissolved in dichloromethane and chromatographed on silica gel (10% water deactivated) using degassed dichloromethane-diethyl ether (8:2) as eluent. The green band gave 287 mg (99%) of the dialcohol **60**. A sample was recrystallised from methanol-hexane as green needles, mp 192-193°C. **^{1}H NMR** (360 MHz, $(CD_3)_2CO$) δ 8.59 (s, 4H, H4, 5, 9, 10), 8.56 (s,4H, H1, 3, 6, 8), 5.20 (d, J=5.8 Hz, 4H, -CH_2-), 4.67 (t,, J=5.7 Hz, 2H, -OH), -4.11 (s, 6H, H of internal methyl). **^{13}C NMR** (360 MHz, $(CD_3)_2CO$) δ 138.1, 137.4, 123.9, 122.7, 66.2, 31.0, 14.7. **IR**: 3280 (b, v), 3020 (m), 2926 (m), 1617 (m), 1325 (m), 1015 (s), 873 (s). **MS** (CI), *m/z* (%): 294 (3.5), 293 (32.7, MH^+), 292 (44.5), 276 (18.0), 275 (100), 247 (3.7). **UV** λ_{max} nm (ε_{max}): 343 (78,800), 361 (36,600, shoulder), 381 (31,200), 457 (6,300), 480 (8,600).

Anal. Calculated for $C_{20}H_{20}O_2$: C 82.15, H 6.90

Found: C 81.47, H 6.80

The $NaBH_4$ reduction of 2-formyl-7-hydroxymethyl-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene **59** under the same conditions above also give the dialcohol **60** in quantitative yield.

2,7-Bis(acetoxymethyl)-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, 64

Dry pyridine (0.08 mL, 0.63 mmol) was added to a solution of dialcohol **60** (73 mg, 0.25 mmol) in dry CH_2Cl_2 (40 mL) and was stirred for 15 minutes. Then a solution of acetyl chloride (0.05 mL, 0.55 mmol) in dry (5 mL) CH_2Cl_2 was added dropwise under N_2. The reaction mixture was stirred for a further two hours and then was poured into ice water, washed well with water and was dried over $MgSO_4$. The solvent was evaporated under reduced pressure at room temperature. The green solid residue was dissolved in methylene chloride and chromatographed quickly on silica gel (10% water deactivated) using dichloromethane as eluent. The green band gave 83 mg (88%) of bisacetate **64** as green crystals. A sample recrystallised from benzene and hexane gave green needles, **mp** 149-151°C. **^{1}H NMR** (250 MHz, $(CD_3)_2CO$) δ 8.58 (s, 4H, H4, 5, 9, 10), 8.52 (s, 4H, H1, 3, 6, 8), 5.75 (s, 4H, -CH_2-O-), 2.22 (s, 6H, -CO-CH_3), -4.09 (s, 6H, H of internal methyl). **^{13}C NMR** (250 MHz,

$(CD_3)_2CO$) δ 170.1, 136.7, 131.3, 124.0, 123.2, 67.0, 27.9, 20.0, 13.8. **IR**: 3017 (w), 2987 (w), 2916 (w), 1724 (s), 1373 (m), 1247 (s), 1021 (m) 900 (m), 680 (m). **MS** (CI), m/z (%): 405 (8, M+29), 377 (20, MH^+), 318 (100), 302 (10).

The macrocyclophane 66

Dry pyridine (0.2 mL, 2.5 mmol) was added to a solution of dialcohol **60** (292 mg, 1 mmol) in dry CH_2Cl_2 (400 mL). The mixture was stirred for 15 minutes. A solution of adipoyl chloride (0.15 mL, 1 mmol) in dry CH_2Cl_2 (100 mL) was added fast in one portion to the mixture above under N_2 protection and with vigorous stirring. After the addition the reaction mixture was stirred for another 3 hours before being concentrated under reduced pressure to about 5 mL. The resultant dark green solution was loaded on to an alumina column (5% water deactivated) and eluted with CH_2Cl_2. The green band was collected and concentrated under reduced pressure to give 78 mg (9.7%) of the macrocyclophane **66**. Recrystallization from benzene gave dark green crystals, **mp** 210-212°C, **^{1}H NMR** (360 MHz, CD_2Cl_2) δ 8.42 (s, 8H, H-4, 5, 9, 10 of two DMDHP units), 8.39 (s, 8H, H-1, 3, 6, 8 of two DMDHP units), 5.72 (s, 8H, -**CH_2**-O-), 2.47-2.42 (m, 8H, -CO-**CH_2**-), 1.78-1.74 (m, 8H, -CO-CH_2-**CH_2**-), -4.31 (s, 12H, H of internal methyl of two DMDHP units). **^{13}C NMR** (360 MHz, CD_2Cl_2) δ 173.4, 137.0, 131.3, 124.4, 123.3, 67.7, 34.4, 30.2, 24.8, 14.4. **IR**: 3042 (w), 2958 (m), 1747(s), 1722 (s), 1630 (w), 1538 (w), 1437(m), 1379 (m),

1337 (m), 1212 (s), 1145 (s) 950 (m), 880 (s), 680 (m). **UV** λ_{max} nm (ε_{max}): 340 (155,000), 361 (38,600, shoulder), 384 (63,700), 457 (14,300), 480 (19,100). **HRMS** calculated for $C_{52}H_{52}O_8$: 804.3662, found: 804.3654.

Attempted Diels-Alder reaction of quinone 17 and isobenzofuran generated from 68

A mixture of quinone **17** (131 mg, 0.5 mmmol) and alcohol **68**[108] (90 mg, 0.5 mmol) in glacial acetic acid (10 mL) was stirred at 100°C under N_2 for 10 hours. The solution was cooled and poured into ice water. The brown solid was filtered, washed well with water and dried under vacuum. The TLC of the chloroform solution of the solid showed a long fluorescent tail, no product could be recognized.

The procedure above was repeated at different temperatures, but no D-A adduct could be recognized.

Attempted Diels-Alder reaction of quinone 17 and *o*-xylylene 72

a). α,α,α',α'-Tetra-bromo-*o*-xylylene **74** as the precursor

A mixture of quinone **17** (65 mg, 0.25 mmol) and sodium iodide (0.23 g, 1.5 mmol) in dry DMF (15 mL) was heated to 60-70°C. A solution of α,α,α',α'-

tetrabromo-*o*-xylene **74** (107 mg, 0.25 mmol) in dry DMF (10 mL) was added slowly to the mixture above. After the addition, the mixture was left at 60-70°C for 24 hours and then was cooled to room temperature. Before pouring into ice water-dichloromethane mixture, aq. sodium bisulphite was added. The aqueous layer was separated and extracted with dichloromethane. The organic layers were combined, washed with water, dried on $MgSO_4$ and concentrated. The residue was dissolved in dichloromethane and chromatographed on silica gel using dichloromethane as eluent to give 58 mg yellow solid which was identified as starting quinone **17**.

b). Ultrasound-promoted reaction of Zn with α,α'-dibromo-o-xylene **75**

To a round-bottom flask, quinone **17** (65 mg, 0.25 mmol), activated Zn powder (45 mg, 0.75 mmol), **75** (65 mg, 0.25 mmol) and freshly distilled dioxane (10 mL) were charged under N_2 protection. The flask was submerged in the water bath (25°C) of the ultrasound cleaner (Branson 1200). The power of the ultrasound cleaner was turned on and the flask was left in the water bath for 12 hours. The reaction mixture changed its colour from grey to green-grey. The solid was removed by filtration and the colour of the clear soultion changed to yellow immediately. After treating the soultion with aq. NH_4Cl and extracting with dichloromethane followed by evaporation of the solvent, 51 mg of yellow solid was obtained. TLC showed that this was only one compound, which was identified as quinone **17**.

c). Benz-fused δ-sultine **76** as the precursor

A mixture of quinone **17** (131 mg, 0.5 mmol) and δ-sultine **76**[113] (85 mg, 0.5 mmol) in dry THF (20 mL) was refluxed under N_2 for 12 hours. The solution was cooled and poured into ice water. The yellow solid was filtered and chromatographed on silica gel with dichloromethane and diethyl ether (3:1) and gave 114 mg yellow solid which was identified as the starting material, quinone **17**. No D-A adduct can be recognized from the crude product.

d). Lewis acid catalyzed Diels-Alder reaction of quinone **17**

$AlCl_3$ (70 mg, 0.52 mmol) was added to a solution of quinone **17** (131 mg, 0.5 mmol) in dry THF (20 mL) held at -78°C. After addition the mixture was warmed to room temperature and a solution of δ-sultin **76**[113] (85 mg, 0.5 mmol) in dry THF (10 mL) was added. The mixture was heated to reflux for 6 hours and then cooled to room temperature and poured into ice water. The aq. solution was extracted with dichloromethane. The organic layers were combined and dried over $MgSO_4$. After evaporating the solvent, the residue was dissolved in dichloromethane and chromatographed under the same conditions as above. The yellow band gave 109 mg yellow solid which was identified as quinone **17** (83% recovered).

1-Bromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, 81 and 4-bromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, 77

Bromine (0.031 mL, 0.60 mmol) in dry dichloromethane (10 mL) was added to a solution of quinone **17** (156 mg, 0.6 mmol) in dry dichloromethane (10 mL). The mixture was stirred at room temperature overnight then washed with aq. Na_2SO_3, saturated aq. $NaHCO_3$ and water and dried over anhydrous $MgSO_4$. After removal of solvent, the orange residue was chromatographed on silica gel using dichloromethane and diethyl ether (19:1) as eluent. The first two yellow bands were small in amount and identified later as two dibromo isomers **82** and **83**. The third yellow band gave 64 mg (31%) of yellow crystals. Recrystallisation from benzene gave yellow crystals of 1-bromoquinone **81**, mp 266.5-268°C; **^{1}H NMR** (360 MHz) δ 6.78 (dd, J=9.8, 0.7 Hz, 1H, H10), 6.40 (dd, J=9.8, 0.7 Hz, 1H, H9), 6.32 (d, J=9.7 Hz, 1H, H5), 6.28 (d, J=9.7 Hz, 1H, H4), 6.18 (s, 1H, H3), 6.13-6.12 (m, 1H, H8), 6.07 (d, J=1.8 Hz, 1H, H6), 1.93 (s, 3H, H of internal methyl), 1.91 (s, 3H, H of internal methyl). These assignments were confirmed by a COSY spectrum, coupling between H4/H5, H9/H10 and long range coupling between H3/H4, H3/H5, H5/H6, H6/H8, H8/H9 and H8/H10 and also by a NOESY spectrum, strong interaction between H4/H5, H9/H10 and H6/H8, weak interaction between H3/H4. H3/H5, H5/H6 and H9/H8. **^{13}C NMR** (360MHz) δ 185.8, 178.8, 156.8, 156.5, 156.4, 153.8, 133.3, 132.2, 131.2, 131.1, 129.2, 128.8, 126.7, 126.6, 50.8, 47.6, 28.9, 28.7. **IR** (KBr disc, main bands): 3027 (w), 2979 (w), 1640 (v), 1620 (s), 1372 (m), 1279 (m), 1237 (m), 952 (s). **MS** (CI), *m/z* (%): 371 (10.1), 369 (9.5), 344 (17.3), 343 (96.0, MH+2), 342 (21.1), 341 (100, MH^+). **UV** λ_{max} nm (ε_{max}): 283 (27,200), 322

(9,100, shoulder), 340 (10,400), 353 (8,100, shoulder).

Anal. Calculated for $C_{18}H_{13}O_2Br$: C 63.36, H 3.84

Found: C 62.96, H 3.90

The fourth yellow band gave 12.4 mg (6%) of yellow crystals. Recrystallization from benzene gave yellow crystals of 4-bromoquinone **77**, **mp** 222-224°C. **^{1}H NMR** (360 MHz) δ 6.78-6.77 (m, 1H, H5), 6.58 (dd, J=0.5, 1.7 Hz, 1H, H3), 6.35 (s, 2H, H9,10), 6.13 (d, J=1.7 Hz, 1H, H1), 6.11 (d, J=1.7 Hz, 1H, H8), 6.08 (dd, J=0.8, 1.7 Hz, 1H, H6), 1.86 (s, 3H, H of internal methyl), 1.84 (s, 3H, H of internal methyl). These assignments were confirmed by a COSY spectrum, long range coupling between H3/H5, H5/H6, H6/H8, and H3/H1, and a NOESY spectrum, weak interaction between H1/H3, H5/H6, H6/H8, H9/H8 and H10/H1. **^{13}C NMR** (360MHz) δ 185.8, 185.7, 156.9, 156.3, 156.1, 154.6,134.5, 131.7, 131.6, 130.8, 128.8, 128.6, 128.2, 126.2, 48.9, 46.9, 28.5, 28.3. **IR**: 3025 (w), 2937 (w), 2910 (w), 1642 (v), 1620 (s), 1379 (m), 1294 (m), 1279 (m), 940 (m). **MS** (CI), *m/z* (%): 383 (4.4), 381 (4.8), 371 (13.7), 370 (2.9), 369 (13.4), 345 (5.3), 344 (18.5), 343 (100, MH+2), 342 (22.1), 341 (98.1, MH^+), 340 (3.2), 297 (1.5), 83 (1.7), 79 (1.5). **UV** λ_{max} nm (ε_{max}): 276 (22,700), 284 (22,700), 319 (7,800. shoulder), 337 (10,300), 351 (7,800, shoulder).

Anal. Calculated for $C_{18}H_{13}O_2Br$: C 63.36, H 3.84

Found: C 63.15, H 4.02

The fifth yellow band gave 78 mg of yellow crystals of the starting quinone **17**.

1,8-Dibromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, 82 and 1,6-dibromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene-2,7-quinone, 83

Bromine (0.11 mL, 2.1 mmol) in dry chloroform (10 mL) was added slowly to a solution of quinone **17** (262 mg, 1.00 mmol) in dry chloroform (30 mL) at reflux. The mixture was then refluxed overnight and then was cooled to room temperature. The resultant dark orange solution was washed with aq. Na_2SO_3, saturated aq. $NaHCO_3$ and water and dried over $MgSO_4$. The solvent was evaporated and the residue was dissolved in dichloromethane, chromatographed on silica gel using dichloromethane as eluent. The first two orange bands were very light in colour and small in amount and were identified as tetrabromoquinone **85** and a mixture of several isomers of tribromoquinones **84** respectively by their **^{1}H NMR** and **MS** spectrums. The third orange band gave 112 mg (27%) of orange solid. Recrystallisation from benzene gave orange crystals of 1,6-dibromoquinone **83**, **mp** decomposed at 290°C. **^{1}H NMR** (360 MHz) δ 6.82 (dd, J=9.84, 0.69 Hz, 2H, H5, 10), 6.39 (dd, J=9.85, 0.77 Hz, 2H, H4, 9), 6.23-6.22 (m, 2H, H3, 8), 1.98 (s, 6H, H of internal methyl). These assignments were confirmed by a COSY spectrum, coupling between H4/H5 and long range coupling between H3/H4 and H3/H5, and by a NOESY spectrum, strong interaction between H4/H5 and weak interaction

between H3/H4 and H3/H5. **^{13}C NMR** (360 MHz) δ 178.6, 156.2, 132.8, 131.8, 127.4, 127.1, 51.0, 29.1. **IR**: 3021 (w), 2979 (w), 1638 (v), 1580 (m), 1546 (m), 1287 (m), 1240 (m), 961 (s). **MS** (CI), m/z (%): 449 (9.6), 424 (7.7), 423 (54.6, MH+4), 422 (25.4), 421 (100, MH+2), 420 (15.1), 419 (52.8, MH^+), 343 (4.4), 341 (4.3), 151 (3.5). **UV** λ_{max} nm (ε_{max}): 288 (23,900), 306 (19,000), 333 (7,500, shoulder), 345 (8,900), 363 (6,700, shoulder).

Anal. Calculated for $C_{18}H_{12}O_2Br_2$: C 51.46, H 2.88

Found: C 51.37, H 2.90

The fourth band gave 104 mg (25%) of orange solid. Recrystallisation from benzene gave orange crystals of 1,8-dibromoquinone **82**, decomposed at 252°C (without melting). **^{1}H NMR** (360 MHz) δ 6.91 (s, 2H, H9, 10), 6.31 (s, 2H, H4, 5), 6.18 (s, 2H, H3, 6), 1.99 (s, 6H, H of internal methyl). **^{13}C NMR** (360 MHz) δ 178.6, 156.3, 153.1, 132.8, 131.7, 127.5, 127.1, 51.0, 29.2. **IR** (KBr disc, main bands): 3025 (w), 2981 (w), 2916 (w), 1638 (v), 1580 (m), 1546 (m), 1250 (m), 977 (s). **MS** (CI), *m/z* (%): 449 (9.1), 424 (8.9), 423 (52.80, MH^++2) 422 (22.1), 421 (100, MH^+), 420 (13.8, M^+), 419 (49.6), 343 (11.9), 341 (9.4), 312 (2.7), 310 (11.4), 308(4.2), 248 (3.1), 246 (4.00, 230 (2.6), 227 (1.6), 177 (2.0), 512 (9.0), 83 (19.2), 79 (34.4). **UV** λ_{max} nm (ε_{max}): 291 (21,300), 302 (20,000), 330 (6,900, shoulder), 345 (8,300), 363 (6,100, shoulder).

Anal. Calculated for $C_{18}H_{12}O_2Br_2$: C 51.68, H 2.89

Found: C 52.10, H 3.19

The fifth band gave 55 mg (16%) of yellow solid which was identified as 1-

bromoquinone **81**. The sixth band gave 17 mg (5%) of yellow solid which was identified as 4-bromoquinone **77**. The last band gave 68 mg of yellow solid which was identified as the starting quinone **17**.

1,8-Dibromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene 94

$LiAlH_4$ (760 mg, 20 mmol) and dry diethyl ether (100 mL) was refluxed for 30 minutes. The suspension was cooled to -20°C. $AlCl_3$ (3.0 g, 20 mmol) was added in small portions under N_2. After the addition, the cooling bath was removed. The mixture was stirred at room temperature for 30 minutes before being cooled to -80°C. 1,8-Dibromoquinone **82** (84 mg, 0.2 mmol) in dry benzene (20 mL) was added dropwise to the mixture above. After the addition the reaction mixture was stirred at -80°C for 2 hours then slowly warmed to 0°C before adding ethyl acetate and ice. The aqueous layer was separated and extracted with ethyl acetate. The organic layers were combined, washed well with water, dried over $MgSO_4$ and concentrated under reduced pressure. The proton NMR spectrum of the resultant light green solid indicates that it was a mixture of 1,8-dibromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene **94** and 1,8-dibromo-*trans*-10b,10c-dimethyl-2,7,10b,10c-tetrahydropyrene **98**. This mixture was reacted with DDQ to dehydrogenate the tetrahydropyrene **98** to dihydropyrene **94**: the residue and DDQ (50 mg, 0.2 mmol) in benzene (30 mL) was refluxed over night. The solvent was evaporated and the solid residue was

chromatographed on silica gel column using petroleum ether as eluent. The green band gave 64 mg (83%) of 1,8-dibromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, **94**, as green crystals. Recrystallization from hexane gave green crystals, **mp** 134-136°C. **^{1}H NMR** (360 MHz) δ 8.96 (s, 2H, H9,10), 8.62 (s, 2H, H4,5), 8.41 (d, J= 8Hz, 2H, H2,7), 8.31 (d, J= 8Hz, 2H, H3,6), -4.04(s, 6H, internal methyl). **^{13}C NMR** (360 MHz) δ 136.8, 132.8, 127.9, 124.9, 124.6, 124.2, 123.8, 119.3, 33.9, 14.4. **IR**: 3031 (m), 2968 (m), 1634 (w), 1517 (w), 1442 (m), 1417 (m), 1341 (m),1299 (m), 1191 (m), 1099 (m), 1065 (m). **MS** (CI), *m/z* (%): 393 (16.9, MH+4), 392 (37.2), 391 (38.2, MH+2), 389 (19.8, MH^+), 388 (36.2), 311 (100), 310 (86.8), 230 (20.1). **UV** λ_{max} nm (ε_{max}): 355 (88,800), 386 (34,200), 454 (5,600), 472 (5,700).

1,6-Dibromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, 96

$LiAlH_4$ (760 mg, 20 mmol) and dry diethyl ether (100 mL) were refluxed for 30 minutes. The suspension was cooled to -20°C. $AlCl_3$ (3.0 g, 20 mmol) was added in small portion under N_2 protection. After the addition, the cooling bath was removed. The mixture was stirred at room temperature for 30 minutes before being cooled to -80°C. 1,6-Dibromoquinone **83** (84 mg, 0.2 mmol) in dry benzene was (15 mL) added dropwise to the mixture above. After the addition the reaction mixture was stirred at -80°C for 2 hours then slowly warmed to 0°C before adding ethyl acetate and ice. The aqueous layer was

separated and extracted with ethyl acetate. The organic layers were combined, washed well with water, dried over $MgSO_4$ and concentrated under reduced pressure. The proton NMR spectrum of the resultant light green solid indicates that it was a mixture of 1,6-dibromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene **96** and 1,6-dibromo--*trans*-10b,10c-dimethyl-2,7,10b,10c-tetrahydropyrene **99**. The mixture was reacted with DDQ to dehydrogenate the tetrahydropyrene **99** to dihydropyrene **96**. The residue and DDQ (50 mg, 0.2 mmol) in benzene (30 mL) was refluxed over night. The solvent was evaporated and the solid residue was chromatographed on silica gel column using petroleum ether as eluent. The green band gave 67 mg (86%) of 1,6-dibromo-*trans*-10b,10c-dimethyl-10b,10c-dihydropyrene, **96**, as green crystals. Recrystallization from hexane gave green crystals, **mp** 202-204°C. **^{1}H NMR** (360 MHz) δ 8.92 (d, J=8Hz, 2H, H5,10), 8.66 (d, J= 8Hz, 2H, H4,9), 8.46 (d, J=8Hz, 2H, H2,7), 8.31 (d, J= 8Hz, 2H, H3,8), -4.04(s, 6H, internal methyl). **^{13}C NMR** (360 MHz) δ 136.6, 133.0, 127.9, 125.2, 124.3 (two peaks over lapped), 119.2, 33.8, 14.3. **IR**: 3031 (m), 2960 (m), 1637 (w), 1518 (w), 1440 (m), 1416 (m), 1341 (m),1300 (m), 1191 (m), 1065 (m), 920 (m), 860 (s), 845 (m), 670 (s). **MS** (CI), *m/z* (%): 393 (47.8, MH+4), 392 (51.1), 391 (100, MH+2), 390 (80.5), 389 (47.8, MH^+), 311(85.4), 310 (70.2), 231 (16.7), 230 (7.91). **UV** λ_{max} nm (ε_{max}): 355 (70,700), 386 (27,600), 420 (4,300), 454 (4,300), 472 (4,100).

Anal. Calculated for $C_{18}H_{14}Br_2$: C 55.42, H 3.62

Found: C 55.69, H 3.62

REFERENCES

1. Roberts, J. D.; Caserio, M. C., *Modern Organic Chemistry*, W. A. Benjamin, New York, **1967**, Chap. 25, 618.
2. Dewar, M. J. S; Gleicher, G. J., *J. Chem. Phys.*, **1966**, *44*, 759.
3. Boekelheide, V; Phillips, J. B., *J. Am. Chem. Soc.*, **1963**, *85*, 1545-1546.
4. Lindsay, W. S; Stokes, P; Humber, L. G.; Boekelheide, V, *J. Am. Chem. Soc.*, **1961**, *83*, 943-949.
5. a). Altwicker, E. R., *Chem. Rev.*, **1967**, *67*, 475-527. b). Weinberg, N. L; Weinberg, H. R. *Chem. Rev.*, **1968**, *68*, 449-511.
6. Zimmer, H.; Lankin, D. C.; Horgan, S. W., *Chem. Rev.*, **1971**, *71*, 229-246.
7. Teuber, H. J.; Dietz, K. H., *Angew. Chem.*, **1965**, *4*, 871.
8. Teuber, H. J.; Thaler, G., *Chem. Ber.*, **1959**, *92*, 667.
9. Ronlan, A., unpublished. Quoted in Chem. Commun., **1971**, 1643
10. Chang, W. H., *J. Org. Chem.* **1962**, *27*, 2921-2923.
11. McKillop, A.; Swann, B. P.; Taylor, E. C., *Tetrahedron*, **1970**, *26*, 4031-4039.
12. a). Teuber, H. J.; Hasselbach, M., *Chem. Ber.*, **1959**, *92*, 674. b). Horner,

L.; Sturm, K., *Chem. Ber.*, **1955**, *88*, 329.

13. Underwood, H. W.; Walsh, W. L., *Org. Syn. Col. Vol. II*, **1943**, 553.

14. Fatiadi, A. J., *Chem. Commun.*, **1967**, 1087-1888.

15. Braude, E. A.; Fawcett, J. S., *Org. Syn. Coll. Vol. IV*, **1963**, 698.

16. Newman, M. S., *J. Am. Chem. Soc.*, **1942**, *64*, 2324-2325; Chatterjea, J. N., *J. Indian Chem. Soc.*, **1954**, *31*, 101.

17. Davies, J. S., Davies V. H., *J. Chem. Soc.* (C), **1969**, 1873-1879.

18. Musgrave, O. C., *Chem. Rev.*, **1969**, *69*, 499-529.

19. Zahn, K., Ochwat, P., *Ann. Chem.*, **1928**, *462*, 72.

20. Sarngadharan, M. M., Seshadri, T. R., *Indian J. Chem.*, **1966**, *4*, 503.

21. Mayer, F., *Ber.*, **1912**, *45*, 1105.

22. Ansell, M. F.; Nah, B. W., *J. Chem. Soc.*, **1961**, 3012-3017.

23. Ansell, M. F.; Knights, B. A., *J. Chem. Soc.*, **1961**, 2903-2907.

24. Alder, E.; Magnusson, R., *Acta Chem. Scand.*, **1960**, *14*, 515.

25. Fieser, L. F., Peters, M. A., *J. Am. Chem. Soc.*, **1931**, *53*, 4080-4093; Dean, F. M.; Jones, P. D., *J. Chem. Soc.*, **1963**, 5342-5347.

26. Fieser, L. F.; Hartwell, J. L., *J. Am. Chem. Soc.*, **1935**, *57*, 1479-1482.

27. Morrocchi, S.; Ricca, A.; Zanarotti, A., *Gazz.* **1969**, *99*, 566.

28. Wöhler, F., *Justus Liebigs Ann. Chem.*, **1844**, *51*, 155.

29. Thiele, J.; Meisenheimer, J., *Ber.* **1900**, *33*. 675.

30. Hawthorne, M. F.; Reintjes, M., *J. Am. Chem. Soc.,* **1964**, *86*, 951-952.

31. Suida, H.; Suida, W., *Justus Liebigs Ann. Chem.* **1918**, *416*, 113.

32. Escales, R., *Chem. Ztg.*, **1905**, *29*, 31.

33. Thiele, J., *Ber.*, **1898**, *31*, 1247.

34. Knoevenagel, E.; Bückle, C., *Ber.*, **1901**, *34*, 3993.

35. Posner, T., *Justus Liebigs Ann. Chem.*, **1904**, *336*, 85.

36. Hinsberg, O.; Himmelschein, A., *Ber.*, **1896**, *29*, 2023.

37. Ramirez, F.; Dershowitz, S., *J. Am. Chem. Soc.*, **1959**, *78*, 5614-5617.

38. Venkataraman, K.; Iyer, V. N., *Chemistry of Synthetic Dyes*, Academic, New York, **1971**, Vol. 5, Chapter 3.

39. Roberts, J. D.; Caserio, M. C., *Basic Principles of Organic Chemistry*, 2nd edition, W. A. Benjamin, Inc., **1977**, 1309.

40. Kehrmann, H.; Mussmann, F., *Ber.*, **1915**, *48*, 2021.

41. Smith, L. I.; Irwin, W. B., *J. Am. Chem. Soc.*, **1941**, *63*, 1036-1038.

42. Krüger, C., Rochow, E. G., *Chem. Ber.*, **1963**, *96*, 2132.

43. Nrumann, W. P., Neumann, G., *J. Organometal Chem.*, **1970**, *25*, C59.

44. Lehnert, W., *Synthesis,* **1978**, 165.

45. Dimroth, O., Eber, H., *Justus Liebigs Ann. Ch*em., **1926**, *446*, 132; Savoie, J. Y., Brassard, P., *Can. J. Chem.*, **1966**, *44*, 2867-2872.

46. Fieser, L. F., Campbell, W. P., *J. Am. Chem. Soc.*, **1939**, *61*, 3216-3223.

47. Woodward, R. B., Sondheimer, F., Taub, D., *J. Am. Chem. Soc.*, **1952**, *74*, 4223-4251.

48. Cookson, R. C., Hill, R. R., *J. Chem. Soc.*, **1964**, 3043-3062.

49. Hill, R, K., Newton, M. G., *J. Org. Chem.*, **1980**, *45*, 1593-1596.

50. Schmidt, C., Sabnis, S. D., Schmidt, E., *Can. J. Chem.*, **1971**, *49*, 371-372.

51. Ansell, M. F., Clements, A. H., *J. Chem. Soc.* (C), **1971**, 269-275.

52. Schmidt, C., *J. Org. Chem.*, **1970**, *35*, 1324-1329.

53. Stojanac, Z., Dickinson, R. A., *J. Chem. Soc.*, **1975**, 616.

54. Bohlman, F., Mathar, W., *Chem. Ber.*, **1977**, *110*, 2028.

55. Jacobs, T., Rusch, W., *J. Org. Chem.* **1980**, *45*, 5012-5014.

56. Kraus, G. A., Tashner, M. J., *J. Org. Chem.*, **1980**, *45*, 1174-1175.

57. Mitchell, R. H., Calder, I., Huisman, H., Boekelheide, V., *Tetrahedron*, **1975**, *31*, 1109-1111.

58. Haddon, R. C., *J. Am. Chem. Soc.*, **1979**, *101*, 1722-1728.

59. Aihara, J., *Bull. Chem. Soc. Jpn.*, **1980**, *53*, 1163-1164.

60. Verbruggen, A., *Bull. Soc. Chim. Belg.* **1982**, *91*, 865.

61. Mitchell, R. H., Williams, R. V., Dingle, T. W., *J. Am. Chem. Soc.*, **1982**, *104*, 2560-2571.

62. Mitchell, R. H., Lai, Y. H., Williams, R. V., *J. Org. Chem.*, **1979**, *44*, 4733-4735.

63. Phillips, J. B., Molyneux, R. J., Sturm, E., Boekelheide, V., *J. Am. Chem. Soc.*, **1967**, *89*, 1704-1709.

64. Mitchell, R. H.; Chaudhary, M.; Dingle, T. W.; Williams, R. V., *J. Am. Chem. Soc.*, **1984**, *106*, 7776-7779.

65. Boekelheide, V.; Phillips, J. B., *J. Am. Chem. Soc.*, **1967**, *89*, 1695-1704.

66. a).Weavers, R. T.; Sondhiemer, F., *Angew. Chem. Int. Ed. English*, **1974**, *13*, 141. b). Jones, R. R.; Sondhiemer, F., *Tetrahedron Lett.*, **1975**, *27*, 4683. c).Walsgrove, T. C.; Sondhiemer, F., *Tetrahedron* Lett., **1978**, *30*, 2719-2722.

67. Zyoda, M.; Nakagawa, M.; *Tetrahedron lett.*, **1974**, 817-820. b). Nakagawa, M., *Tetrahedron Lett.* **1974**, 4441-4444. c). Yasahara, A.; Nakagawa, M., *Tetrahedron Lett.* **1975**, 895-898.

68. Mahadevan, R., *Ph.D. thesis*, University of Victoria, **1981**.

69. a). Mitchell, R. H.; Zhou, P., *Tetrahedron Lett.*, **1990**, *30*, 5277-5280. b). Mitchell, R. H.; Zhou, P., *Tetrahedron Lett.*, **1992**, *32*, 6319-6322.

70. a). Mitchell, R. H.; Yan, J. S.; Dingle, T. W., *J. Am. Chem. Soc.*, **1982**, *104*, 2551-2559. b). Mitchell, R. H.; Yan, J. S., *Can. J. Chem.*, **1977**, *55*, 3347-3348.

71. Mitchell, R. H.; Venugopalan, S., unpublished result.

72. Mitchell, R. H.; Iyer, V. S., unpublished result.

73. Cremer, D.; Gunther, H., *Liebigs Ann. Chem.*, **1972**, *763*, 87.

74. Wilson, D. J.; Boekelheide, V., *J. Am. Chem. Soc.*, **1960**, *82*, 6303-6304.

75. Lindsay, W. S.; Boekelheide, V., *J. Am. Chem. Soc.*, **1961**, *83*, 943-949.

76. Hewgill, F. R.; Middleton, B. S., *J. Chem. Soc.*, **1965**, 2914-2918.

77. Mitchell, R. H.; Khalifa, N. A., unpublished result.

78. Mitchell, R. H.; Boekelheide, V., *J. Am. Chem. Soc.*, **1974**, *96*, 1547-1557.

79. Borch, R. F., *J. Org. Chem.*, **1969**, *34,* 627-630.

80. Underwood, H. W.; Walsh, W. L., *Org. Syn. Col. Vol.* II, **1943**, 255.

81. Fatiadi, A. J., *Chem. Commun.*, **1967**, 1087-1090.

82. Pletcher, D.; Stephen, J. D., *J. Chem. Soc. Perkin* II., **1979**, 788-791.

83. Adam, W.; Ganeshpure, P. A., *Synthesis,* **1993**, 280-282.

84. Periasamy, M.; Bhatt, M. V., Synthesis, **1977**, 330-332.

85. Periasamy, M.; Bhatt, M. V., *Tetrahedron Lett.* **1978**, *46*, 4561-4562.

86. Mitchell, R. H., *personal communication.*

87. Filler R., *Chem. Rev.*, **1963**, *63*, 21-40.

88. Finucane, B. W.; Thomson, J. B., *Chem. Commun.*, **1969**, 1220-1222.

89. Wolfe, S.; Pilgrim, W. R., *Can. J. Chem.* **1971**, *49*, 1099-1105.

90. Fieser, M., *Fieser and Fieser's Reagents for Organic Synthesis,* John Wiley & Sons, **1982**, Vol. 9, 399

91. a). Corey, E. J.; Schmidt, G., *Tetrahedron Lett.*, **1979**, 399-402. b). Corey, E. J.; Schmidt, G., *Tetrahedron Lett.*, **1980**, 731-734.

92. Cho, H., *Tetrahedron Lett.*, **1974**, 1491-1494.

93. Moriaty, R. M., *Tetrahedron Lett.*, **1975**, 2557-2560.

94. Acker, D. S.; Hertler, W. R., *J. Am. Chem. Soc.*, **1962**, *84*, 3370-3374.

95. Kini, A. M.; Cowan, D. O.; Gerson, F.; Mockel, R., *J. Am. Chem. Soc.*, **1985**, *107*, 556-562.

96. Diekmann, J.; Hertler, W. R.; Benson, R. E., *J. Org. Chem.*, **1963**, *28*, 2719-2723.

97. Maxfield, M.; Bloch, A. N.; Cowan, D. O., *J. Org. Chem.*, **1985**, *50*, 1789--

1796.

98. Aumuller, A.; Hunig, S., *Liebigs Ann. Chem.*, **1984**, 618.

99. Corey, E. J.; Chaykovsky, M., *J. Am. Chem. Soc.*, **1965**, *87*, 1353-1364.

100. Corey, E. J.; Chaykovsky, M., *J. Am. Chem. Soc.*, **1962**, *84*, 866-868.

101. Iwamura, H.; Kinara, D.; Misumi, S.; Sakata, Y.; Umemoto, T., *Tetrahedron Lett.*, **1975**, 219-222.

102. Mitchell, R. H.; Carruthers, R. J., *Tetrahedron Lett.* **1976**, 2585-2588.

103. Umemoto, T.; Satani, S.; Sakata, Y.; Misumi, S., *Tetrahedron Lett.* **1975**, 3159-3162.

104. Irngartinger, H.; Kirrstetter, R. G. H.; Krieger, C; Rodewald, H.; Staab, H,. A., *Tetrahedron Lett.*, **1977**, 1425-1428.

105. Rodrigo, R., *Tetrahedron Lett.*, **1988**, *44*, 2093-2096.

106. Friedrichsen, W., *Adv. Heterocyclic Chem.*, **1980**, *26*, 135.

107. a). Rynard, C. M.; Thankachan, T., *J. Am. Chem. Soc.*, **1979**, *101*, 1196-1201. b). Naito, K.; Rickborn, F. T., *J. Org. Chem.*, **1980**, *45*, 4061-4062.

108. Smith, J. G.; Dibble, P. W., *J. Org. Chem.*, **1983**, *48*, 5361-5362.

109. a). Fallis, A. G., *Can. J. Chem.*, **1984**, *62*, 183-234. b). Oppolzer, W.; *Synthesis*, **1978**, 793-802. c). Kametami, T.; Nemoto, H., *Tetrahedron*, **1981**, *37*, 3-16.

110. a). Quinkert, G.; Stark, H., *Angew. Chem. Int. Ed. Engl.*, **1983**, *22*, 637. b). Kametani, T., *Pure Appl. Chem.*, **1979**, *51*, 747-768.

111. a). Cava, M. P.; Deana, A.A.; Muth, K., *J. Am. Chem. Soc.*, **1959**, *81*,

6458-6460. b). McOmie, F. W.; Perry, D. H., *Synthesis*, **1973**, 416-420.

c). Wiseman, J. R.; Pendery, J. J.; Otto, C. A.; Chiong, K. G., *J. Org. Chem.*, **1980**, *45*, 516-519. d). Farina, F.; Primo, J.; Torres, T., *Chemistry Letter*, **1980**, 77. e). Broadnurst, M. J.; Hassall, C. H.; Thomas, G. J., *J. Chem. Soc., Chem. Commun.*, **1982**, 158-160. f). Carreno, M. C.; Farina, F.; Ruano, J. L. G.; Puebla, L., *J. Chem. Research* (S), **1984**, 288.

112. Trost, B. M.; Ornstein, P. L., *J. Org. Chem.*, **1982**, *47*, 751-752.

113. Durst. T.; Charlton, J. L.; Mount, D. B., *Can. J. Chem.*, **1986**, *64*, 246-249.

114. Savoie, J. Y.; Brassard, P., *Can. J. Chem.*, **1966**, *44*, 2867-2872.

115. Huisman, H. O., *Rec. Trav. Chim.*, **1950**, *69*, 1133.

116. a). Wheeler, A. S.; Scott, J. W., *J. Am. Chem. Soc.*, **1919**, *41*, 833-841. b). Wheeler, A. S.; Naiman, B., *J. Am. Chem. Soc.*, **1922**, *44*, 2331-2334. c). Thomson, R. H., *J. Org. Chem.*, **1948**, *13*, 337-338.

117. Wilson, C. V., *Org. Synth. Col. Vol. 4*, **1963**, 980.

118. Smith II, A. B.; Branca, S. J.; Pilla, N. N.; Cuaciaro, M. A.; *J. Org. Chem.*, **1982**, ,*47*, 1855-1869.

119. a). Mitchell, R. H.; Dingle, T. W.; West, P. R.; Williams, R. V., *J. Org. Chem.*, **1982**, *47*, 5210-5214. b). Mitchell, R. H.; Weerawarn, *S. A., Tetrahedron Lett.* **1986**, *27*, 453-456.

120. Mitchell, R. H.; Zhou, P., *unpublished result.*

121. Corey, E. J.; Chaykovsky, M., *J. Am. Chem. Soc.*, **1962**, *84*, 3782-3783.

122. Chapleo, C. B., *Helv. Chim. Acta.*, **1973**, *56*, 272.

123. a). Halton, B., *Chem. Rev.*, **1973**, *73*, 113-114. b). Billups, W. E., *Acc. Chem. Res.* **1978**, *11*, 245. c). Billups, W. E.; Rodin, W. A.; Haley, M. M., *Tetrahedron*, **1988**, *44*, 1305-1338.

124. Lindsay, W. S.; Stokes, P.; Humber, L. G.; Boekelheide, V.; *J. Am. Chem. Soc.*, **1961**, *83*, 943-949.

125. Micovic, V. M.; Mihailovic, M. L. J., *J. Org. Chem.*, **1953**, *18*, 1190-1200.

VITAE

Surname: Jin **Given Names:** Xin

Place of Birth: Shanxi, P.R. CHINA **Date of Birth:** Feb. 2, 1963

Educational Institutions Attended:

University of Victoria, Victoria, CANADA	1991 to 1994
Beijing Institute of Technology, Beijing, CHINA	1984 to 1987
East China Institute of Technology, Nanjing, CHINA	1978 to 1982

Degrees Awarded:

M.Sc.	1987	Beijing Institute of Technology, Beijing, CHINA
B.Sc.	1982	East China Institute of Technology, Nanjing, CHINA

Honours and Awards:

Graduate Assistantship	University of Victoria	1991-1994
Academic Scholarship	Beijin Institute of Technology, Beijing	1984-1987

Publications and Presentations:

"The Studies of The Synthesis and Purification of HMX and Its Content of Acids" Chen Li, Xin Jin, *ACTA ARMAMENTARIA, Fascicle of Powder and Explosive*, **1987**, *1*, 1-4.

"Synthesis of A Macrocycle Containing Large Hydrophobic Bridged Annulene Units" Reginald H. Mitchell, Xin Jin, manuscript under preparation.

"A New Synthesis of 10b,10c-Dimethyldihydropyrene-2,7-quinone and The Investigation of Its Diels-Alder Reactions" (poster presentation) the 33rd National Organic Chemistry Symposium of the American Chemical Society, Bozeman, Montana, June 13-17, **1993**.

"The Synthesis of An Annulene Derived Tetracyanoquinodimethane; A Novel Electron Acceptor" (poster presentation) the 49th American Chemical Society Northwest Regional Meeting, Anchorage, Alaska, June 16-18, **1994**.

PARTIAL COPYRIGHT LICENSE

I hereby grant the right to lend my thesis to users of the University of Victoria Library, and to make single copies only for such users or in response to a request from the Library of any other university, or similar institution, on its behalf or for one of its users. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by me or a member of the University designated by me. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Title of Thesis:

A NEW SYNTHESIS OF DIMETHYLDIHYDROPYRENE-2,7-QUINONE AND THE STUDY OF ITS REACTIONS IN THE SYNTHESIS OF NOVEL AROMATIC AND OTHER INTERESTING MOLECULES

Author [redacted]
(Signature)

XIN JIN
(Name in Block Letter)

Jan. 25, 1995.
(Date)