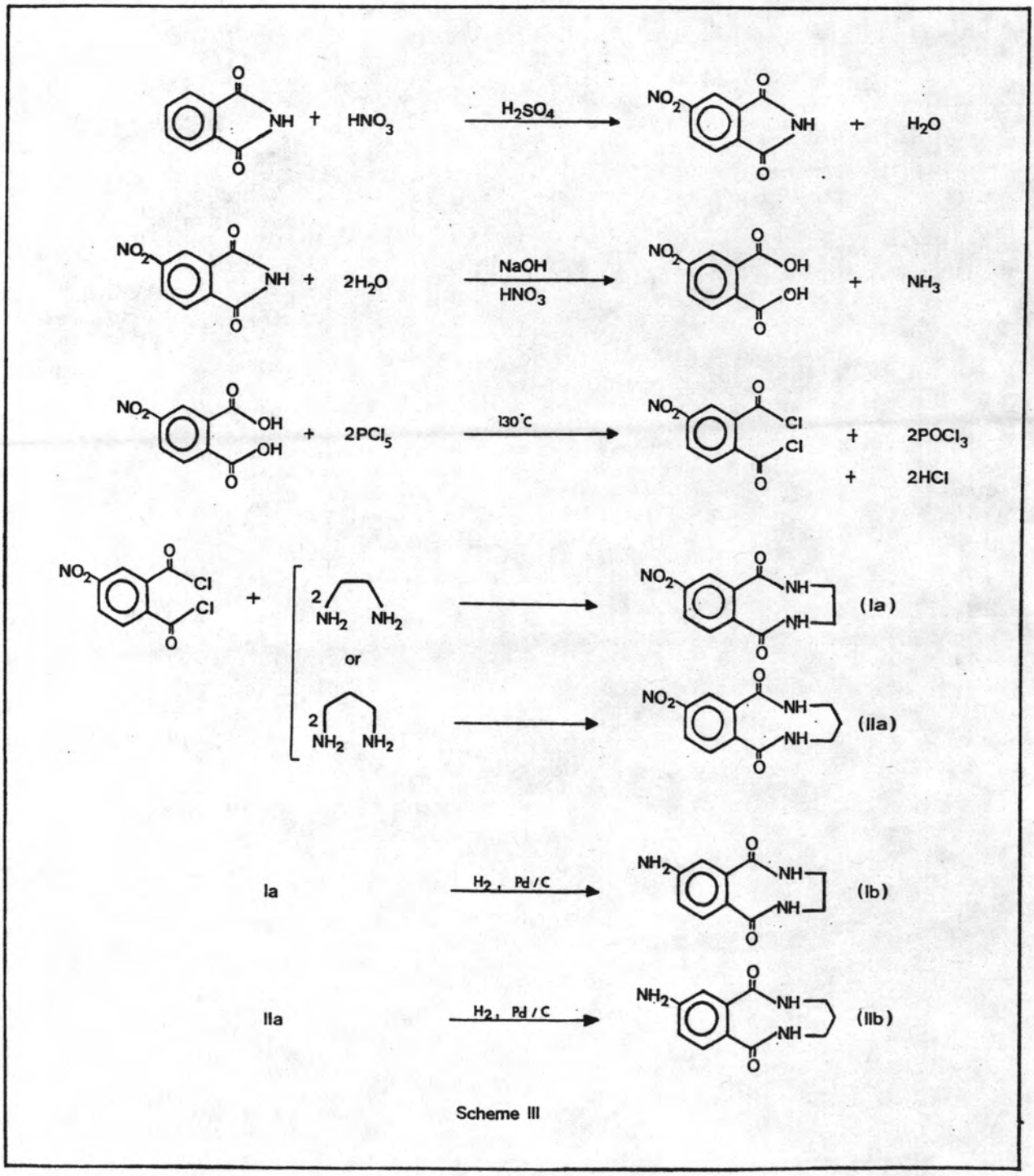
Chapter IV

Results and Discussion

4.1 Synthesis of the Macrocyclic Polyamide Compounds

The synthetic processes for four macrocyclic polyamide compounds, 3,4-(4'-nitrobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ia); 3,4-(4'-aminobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ib) ; 3,4-(4'-nitrobenzo)-1,6-diazacyclonona-3-en-2,5-dione (IIa) ; 3,4-(4'-aminobenzo)-1,6-diazacyclonona-3-en-2,5-dione (IIb), are described in Scheme III. Along with the reaction, the disappearance of the reactants and the formation of the products were monitored by thin layer chromatography.

Some other synthetic routes to synthesize the macrocyclic polyamide compounds were tried but they often suffered some problems. For instance, when phthalic acid was employed as a starting material for nitrating reaction in order to synthesize 4-nitrophthalic acid, instead of the process used in this study, two isomers of 3-nitrophthalic acid and 4-nitrophthalic acid were obtained in equivalent yield. The separation of 4-nitrophthalic acid from the products was rather difficult. In cyclization step, a condensation reaction of diamines with diesters can also give macrocyclic polyamides but the yield is generally low and more than one product obtained is always the problem. Tetrahydrofuran was chosen as a solvent for cyclization of diamines and diacidchlorides since the


+ HNO3
H2SO4
+ H2O
+ 2H2O
NaOH
HNO3
+ NH3
+ 2PCl5
130°C
+ 2POCl3
+ 2HCl
or
(Ia)
(IIa)
Ia
IIa
H2 , Pd / C
(Ib)
(IIb)

Scheme III

desired nitrobenzo macrocyclic polyamide products were practically insoluble in this solvent at room temperature. The yield of the cyclization step does not exceed 50% for both compounds (Ia and IIa) due to the low stability of the products. A reaction temperature higher than room temperature and reaction time shorter than 20 hours produce more viscous by products hence decrease the cyclization yield especially in the nitrobenzo macrocyclic polyamide Ia which contains less carbon atoms.

The nitrobenzo macrocyclic polyamides Ia and IIa were reduced to their amino derivatives on palladium carbon. If the absorption of the hydrogen gas stopped before the completion of the reaction process, due to the poisonage of palladium carbon, an additional amount of palladium carbon was added. The resulting aminobenzo macrocyclic polyamide compounds, Ib and IIb, are quite labile to air oxidation. This hydrogenation process can reduce only nitro- to amino - functional group but not amide to amine for the reason that the reduction of amide to amine by hydrogenation requires higher pressure condition. However, a use of lithium aluminium hydride ($LiAlH_4$) as reducing agent did break these small, 8 to 9 membered, rings containing two nitrogen as donor atoms though $LiAlH_4$ was proved to be a suitable reducing agent for some larger rings (121). Therefore, the macrocyclic polyamide compounds were studied instead of their corresponding polyamine compounds which were our primary goal.

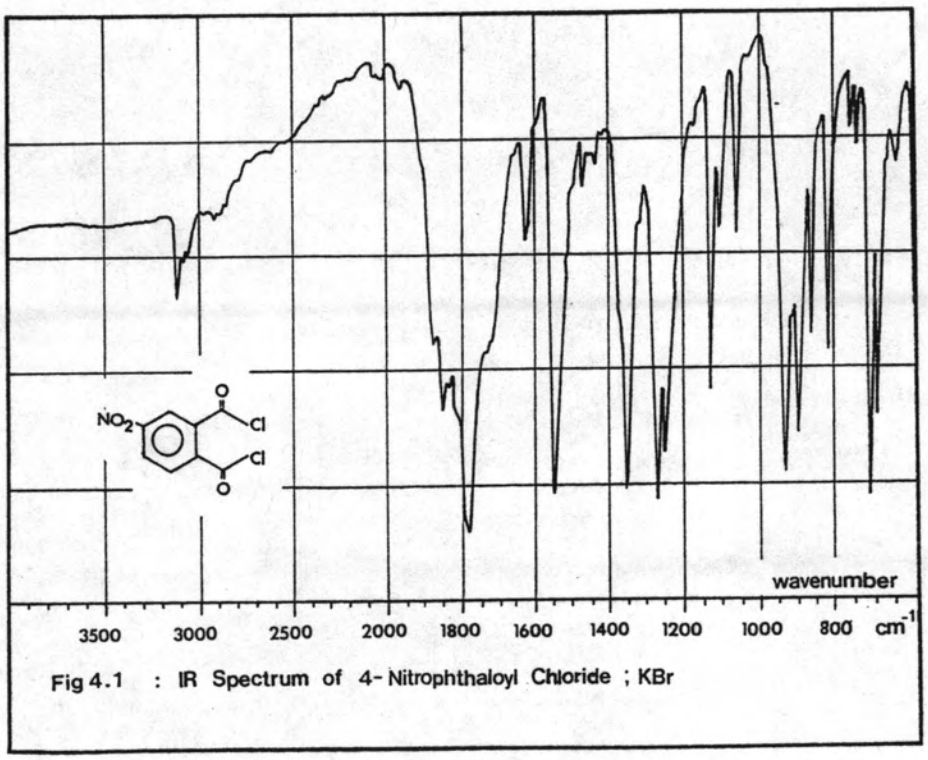


Fig 4.1 : IR Spectrum of 4- Nitrophthaloyl Chloride ; KBr

4.2 Structural Elucidation of the Synthesized Macrocyclic Polyamide Compounds

4.2.1 4-Nitrophthaloyl Chloride

4-nitrophthaloyl chloride is one of the starting materials for the cyclization step. It has been characterized by IR spectroscopy and its IR spectrum is viewed in Fig 4.1. The assignments of the peaks are listed in Table 4.1.

Table 4.1 Assignments of Peaks in IR Spectrum of 4-Nitrophthaloyl Chloride

Absorption frequency (cm^{-1})	Inten-sity	Remark and Assignnment
A) 3030-3100	w	C-H stretch (aromatic)
1620,1470,1435	w	C=C ring stretch
1055,700	m	C-H bend (in and out of plane)
B) 1785	s	C=O stretch ; acidchloride
1725	m	Fermi resonance band of C=O strecth and overtone at $865cm^{-1}$
C) 1545,1350	s	N-O stretch (aromatic ; asym and sym)
815	m	$ArNO_2$; C-N stretch

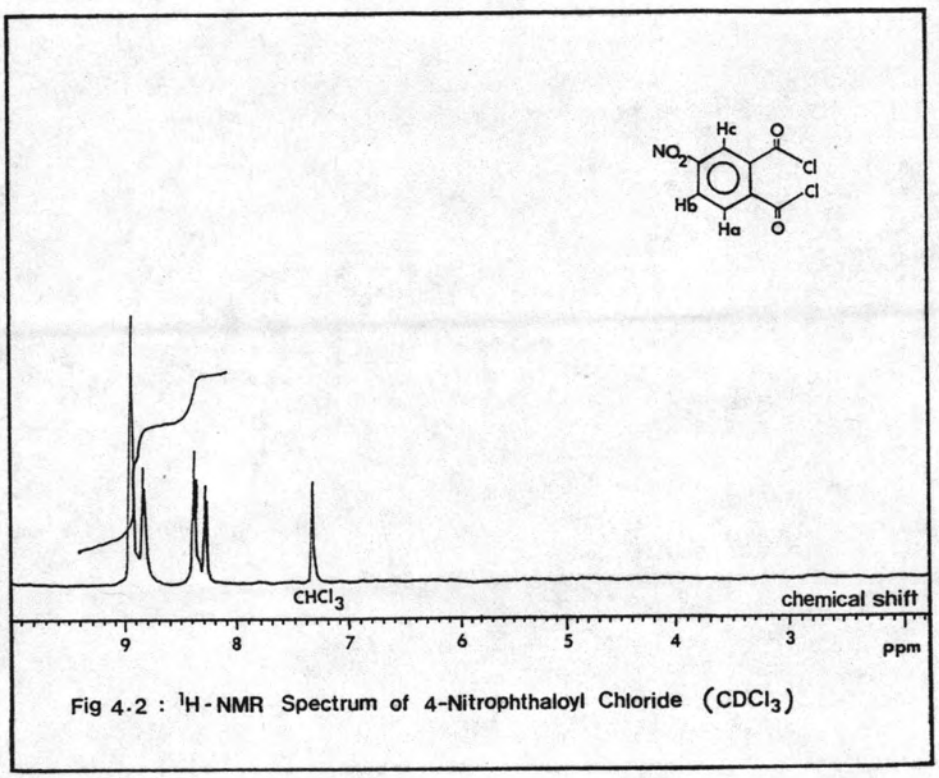


Fig 4.2 : ^1H-NMR Spectrum of 4-Nitrophthaloyl Chloride ($CDCl_3$)

The vibration at 1740 cm^{-1} of 4-nitrophthalic acid (not shown here) which has been assigned to C=O stretching of carboxylic acid did show a shift to 1785 cm^{-1}, C=O stretching of acid chloride (Table 4.1).

Nuclear magnetic resonance (NMR) spectroscopy also supports the formation of 4-nitrophthaloyl chloride from 4-nitrophthalic acid. ^{1}H-NMR spectrum of 4-nitrophthaloyl chloride is illustrated in Fig 4.2 and the corresponding assignments are in Table 4.2.

Table 4.2 Assignments of Peaks in NMR Spectrum of 4-Nitrophthaloyl Chloride

Chemical shift (ppm)	Multi-plicity	Inte-gration	Tentative assignment
A) 8.2	double doublet	1	Ha (coupled with Hb and long range coupling with Hc)
B) 8.7*	double doublet	1	Hb (coupled with Ha and long range coupling with Hc)
C) 8.8	doublet	1	Hc (long range coupling with Ha and Hb)

* Hb peak is overlapped with Hc peak.

4.2.2 3,4-(4'-nitrobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ia) and 3,4-(4'-nitrobenzo)-1,6-diazacyclonona-3-en-2,5-dione (IIa)

4.2.2.1 Infrared Spectroscopy

The cyclization step of 4-nitrophthaloyl chloride with 1,2-diaminoethane gave 3,4-(4'-nitrobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ia) and with 1,3-diaminopropane gave 3,4-(4'-nitrobenzo)-1,6-diazacyclonona-3-en-2,5-dione (IIa). The obtained products have been characterized by various techniques. Figure 4.3 shows an IR spectrum of Ia and Table 4.3 presents the assignments of the spectrum. An IR spectrum of IIa is depicted in Fig 4.4 and the corresponding assignments are listed in Table 4.4.

Both nitrobenzo macrocyclic polyamides, Ia and IIa, have same functional groups that their IR spectra (Fig 4.3 and Fig 4.4) are similar. The strong carbonyl band at 1670 cm^{-1} together with bands at 3400 (Ia) or 3340 (IIa) and 3085 (Ia) or 3140 cm^{-1} (IIa) suggest an aromatic amide group. A broad band, 3200-2500 cm^{-1} in both spectra (Fig 4.3 and Fig 4.4) is due to -OH stretching of H_2O (vide infra).

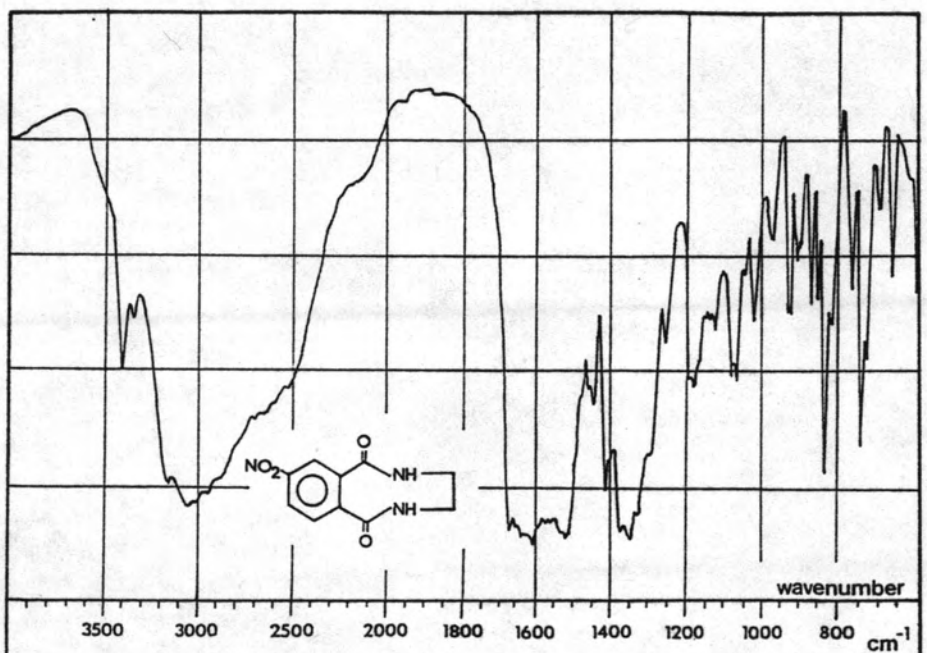


Fig 4.3 : IR Spectrum of 3,4-(4'-nitrobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ia) ; KBr

Table 4.3 Assignments of Peaks in IR Spectrum of 3,4-(4'-nitrobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ia)

	Absorption frequency (cm^{-1})	Intensity	Remark and Assignnment
A)	2860-2940	s	C-H stretch (aliphatic)
	1460,1375	w	C-H bend (aliphatic)
B)	3040-3170	s	C-H stretch (aromatic)
	1640*,1600*,	m->s	C=C ring stretch
	1450,1410		
	1075,1020,1120,	w	C-H bend (in plane)
	740,720		(out of plane)
C)	1670*	s	C=O stretch ; amide I band
	3400	w	N-H stretch
	1550*	m	N-H bend ; amide II band
D)	1530*,1350	s	N=O stretch
			(aromatic ; asym and sym)
	830	m	$ArNO_2$; C-N stretch

* These peaks are overlapped.

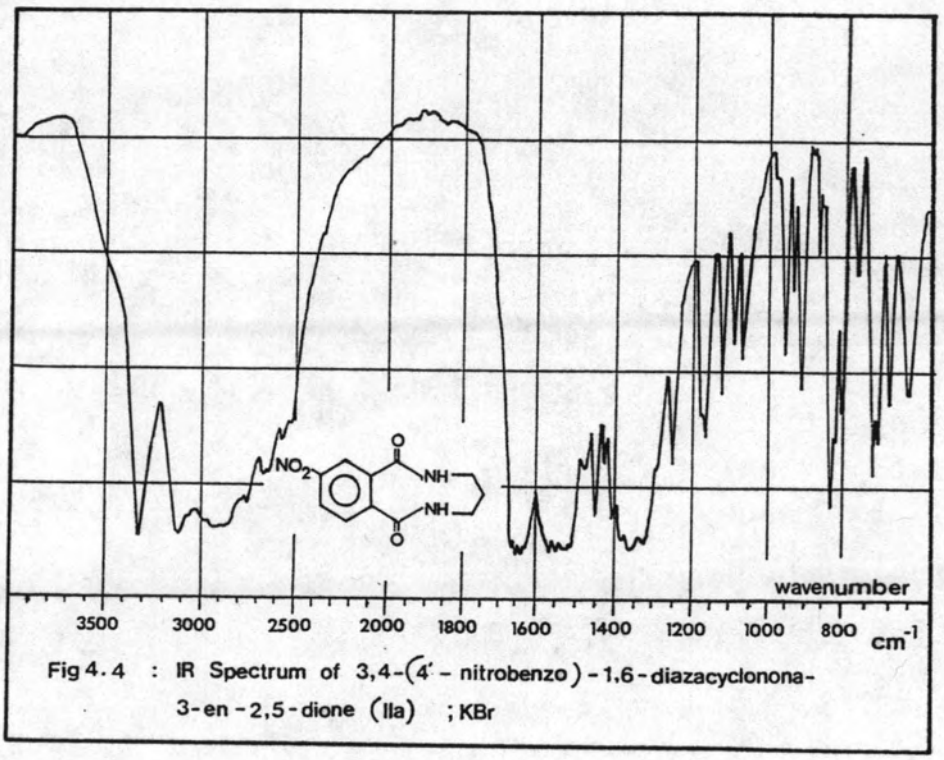


Fig 4.4 : IR Spectrum of 3,4-(4' - nitrobenzo) - 1,6 - diazacyclonona-3-en-2,5-dione (IIa) ; KBr

Table 4.4 Assignments of Peaks in IR Spectrum of 3,4-(4'-nitrobenzo) -1,6-diazacyclonona-3-en-2,5-dione (IIa)

Absorption frequency (cm^{-1})	Intensity	Remark and Assignnments
A) 2870-2950	s	C-H stretch (aliphatic)
1425,1380	w	C-H bend (aliphatic)
B) 3140-3050	s	C-H stretch (aromatic)
1650*,1635*,	m->s	C=C ring stretch
1450,1045		
1075,1020,1120,	w	C-H bend (in plane)
750,740		(out of plane)
C) 1670*	s	C=O stretch ; amide I band
3340	s	N-H stretch
1560*	m	N-H bend ; amide II band
D) 1530*,1350	s	N=O stretch (aromatic ; asym and sym)
835	m	$ArNO_2$; C-N stretch

* These peaks are overlapped.

4.2.2.2 Nuclear Magnetic Resonance Spectroscopy

The synthesized nitrobenzo macrocyclic polyamide compounds were also characterized by nuclear magnetic resonance spectroscopy. The proton NMR spectrum was able to characterize aliphatic and aromatic proton patterns while the ^{13}C - NMR spectrum indicated the

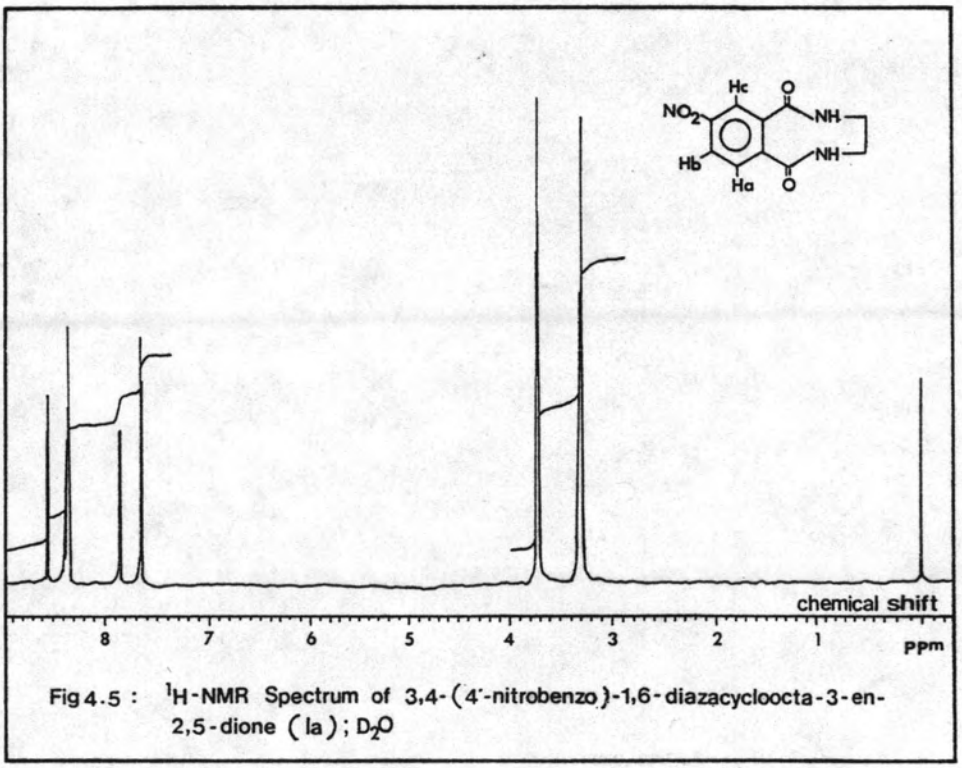


Fig 4.5 : ^{1}H-NMR Spectrum of 3,4-(4'-nitrobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ia); D_2O

number of carbon atoms and their positions. The obtained ^{1}H and ^{13}C-NMR spectra of Ia in D_2O as solvent are shown in Fig 4.5 and Fig 4.6 respectively. Tables 4.5 and 4.6 present relevant assignments of those spectra.

Table 4.5 Assignments of Peaks in ^{1}H - NMR Spectrum of 3,4-(4'-nitrobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ia)

Chemical shift (ppm)	Multiplicity	Integration	Tentative assignment
A) 3.2	triplet	2	$-\underline{CH_2}-NH-$ protons
3.7	triplet	2	[coupled with each other]
B) 7.8	double doublet	1	aromatic protons (Ha)
8.4*	complex	2	(Hc)
8.5			(Hb)

* Hb peak is overlapped with Hc

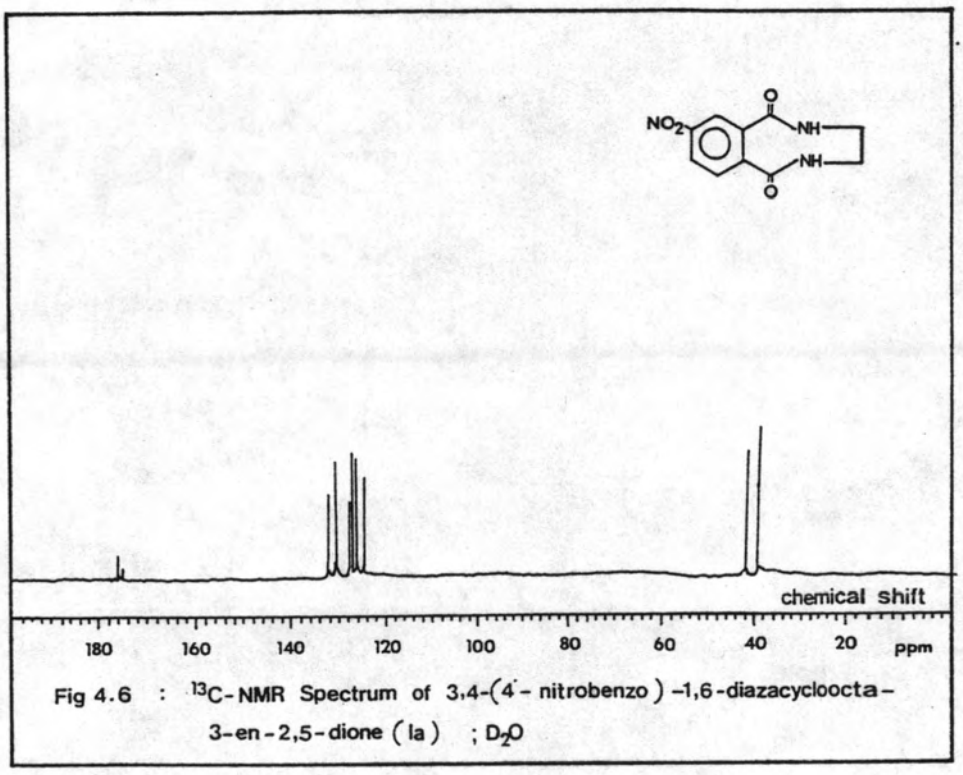


Fig 4.6 : ^{13}C-NMR Spectrum of 3,4-(4'- nitrobenzo) -1,6-diazacycloocta-3-en-2,5-dione (Ia) ; D_2O

Table 4.6 Assignments of Peaks in ^{13}C - NMR Spectrum of 3,4-(4'-nitrobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ia)

Chemical shift (ppm)	Tentative assignment
A) 39.6	2 x $-\underline{CH_2}-NH-$ carbon
42.2	
B) 124.9	aromatic carbons
126.6	
127.5	
128.0	
130.9	
132.3	
C) 175.2	2 x C=O carbon (amide)
176.1	

Nuclear magnetic resonance spectral studies of IIa in D_2O reveal ^1H - NMR spectrum in Fig 4.7 and ^{13}C - NMR spectrum as in Fig 4.8. The corresponding peak asssignments are listed in Tables 4.7 and 4.8 respectively.

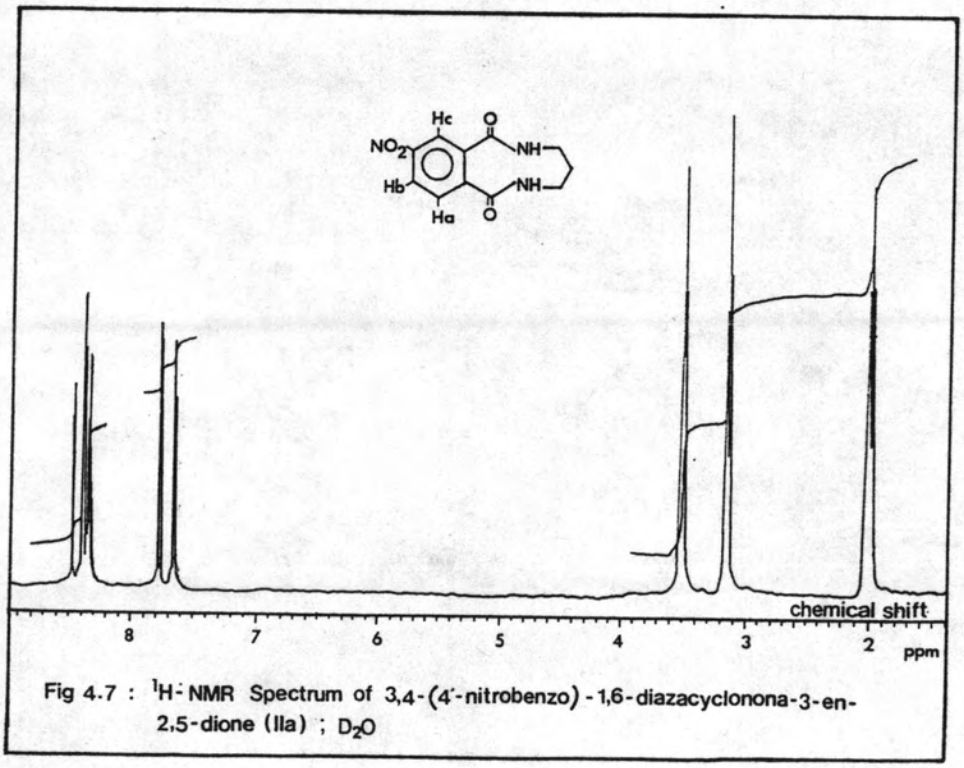


Fig 4.7 : ^1H-NMR Spectrum of 3,4-(4'-nitrobenzo)-1,6-diazacyclonona-3-en-2,5-dione (IIa) ; D_2O

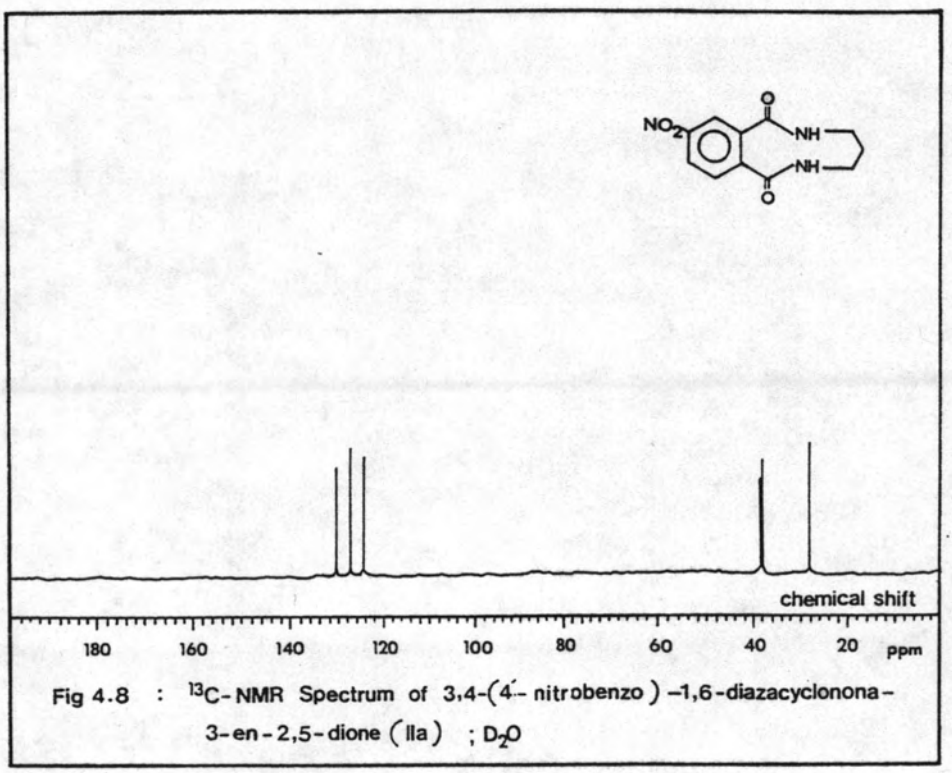


Fig 4.8 : ^{13}C-NMR Spectrum of 3,4-(4´- nitrobenzo) -1,6-diazacyclonona-3-en-2,5-dione (IIa) ; D_2O

Table 4.7 Assignments of Peaks in ^{1}H - NMR Spectrum of 3,4-(4'-nitrobenzo)-1,6-diazacyclononа-3-en-2,5-dione (IIa)

Chemical shift (ppm)	Multiplicity	Integration	Tentative assignment
A) 2.0	quintet	2	$-CH_2-\underline{CH_2}-CH_2$ protons
B) 3.2	triplet	2	$-\underline{CH_2}$-NH- protons
3.5	triplet	2	
C) 7.7	double doublet	1	aromatic protons (Ha)
8.4*	complex	2	(Hc)
8.5			(Hb)

* Hb peak is overlapped with Hc

Table 4.8 Assignments of Peaks in ^{13}C - NMR Spectrum of 3,4-(4'-nitrobenzo)-1,6-diazacyclononа-3-en-2,5-dione (IIa)

Chemical shift (ppm)	Tentative assignment
A) 29.2	$-CH_2-\underline{CH_2}-CH_2-$ carbon
B) 39.1	2 x $-\underline{CH_2}$-NH- carbon
39.6	
B) 125.0	aromatic carbons
128.0	
131.4	

The macrocyclic compound Ia distinguishes IIa by a difference in number of carbon atoms in the ring which is also exhibited in their NMR spectra. Figure 4.5 shows two triplet peaks (3.2 and 3.7 ppm) that indicate two methylene groups. The two methylene groups in Ia are not equivalent for which the strain in the ring is responsible. The ^{13}C - NMR spectrum (Fig 4.6) confirms the presence of these methylene groups with signals at 39.6 and 42.2 ppm. Figure 4.7 shows three signals for methylene protons at 2.0, 3.2 and 3.5 ppm. Both ^{1}H - NMR spectra reveal signals in the range of 7.5-8.2 ppm which account for aromatic protons in the nitrobenzo moiety. Amide protons were not observed in this study due to the rapid proton exchange with D_2O. Only ^{13}C - NMR spectrum of Ia (Fig 4.6) exhibits six aromatic carbon signals between 125-133 ppm but not that of IIa (Fig 4.8). Besides, Fig 4.8 does not show any significant signals that could account for amide carbon. This is probably due to the low intensity of the peaks. However, the ^{1}H - NMR spectrum of IIa agrees well with its structure.

4.2.2.3 Mass Spectrometry

The mass spectrum of nitrobenzo macrocyclic polyamide Ia is shown in Fig 4.9. This exhibits the molecular ion peak at m/e 235. The base peak at m/e 43 is due to the $[O=C=NH^{+}]$ ion resulted from the cleavage of the macrocyclic ring. The mechanism of fragmentation is described in Scheme IV. Nitrobenzo macrocyclic polyamide IIa yielded a mass spectrum with the molecular ion peak at 249 as illustrated in Fig 4.10. A mechanism of the cleavage of macrocyclic polyamide IIa is described in Scheme V.

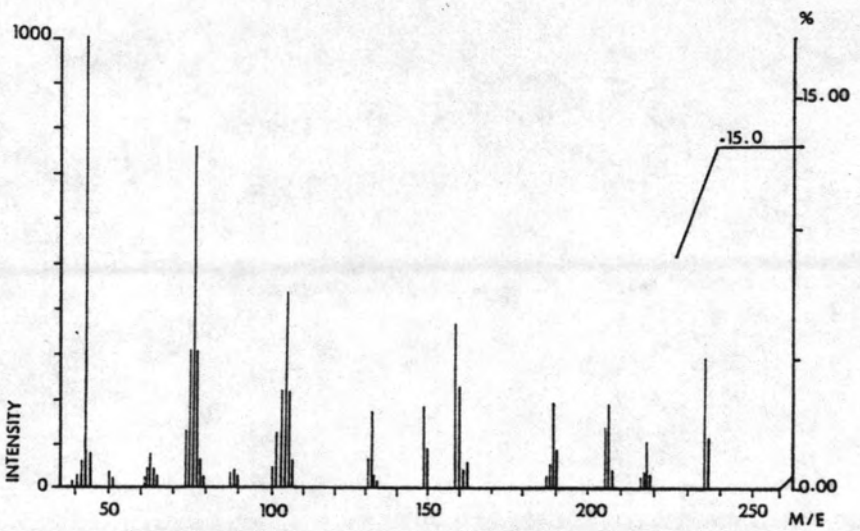
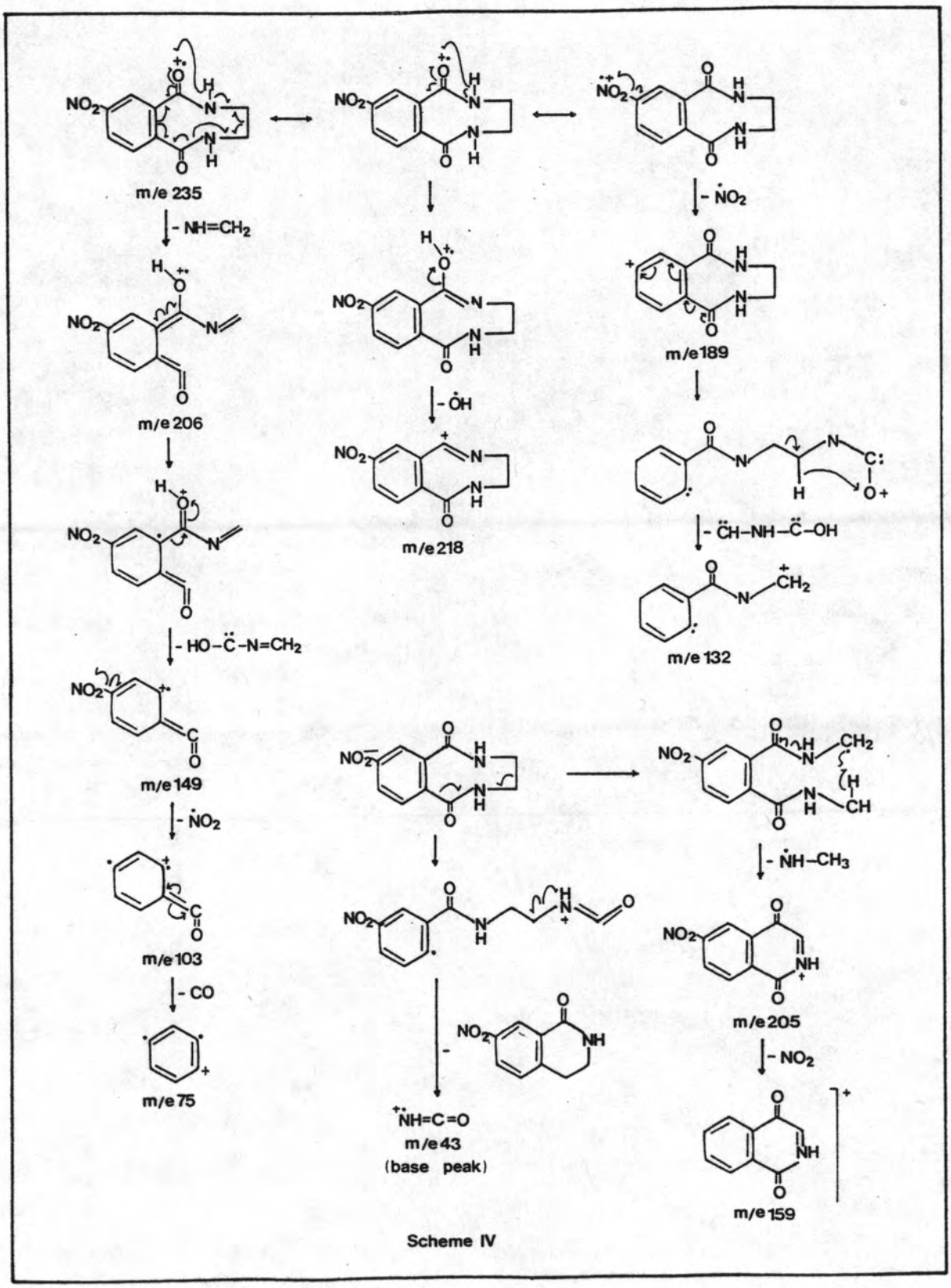


Fig 4.9 : Mass Spectrum of 3,4-(4′- nitrobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ia)


m/e 235
- NH=CH2
m/e 206
- HO-C-N=CH2
m/e 149
- NO2
m/e 103
- CO
m/e 75
m/e 218
- OH
- NO2
m/e 189
- CH-NH-C-OH
m/e 132
- NH-CH3
m/e 205
- NO2
m/e 159
- NH=C=O
m/e 43
(base peak)

Scheme IV

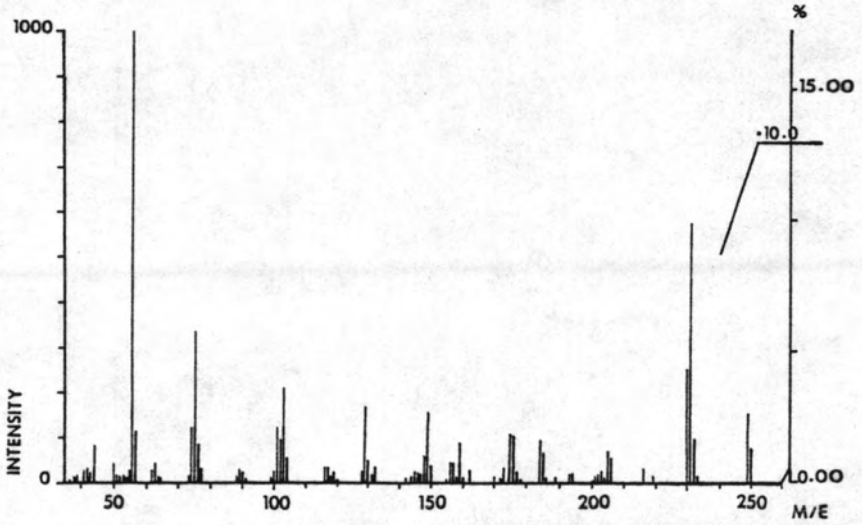
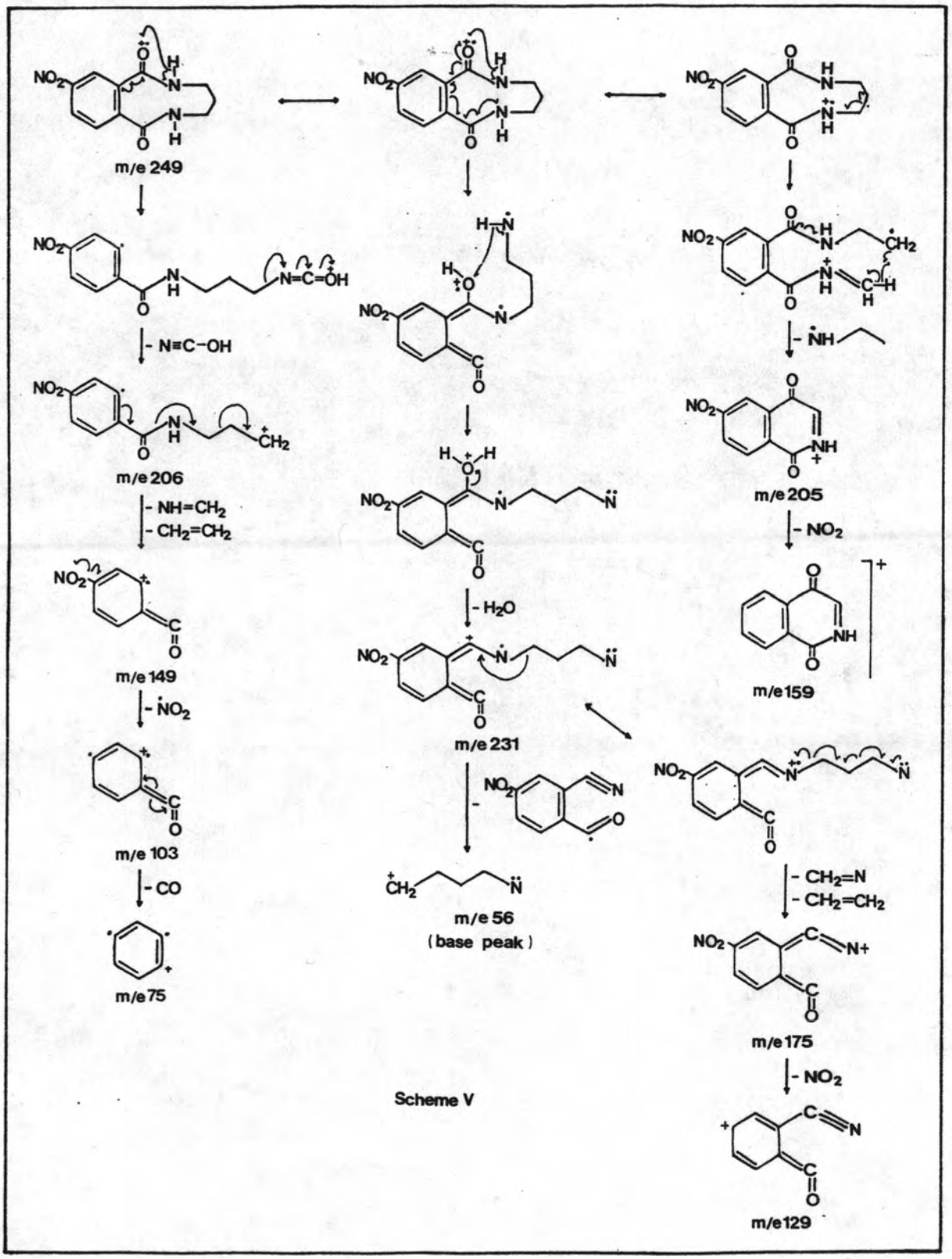


Fig 4.10 : Mass Spectrum of 3,4-(4'- nitrobenzo)-1,6-diazacyclonona-3-en-2,5-dione (IIa)


m/e 249
- N≡C-OH
m/e 206
- NH=CH2
- CH2=CH2
m/e 149
- NO2
m/e 103
- CO
m/e 75
- H2O
m/e 231
m/e 56
(base peak)
m/e 205
- NO2
m/e 159
- CH2=N
- CH2=CH2
m/e 175
- NO2
m/e 129

Scheme V

4.2.2.4 Elemental Analysis

The analysis C H N percentages compared with their calculated values of the synthetic nitrobenzo macrocyclic polyamide compounds are listed in Table 4.9.

Table 4.9 Elemental analysis data* of 3,4-(4'-nitrobenzo)-1,6-diaza-cycloocta-3-en-2,5-dione (Ia) and 3,4-(4'-nitrobenzo)-1,6-diazacyclo-nona-3-en-2,5-dione (IIa)

Macrocyclic polyamides		%C	%H	%N
Ia	Found	44.90	4.59	15.98
($C_{10}H_9N_3O_4.2H_2O$)	Calculated	44.28	4.79	15.49
IIa	Found	48.86	5.01	15.52
($C_{11}H_{11}N_3O_4.H_2O$)	Calculated	49.40	4.87	15.70

* The analysis was done much later after the synthesis.

The data indicate water adducts for both compounds. This also shows in their IR spectra (Fig 4.3 and Fig 4.4) as a strong broad band between 3200-2500 cm^{-1} has been observed (vide supra). The presence of H_2O in the obtained products did not show up in the NMR spectra since D_2O was employed as solvent. The mass spectral study of Ia and IIa showed the correspoding molecular ion peaks, as mentioned earlier, at m/e 235 and 249, respectively. The observed

molecular ion peaks correspond to structures without water molecules. It is believed that the water molecules had left the structure before the molecular ionization occured.

A purity of the synthesized macrocyclic polyamides (Ia and IIa) were also tests by using High Performance Thin Layer Chromatography (HPTLC). The freshly prepared solids were of high purity that the instrument could not detect any contamination. Upon contacting with air for several weeks, no color change was observed. The Rf values (1:5 chloroform:methanol) of Ia and IIa were 0.537 and 0.567, respectively.

2.4.2.5 Electronic Absorption Spectroscopy

The spectrum in ultraviolet region was studied to examine absorptions of aromatic portion of the structure. Spectral lines of both Ia and IIa are illustrated in Fig 4.11. The absorption at 271.0 nm (ε_{max} = 7490) of Ia and 276.6 nm (ε_{max} = 7950) of IIa have been assigned as $\pi \rightarrow \pi^*$ of the benzene ring (K band) which normally observed at 204 nm (ε_{max} = 7900). The bathochromic shift is due to 1,2,4-substitution on the benzene ring. The absorption of amide chromophore ($n \rightarrow \pi^*$) at < 208 nm is generally weak and was therefore not observed in this study.

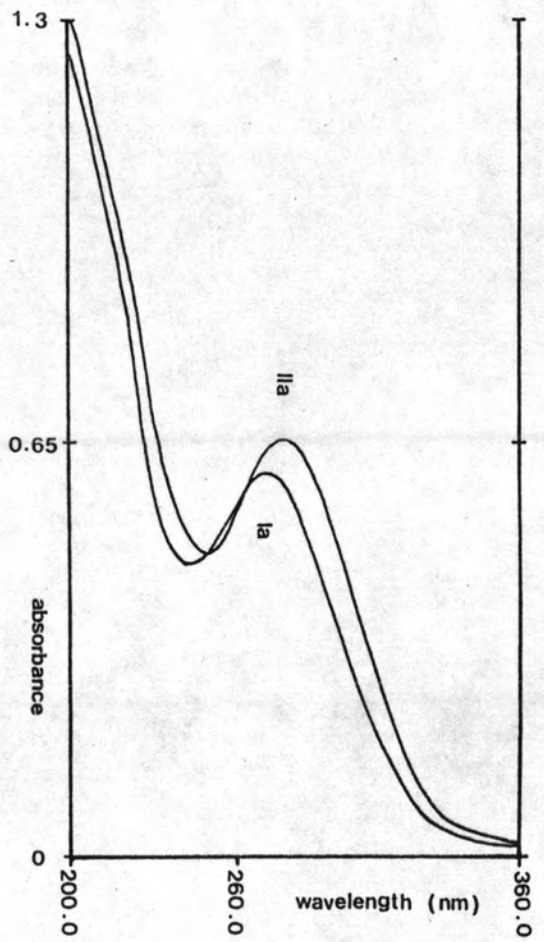


Fig 4.11 : UV Spectra of 3,4-(4-nitrobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ia) and 3,4-(4 nitrobenzo)-1,6-diazacyclonona-3-en-2,5-dione (IIa)

4.2.3 3,4-(4'-aminobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ib) and 3,4-(4'-aminobenzo)-1,6-diazacyclonona-3-en-2,5-dione (IIb)

4.2.3.1 Infrared Spectroscopy

The aminobenzo macrocyclic polyamides, Ib and IIb were obtained by hydrogenating the corresponding nitrobenzo macrocyclic polyamides, Ia and IIa respectively. An IR spectrum of the synthesized aminobenzo derivative, Ib, was investigated and depicted in Fig 4.12. The following table (Table 4.10) presents the assignments of the spectrum. Aminobenzo macrocyclic polyamide IIb yielded a similar IR spectrum as shown in Fig 4.13 along with the corresponding assignments in Table 4.11

The observed primary amine N-H stretching bands in both spectra indicate the hydrogenation of the nitro group. A disappearence of the two bands of nitro group (1530 and 1350 cm^{-1}) is not obviously seen due to a complexity of the spectrum in that region. The amide groups were not reduced to amine as the amide I band at 1670 cm^{-1} and amide II band at 1560 cm^{-1} are still observed in the aminobenzo derivative spectra. This is also confirmed in the NMR study (vide infra). A broad envelope centered at around 2900 cm^{-1} in both spectra (Fig 4.12 and Fig 4.13) is once again observed as in the spectra of their corresponding nitrobenzo derivatives (Fig 4.3 and Fig 4.4) This indicates hydrate products.

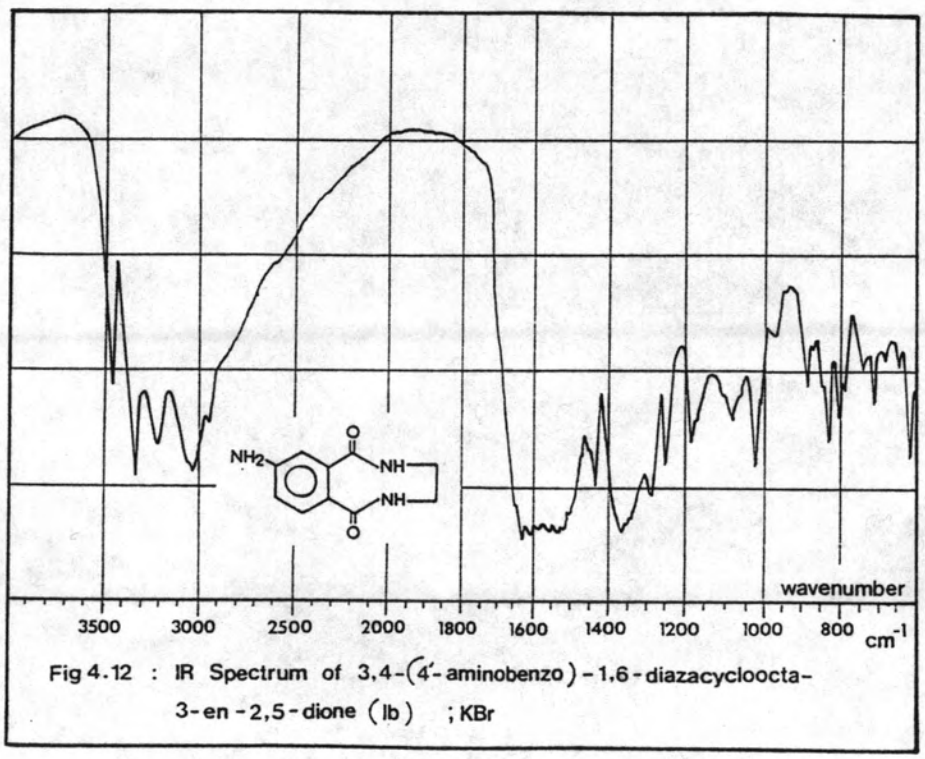


Fig 4.12 : IR Spectrum of 3,4-(4'-aminobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ib) ; KBr

Table 4.10 Assignments of Peaks in IR Spectrum of 3,4-(4'-aminobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ib)

Absorption frequency (cm^{-1})	Intensity	Remark and Assignnment
A) 2960	s	C-H stretch (aliphatic)
1450,1360	w	C-H bend (aliphatic)
B) 3040	s	C-H stretch (aromatic)
1620*,1605*,	m->s	C=C ring stretch
1450,1400		
1090,1060,1030,	w	C-H bend (in plane)
740,715		(out of plane)
C) 1670*	s	C=O stretch ; amide I band
3470	s	N-H stretch (amide)
1560*	m	N-H bend ; amide II band
D) 3375,3220	s	N-H stretch (amine)
1590	m	N-H bend (in plane)
1370	s	C-N stretch

* These peaks are overlapped.

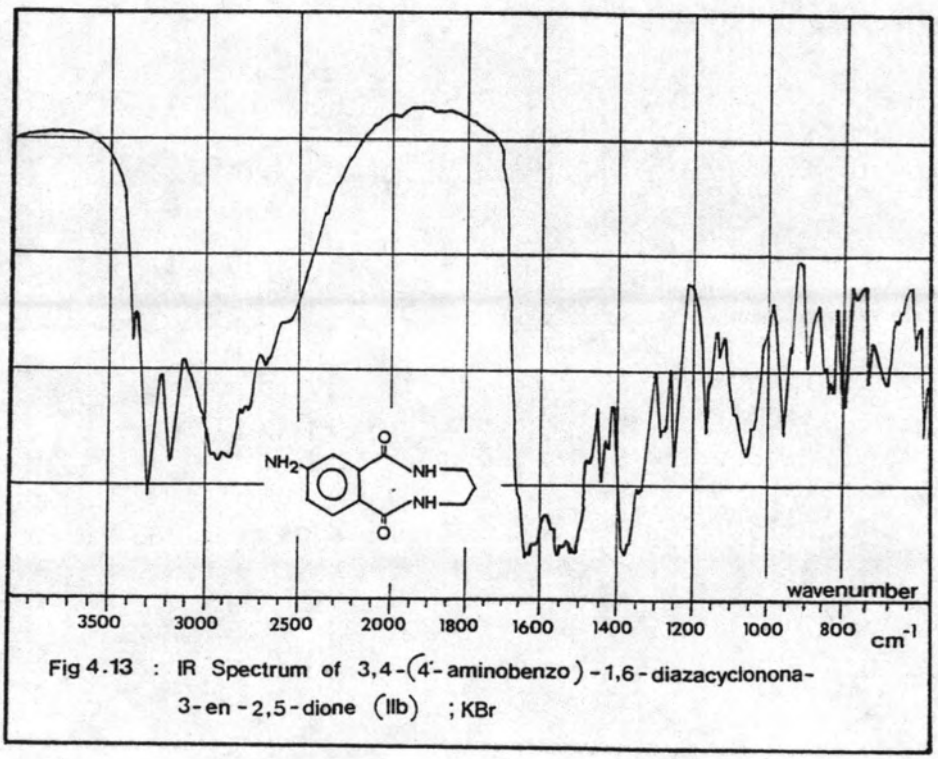


Fig 4.13 : IR Spectrum of 3,4-(4'-aminobenzo)-1,6-diazacyclonona-3-en-2,5-dione (IIb) ; KBr

Table 4.11 Assignments of Peaks in IR Spectrum of 3,4-(4'-aminobenzo) -1,6-diazacyclonona-3-en-2,5-dione (IIb)

Absorption frequency (cm^{-1})	Inten-sity	Remark and Assignnment
A) 2860-2940	s	C-H stretch (aliphatic)
1420,1360	w	C-H bend (aliphatic)
B) 2980	s	C-H stretch (aromatic)
1630*,1605*,	m->s	C=C ring stretch
1445,1400		
1130,1060,1030,	w	C-H bend (in plane)
750,710		(out of plane)
C) 1670*	s	C=O stretch ; amide I band
3400	s	N-H stretch (amide)
1560*	m	N-H bend ; amide II band
D) 3300-3180	s	N-H stretch (amine)
1590	m	N-H bend (in plane)
1370	s	C-N stretch

* These peaks are overlapped.

4.2.3.2 Nuclear Magnetic Resonance Spectroscopy

Both ^{1}H - NMR and ^{13}C - NMR spectroscopy of the two aminobenzo macrocyclic polyamides were studied and compared to their starting nitrobenzo compounds. The obtained spectra for Ib are shown in Fig 4.14 for proton nuclei and Fig 4.15 for carbon nuclei. The

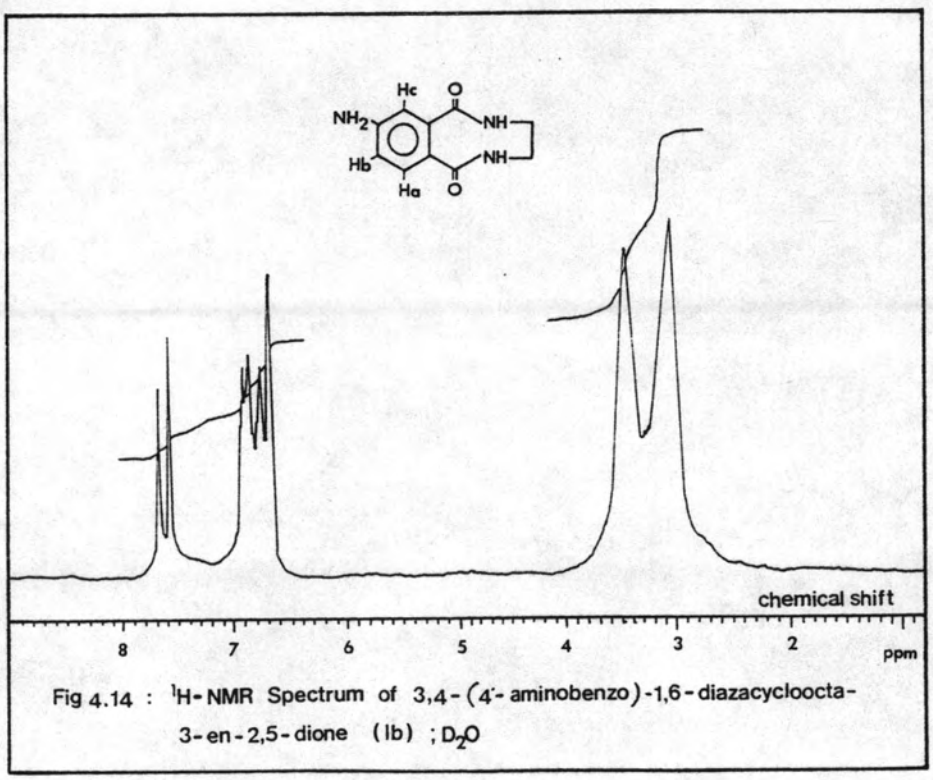


Fig 4.14 : ^{1}H-NMR Spectrum of 3,4-(4'-aminobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ib) ; D_2O

corresponding assignments are tabulated in Tables 4.12 and 4.13, respectively. IIb exhibits a ^{1}H - NMR spectrum (Fig 4.16) similar to that of IIa (Fig 4.7) and the assignments of Fig 4.16 is presented in Table 4.14. Its ^{13}C - NMR spectrum was also recorded and reported here as in Fig 4.17 with the corresponding assignments in Table 4.15.

Table 4.12 Assignments of Peaks in ^{1}H - NMR Spectrum of 3,4-(4'-aminobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ib)

Chemical shift (ppm)	Multiplicity	Integration	Tentative assignment
A) 3.3	triplet*	2	$-\underline{CH_2}$-NH- protons
3.6	triplet*	2	[coupled with each other]
C) 6.7	complex	2	aromatic protons (Hc)
6.9			(Hb)
7.6	double doublet	1	(Ha)

* The multiplicitiies of these peaks are not completely resolved.

When ^{1}H - NMR spectum of Ib (Fig 4.14) is compared to that of Ia (Fig 4.5), a difference in the aromatic region is noticable. The protons that are ortho- to amide group and meta- to amine group (Ha - proton) appear at higher ppm than Hb and Hc protons in Ib spectrum but at lower ppm in Ia spectrum. This is an effect resulted from the electron releasing group $-NH_2$ on the benzene ring in the position of electron donating group $-NO_2$. The ^{13}C - NMR spectrum of Ib is rather

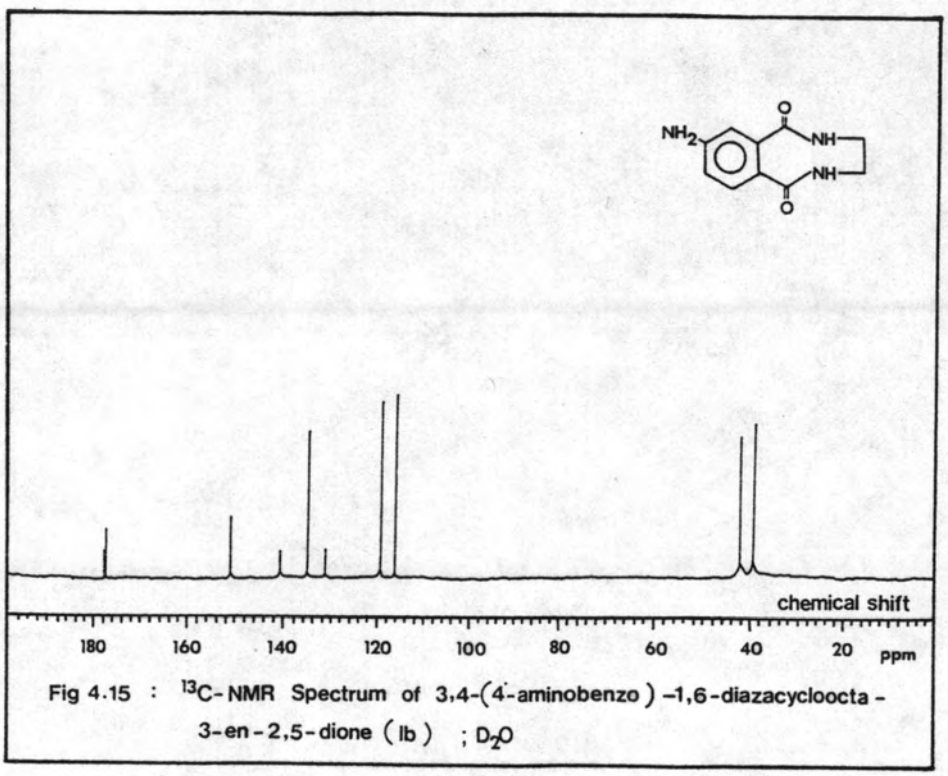


Fig 4.15 : ^{13}C-NMR Spectrum of 3,4-(4-aminobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ib) ; D_2O

complex as compared to that of its precursor, Ia (Fig 4.6). However, it exhibits signals which count for all carbon nuclei in the structure.

Table 4.13 Assignments of Peaks in ^{13}C - NMR Spectrum of 3,4-(4'-aminobenzo)-1,6-diazacyclooctane-2,5-dione-3-ene (Ib)

Chemical shift (ppm)	Tentative assignment
A) 39.4	2 x -$\underline{CH_2}$-NH carbon
42.5	
B) 116.0	aromatic carbons
119.0	
131.4	
134.8	
148.3	
151.6	
C) 177.2	2 x C=O carbon (amide)
177.7	

The effect of $-NH_2$ group on the position of aromatic proton of IIb in its ^1H - NMR spectrum is similar to Ib as discussed earlier. The rest of the pattern is consistent with the proposed structure. The ^{13}C - NMR spectrum of IIb (Fig 4.17) reveals signals in a similar fashion as in the spectrum of Ib except the extra methylene carbon signal (integration = 2) at 29.2 ppm. However, IIb shows a better resolved ^{13}C - NMR spectrum than its precursor, IIa (Fig 4.8).

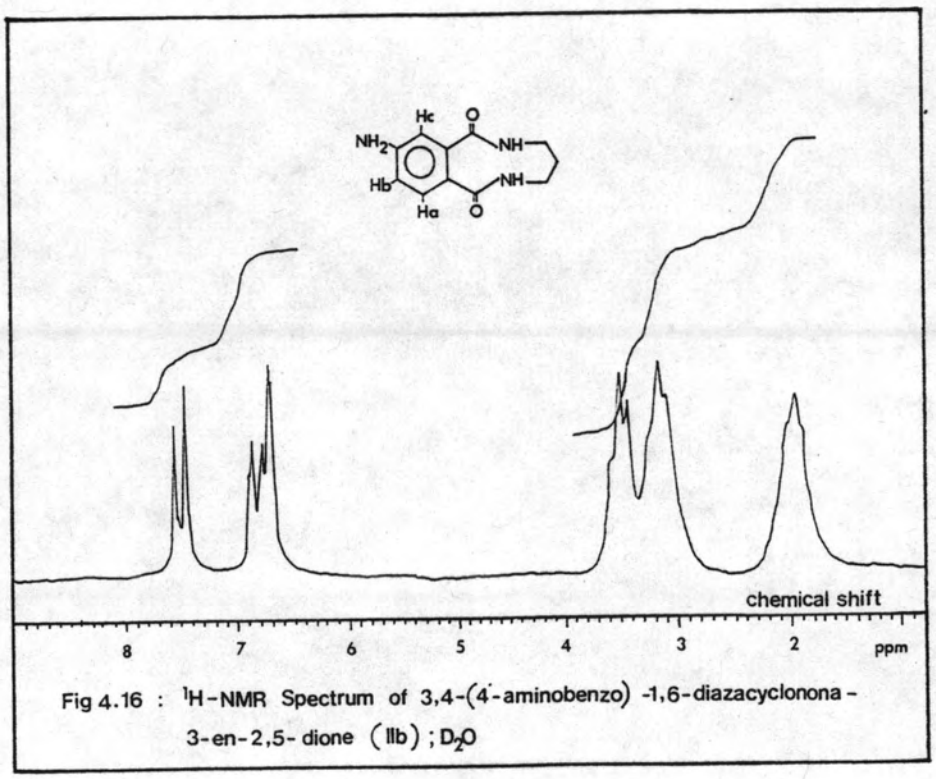


Fig 4.16 : ^1H-NMR Spectrum of 3,4-(4'-aminobenzo) -1,6-diazacyclonona-3-en-2,5-dione (IIb) ; D_2O

Table 4.14 Assignments of Peaks in ^1H - NMR Spectrum of 3,4-(4'-aminobenzo)-1,6-diazacyclonona-3-en-2,5-dione (IIb)

Chemical shift (ppm)	Multiplicity	Integration	Tentative assignment
A) 1.9	quintet*	2	$-CH_2-\underline{CH_2}-CH_2-$ protons
B) 3.1	triplet*	2	$-\underline{CH_2}-NH-$ protons
3.4	triplet*	2	
C) 6.7	complex	2	aromatic protons (Hc)
6.8			(Hb)
7.5	double doublet	1	(Ha)

* The multiplicitiies of these peaks are not completely resolved.

Both amide and amine protons were not observed in both ^1H- NMR spectra of the aminobenzo macrocylcic polyamide compounds, Ib and IIb, since D_2O was the solvent of choice in this study. However, the presence of the $-NH_2$ and $-\overset{O}{\overset{\|}{C}}-NH$ groups has been discussed in their IR study.

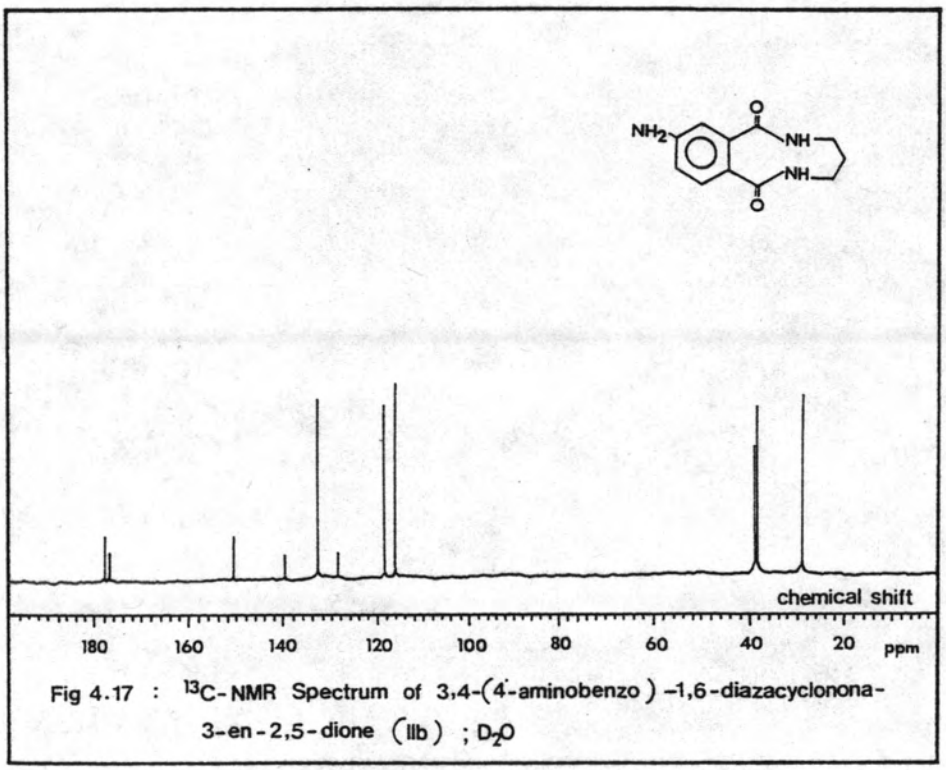


Fig 4.17 : ^{13}C-NMR Spectrum of 3,4-(4-aminobenzo)-1,6-diazacyclonona-3-en-2,5-dione (IIb) ; D_2O

Table 4.15 Assignments of Peaks in ^{13}C - NMR Spectrum of 3,4-(4'-aminobenzo)-1,6-diazacyclonona-3-en-2,5-dione (IIb)

Chemical shift (ppm)	Tentative assignment
A) 29.2	$-CH_2-\underline{CH_2}-CH_2-$ carbon
B) 39.1	2 x $-\underline{CH_2}-NH-$ carbon
39.7	
B) 116.5	aromatic carbons
119.0	
129.2	
133.3	
139.9	
150.9	
C) 176.7	2 x C=O carbon (amide)
177.6	

4.2.3.3 Mass Spectrometry

The mass spectrum of Ib (Fig 4.18) shows its molecular ion peak at m/e 205. Several peaks with high intensity are observed at m/e 43 (base peak), 119 and 176. The peak at m/e 43 appears in both mass spectra. A fragmentation scheme is proposed in a similar fashion as that for Ia, as described in Scheme VI.

The mechanism differs only at the very last step that nitrobenzo derivative Ia (Scheme IV) is cleaved to phenyl radical

cation with m/e 75 whereas aminobezo derivaive Ib (Scheme VI) is cleaved to cyclopentadienyl radical cation with m/e 64.

A fragmentation pattern in Scheme VII is proposed to account for the mass spectrum of IIb in Fig 4.19. It should also be noticed that is a resemblance between Scheme VII for IIb and Scheme V for IIa, eary steps of the pathway. The amino pendant group on the benzene ring alters the later steps by rearranging the fragment ion m/e 90 to fragment ion m/e 63 with a loss of HCN. The rest of the fragmentation mechanism is similar to Scheme VI.

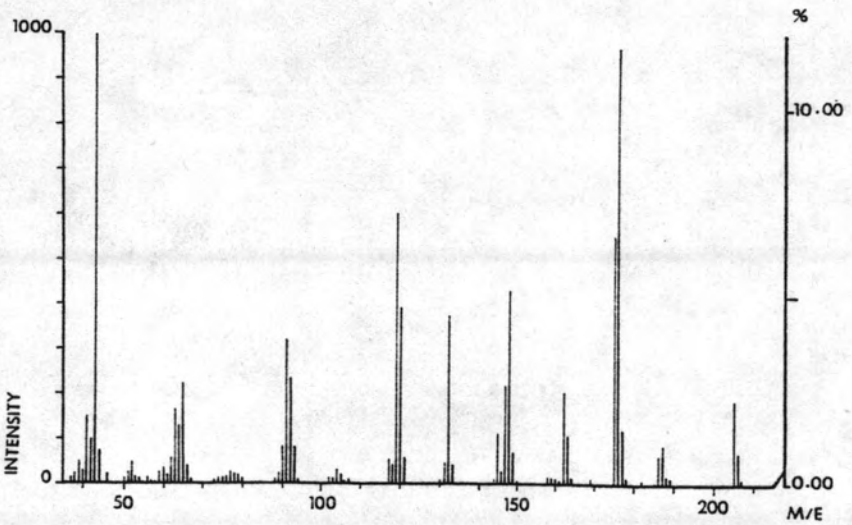
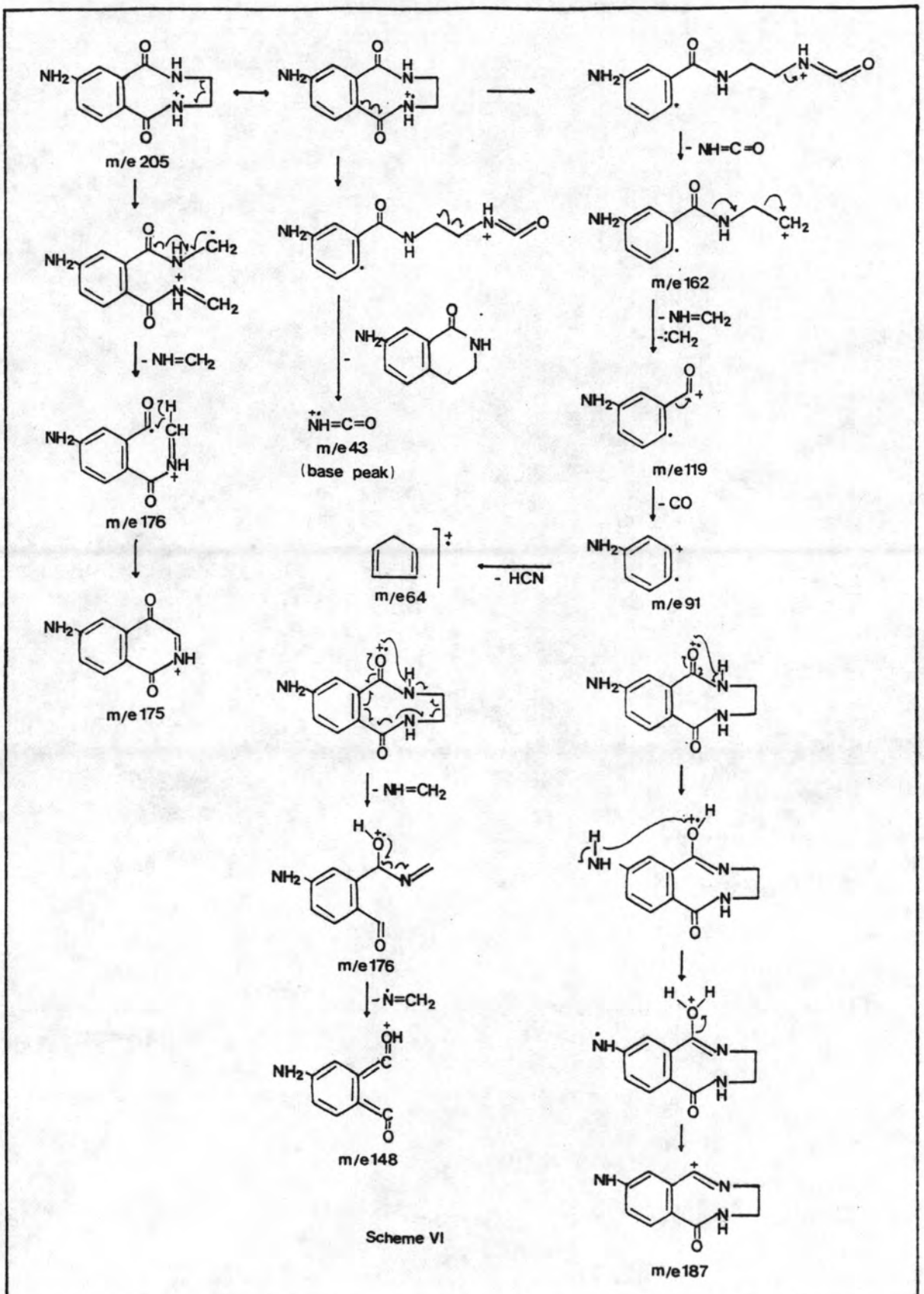


Fig 4.18 : Mass Spectrum of 3,4-(4'-aminobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ib)


m/e 205
- NH=CH2
m/e 176
m/e 175
m/e 43
(base peak)
m/e 162
- NH=CH2
-:CH2
m/e 119
- CO
m/e 91
- HCN
m/e 64
- NH=CH2
m/e 176
- ·N=CH2
m/e 148
- NH=C=O
m/e 187

Scheme VI

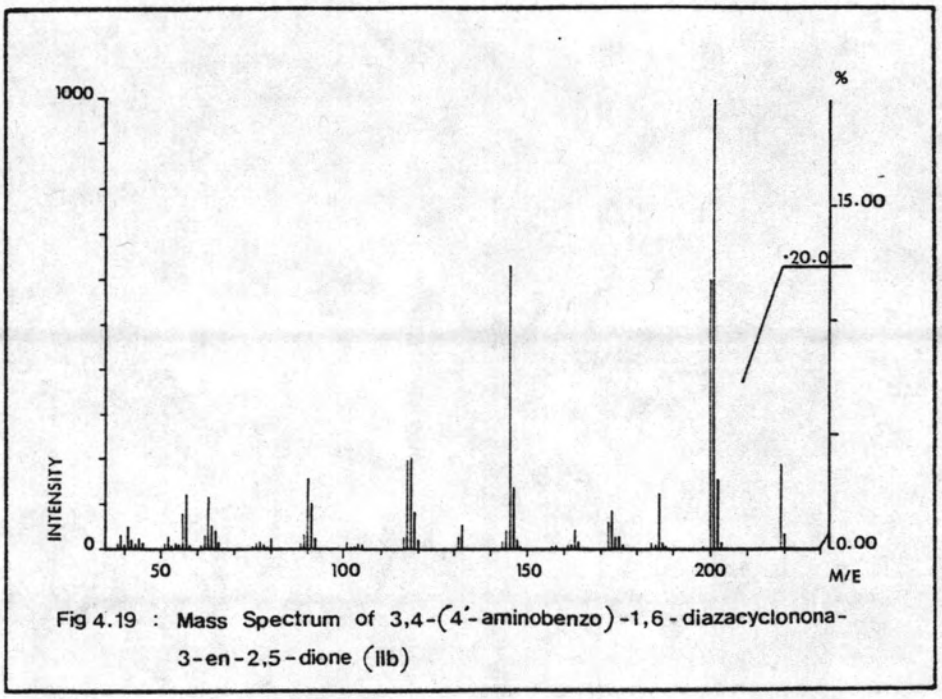
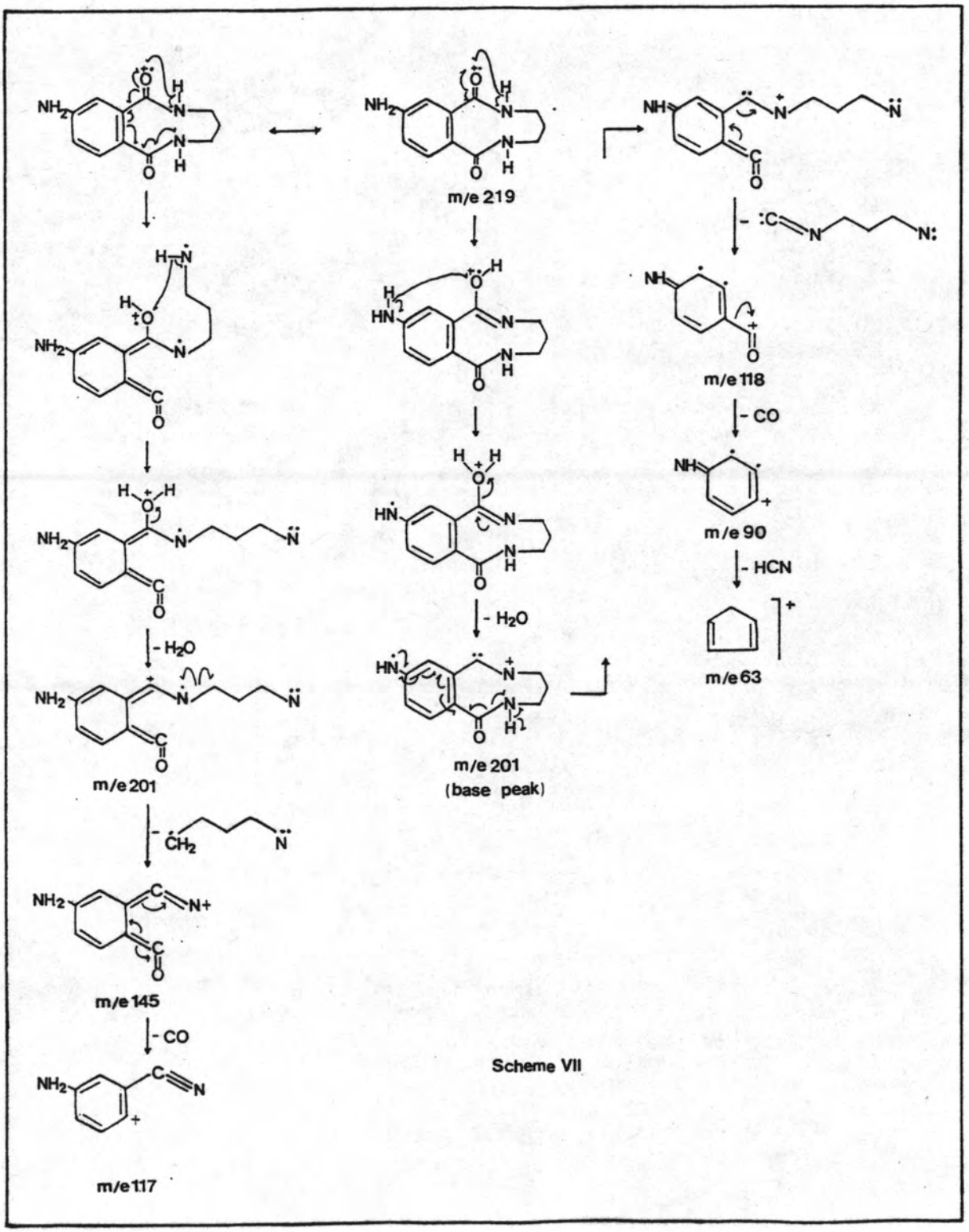


Fig 4.19 : Mass Spectrum of 3,4-(4'-aminobenzo)-1,6-diazacyclonona-3-en-2,5-dione (IIb)


m/e 219
m/e 118
- CO
m/e 90
- HCN
m/e 63
- H2O
m/e 201
(base peak)
m/e 201
- H2O
m/e 145
- CO
m/e 117

Scheme VII

4.2.3.4 Elemental Analysis

The elemental percentages for C H and N of Ib (Table 4.16) suggest a water adduct product similar to Ia and IIa. The values for IIb are out of range for any possibly proposed structure. The great deviation in the elemental percentages of IIb could be due to a decomposition of the compound prior to the analysis. Both aminobenzo derivatives (Ib and IIb) did show a color change, from white to yellowish, after several weeks with a more distinctive change in the case of IIb than Ib. However the data from spectroscopic studies discussed earlier have confirmed the formation of IIb. Moreover, the

Table 4.16 Elemental analysis data* of 3,4-(4'-aminobenzo)-1,6-diaza-cycloocta-3-en-2,5-dione (Ib) and 3,4-(4'-aminobenzo)-1,6-diazacyclo-nona-3-en-2,5-dione (IIb)

Macrocyclic polyamides		%C	%H	%N
Ib	Found	47.82	6.50	15.61
($C_{10}H_{11}N_3O_2.3H_2O$)	Calculated	46.33	6.56	16.20
IIb	Found	43.79	6.83	15.83
($C_{11}H_{13}N_3O_2.H_2O$)	Calculated	55.69	6.33	17.70
($C_{11}H_{13}N_3O_2.2H_2O$)		51.76	6.67	16.47
($C_{11}H_{13}N_3O_2.3H_2O$)		48.35	6.96	15.38

* The analysis was done much later after the synthesis.

synthesized IIb was belived to exist in a hydrated form according to its IR spectrum (Fig 4.13).

High performance thin layer chromatographic study of the freshy prepared Ib and IIb indicated a purity of >95%. Rf values (in a 1:5 chloroform : methanol solvent system) of Ib and IIb were 0.329 and 0.291, respectively. These aminobenzo analogues were considered to be less stable than their nitrobenzo analogues according to the color change mentioned above.

4.2.3.5 Electronic Absorption Spectroscopy

Spectral lines in ultraviolet region of Ib and IIb are presented in Fig 4.20. Both reveal a similarity to the spectra of their corresponding nitrobenzo analogues (Fig 4.11). The K-bands around 270 nm of Ib and IIb show a hypsochromic shift in the spectra of Ib and IIb. This could be due to the substitution of chromophoric group ($-NO_2$) with auxochromic group ($-NH_2$) which usually causes bathochromic shift to a lesser extent than the former. The K-bands of Ib and IIb are reported at 264.4 nm and 263.8 nm with molar absorptivity of 8619 and 6942, respectively. A band near 200 nm is observed in both spectra of the aminobenzo analogues and has been assigned as E_1-band ($\pi \rightarrow \pi^*$ transition). Auxochromic substitution facilitates the $\pi \rightarrow \pi^*$ transition by sharing the lone pair of electrons on the heteroatom with π - electron system of the ring and thus causes a red shift of the E_1-band from 180 nm in pure benzene to 264.4 nm and 263.8 nm in spectra of Ib and IIb. Various groups on the benzene ring, the rest of the structure ; $-NH_2$, $-\overset{O}{\overset{\|}{C}}-NH-$, $-CH_2-CH_2-$;

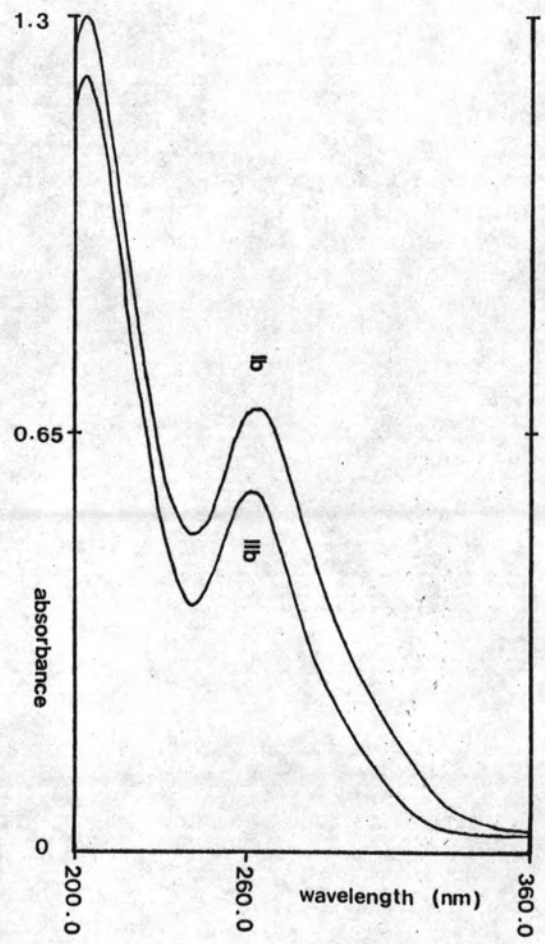


Fig 4.20 : UV Spectra of 3,4-(4'-aminobenzo)-1,6-diazacycloocta-3-en-2,5-dione (Ib) and 3,4-(4'-aminobenzo)-1,6-diazacyclonona-3-en-2,5-dione (IIb)

gave only absorptions with low intensity therefore were not observed.

2.3 Cation Binding Property and Complex Formation Study

These following cations were examined: Na(I), Mg(II), Cr(III), Mn(II) and Fe(III) as class A metals; Co(II), Ni(II), Cu(II), Pb(II) and Zn(II) as class AB metals; and Ag(I), Cd(II) and Hg(II) as class B metals. The cation binding property of synthesized macrocycles was investigated by shaking these metal ions with the synthesized ligands and the resulting complex was then extracted into chloroform. A reduction of the metal ion concentration in aqueous phase measured by atomic absorption spectrophotometric technique, indicated the extent of the extraction. The results are shown in Table 4.17. All extracting conditions were kept constant so that the data for percent extraction (%E) for each metal ion could be mutually compared.

It has been known that crown ethers have great binding ability for hard cation such as alkali or alkaline earth metal ions and thiacrown ethers, in which some or all of oxygen atoms in crown ethers are placed with sulfur atoms, posses affinity for soft cations. Macrocyclic polyamine compounds have been reported to react preferentially with transition metal or heavy metal ions. There are also some other factors, discussed in Chapter I that control the selectivity of macrocycles in binding with metal ions besides the type of the metals.

Table 4.17 Data for the Extraction of Various Metals with the Synthesized Macrocyclic Polyamide Ligands in Chloroform Solution*

Metal Ions	Types of Metal	Ionic Size(°A)	Percent Extraction (%E)			
			Ia	IIa	Ib	IIb
Na(I)	A	1.90	63.02	37.42	46.88	71.66
Mg(II)	A	1.30	5.81	4.73	8.72	8.23
Cr(III)	A	1.38	0.00	0.21	5.50	42.64
Mn(II)	A	1.60	0.71	0.39	0.00	0.00
Fe(III)	A	1.28	>99.00**	>99.00**	>99.00**	10.79
Co(II)	AB	1.48	0.29	0.80	4.10	4.76
Ni(II)	AB	1.44	0.00	0.00	0.44	0.90
Cu(II)	AB	1.78	0.00	2.20	11.18	55.80
Pb(II)	AB	2.40	90.26	49.60	90.81	17.52
Zn(II)	AB	1.48	0.00	0.00	0.00	49.27
Ag(I)	B	2.52	0.00	0.00	1.67	1.74
Cd(II)	B	1.94	0.00	0.48	0.00	10.88
Hg(II)	B	2.20	0.01	3.19	50.79	46.81

* All data for liquid - liquid extraction were triplicate analysis.

** The metal concentrations in aqueous phase after extraction were lower than the detection limit of the instrument.

The macrocyclic polyamides synthesized in this work showed binding ability to hard (class A), borderline (class AB) and soft (class B) metal ions but to a lesser extent than the other two classes (Table 4.15). All synthesized compounds appreciably bound an alkali ion like Na^+ ion with not large discrepancy in %E values between nitrobenzo and aminobenzo derivatives. Among first row transition metals; Mn(II), Cr(III), Co(II), Ni(II) and Cu(II) and post transition metals; Zn(II) and Cd(II), the experimental %E values are well less than 1 for nitrobenzo macrocyclic polyamides (Ia and IIa). This implies that the complex formation did not substantially occur therefore the metals were practically not extracted. However, the %E values are slightly higher in the case of aminobenzo macrocyclic polyamides (Ib and IIb), except Cr (III)-IIb and Zn(II)-IIb, with the value for IIb being much higher than that of Ib in each metal. This could be partly due to the ring size difference. In all cases, the stability of complexes (according to %E values) does not strictly follow Irving - Williams series (113). Therefore, the functional group on benzene ring is not believed to play any role in the complex formation.

Aminobenzo macrocyclic polyamides (Ib and IIb) exhibited a considerable affinity for Hg (II) ion, 50.79 %E and 46.81 %E, respectively. The %E values for the nitrobenzo derivatives are much lower than those of aminobenzo derivatives (Table 4.15). This observance supports the effect of pendant groups of the macrocycle on cation binding property.

All synthesized macrocycles, except IIb, showed high values of %E (>99.00%) for Fe(III) which belongs to class A metals. Lead (II) ion (class AB) was also significantly extracted by the synthesized macrocyclic compounds though IIb gave a low %E value. It is noticed that among metal ions with high %E values; Na (I), Fe(III) and Pb(II); the ionic sizes differ appreciably therefore the ring sizes of the rather small synthetic macrocycles in this study were not the only predominant factor affecting their binding ability to these metals.

According to the experimental data in Table 4.15 there are no general trends concerning either the type of metal, the size of metal, the charge on metal or the size of the macrocycle could be drawn. The amide functional group, which now acts as a donor of the mcrocycle via N atom, seems to be a softer base than amine group that it selectively bound all three classes while macrocyclic polyamines mostly bind with first row transition metals especially Ni(II) (70-72). Earier studies (13,33) of macrocyclic polyamines with comparable sizes to those of metal ions have shown that the metal ion size plays an important role in the binding ability of the ligand. This was not distinctly observed in this study due to a much rather small size of the macrocyclic polyamide compounds.

Lead(II) and sodium(I) ions were chosen for the complex formation study. A conductance of Pb(II)-ligand solution at various mole ratios was measured and plotted against the mole ratio value. Figure 4.21 illustrates such a plot. Each graph shows a curvation at the break point which indicates a dissociation of the complex. All four macrocyclic polyamide ligands bound with Pb(II) ion as a 1:1

complex. The cation was not expected to fit in the cavity of the macrocyclic ring in all cases due to its large size (2.40 ^{o}A) as compared to the rather small 8- or 9-membered ring macrocycle. Pb(II) - IIb complex system gave a line with similar degree of curvature as in the cases of Ia, IIa and Ib though the %E value for IIb was much lower than the other three numbers. This may imply the same extent in complex formation but different in extractability. Na(I) ion also yielded a 1:1 complex formation with all macrocycles with a less slope value than in the case Pb(II) - macrocycle complexes (Fig 4.21 - Fig 4.24). This is in a good agreement with the less %E of Na(I) than that of Pb (II) (Table 4.17).

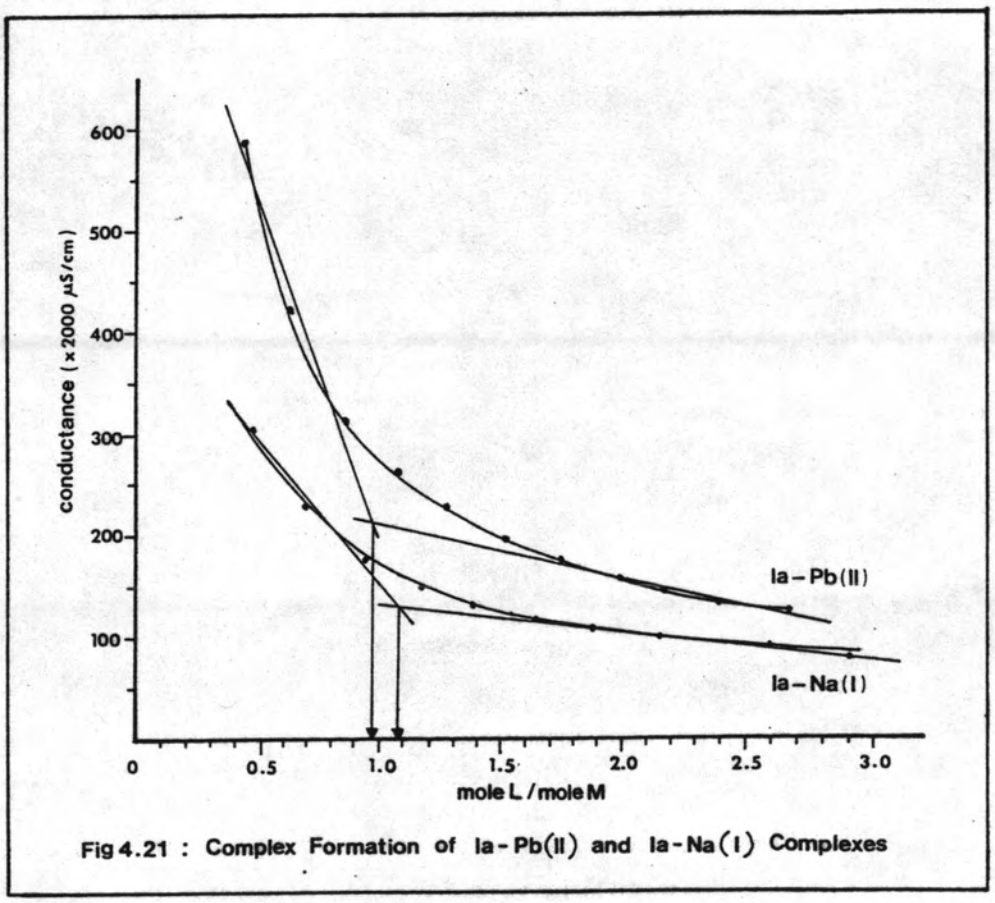


Fig 4.21 : Complex Formation of Ia - Pb(II) and Ia - Na(I) Complexes

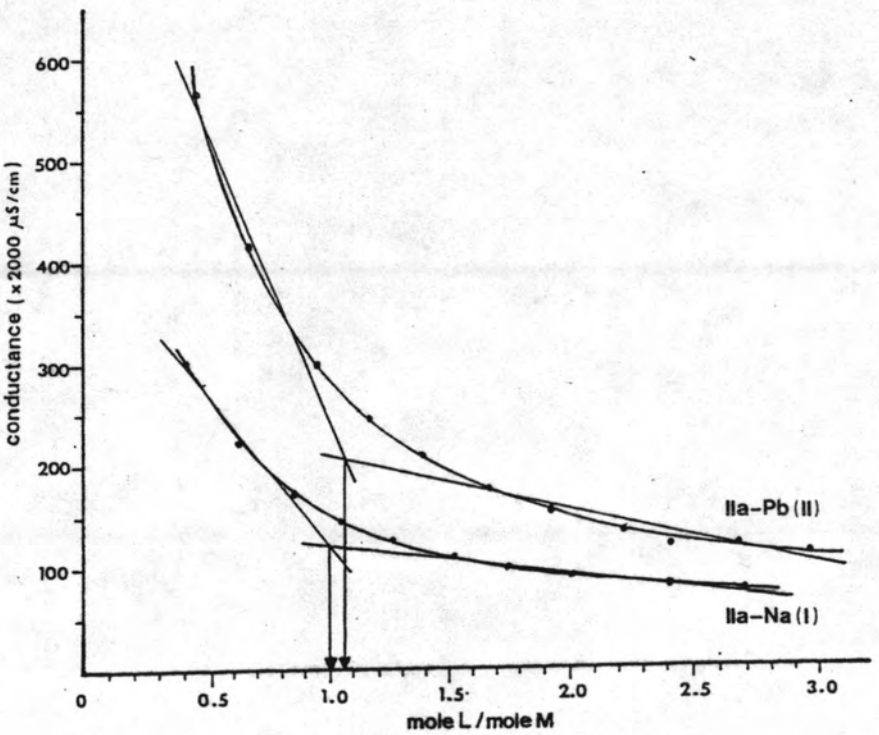


Fig 4.22 : Complex Formation of IIa - Pb(II) and IIa - Na(I) Complexes

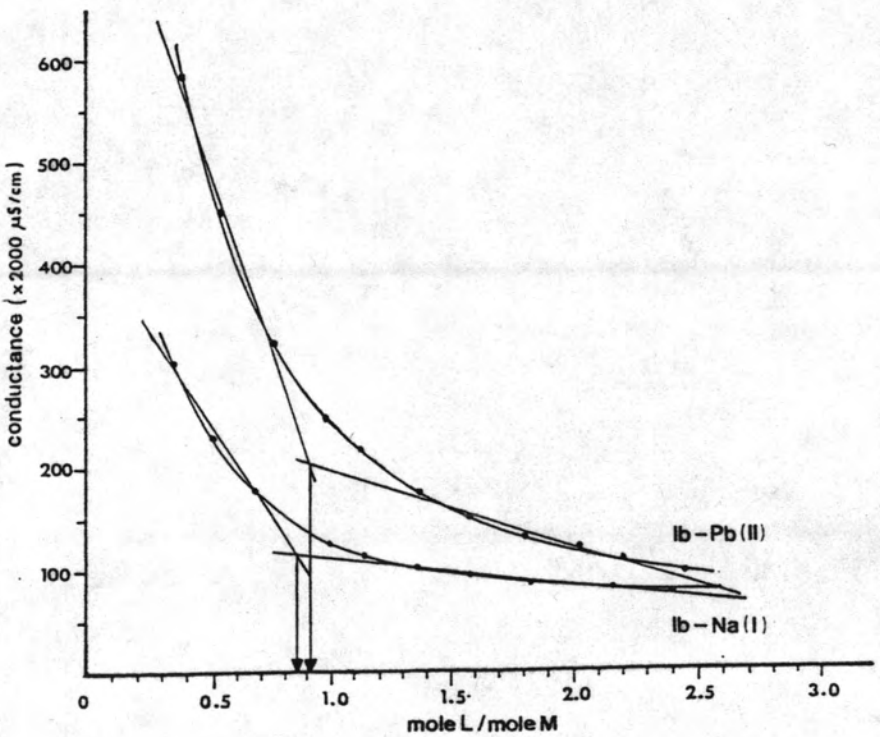


Fig 4.23 : Complex Formation of Ib – Pb(II) and Ib – Na(I) Complexes

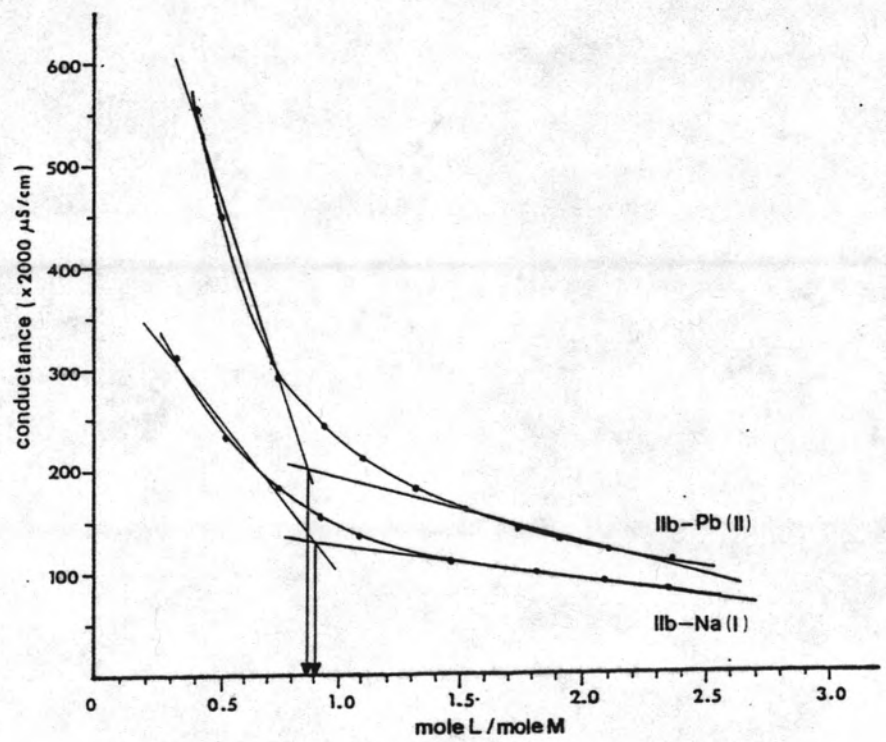


Fig 4.24 : Complex Formation of IIb - Pb(II) and IIb - Na(I) Complexes