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SYNTHESIS OF SOME SELECT BENZO-ANNELATED AND/OR
METHANO-BRIDGED SULFUR HETEROCYCLICS--
MECHANISTIC AND THEORETICAL STUDY OF THEIR SULFUR
EXTRUSION

by

RONNIE BENSCHAFRUT

A dissertation submitted to the
Graduate Faculty in Chemistry in
partial fulfillment of the requirements
for the degree of Doctor of Philosophy,
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Abstract**SYNTHESIS OF SOME SELECT BENZO-ANNELATED AND/OR
METHANO-BRIDGED SULFUR HETEROCYCLICS--
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EXTRUSION**

by

Ronnie Benshafut

Adviser: Professor Klaus G. Grohmann

The studies of thiepins and 1,2-dithiocins have seen only limited success due to their great instabilities and tendencies of valence isomerization leading to sulfur extrusion. This still unknown mechanism of sulfur extrusion may be controlled by various methods such as selective substitution and annelation. Benzannelation allowed the synthesis of various thiepins and 1,2-dithiocins which were found sensitive and difficult to study. Benzannelation is traditionally believed to increase the barrier for extrusion of sulfur units as an o-quinoid is formed en route to extrusion. We thus attempted the synthesis of such thiepins where sulfur extrusion is minimized and controlled. Increased stability of the thiepin skeleton

was found when methano-bridging was present. Thiepin **IV** has been synthesized and determined to be resistant of sulfur extrusion. The effects of benzannelation are further examined in regards to reduction in paramagnetic/diamagnetic ring currents.

The effects of benzannelation have been extensively investigated in various systems and were shown to result in bond fixation and reduction in ring currents. Benzannelation of methano-bridged annulenes, however, has been studied only rarely due to the unavailability of simple precursors. The new, one-pot synthesis of 3,4-benzcycloheptatriene-1,6-dicarboxaldehyde opens the door to such investigations. Successful synthesis of benzannelated, non-aromatic and $4n$ antiaromatic annulenes has been achieved providing insight as to the stability, chemistry and ring currents as compared with known parent non-annelated systems. In the $4n$ systems, reduction in paratropicity is evident with annelation sites determining the degree of reduction. With $4n+2$ systems, however, such reductions were not obvious.

This dissertation as a whole describes and discusses the synthesis and study of benzannelation of methano-bridged annulenes. Complete experimental discussions and results are presented, supported by relevant spectroscopical data.

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Beginnings, I find, are difficult creations. Where do I start thanking all of those I owe greatly? Probably where all creations start--at the beginning. To my parents who have been an inspiration and a great source of support I send my immense love and appreciation. A person is only blessed with family such as mine. To my brother, sister and their families, who stood behind me, throughout this ordeal, in full armor I send my love and thanks. To my wife, my light and delight I owe a lifetime of gratitude; for her exceptional devotion, support, patience and understanding in times of trouble, I thank her. A man, again, can not ask for more.

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TO MY PARENTS AND MY WIFE

IN MEMORY OF MY GRANDMOTHER

Table of Contents

ABSTRACT.....	iv
ACKNOWLEDGEMENT.....	v

CHAPTER 1

1.0.0	INTRODUCTION	
1.1.0	OXEPIN, AZEPIN, THIEPIN AND OTHER HETEROCYCLIC SEVEN-MEMBERED RINGS.....	1
1.2.0	THIEPINS	
1.2.1	THERMAL STABILITY AND SULFUR EXTRUSION.....	7
1.2.2	THE EARLY YEARS.....	7
1.2.3	MECHANISM OF SULFUR EXTRUSION.....	10
1.3.0	STABILIZING DEVICES FOR THIEPIN.....	14
1.3.1	FUSION OF BENZENE RINGS.....	14
1.3.2	ELECTRONIC EFFECTS ON SUBSTITUTION.....	20
1.3.3	METHANO BRIDGED THIEPINS.....	24
1.3.4	STERIC EFFECTS OF SUBSTITUENTS ON C ₂ AND C ₇	25
1.3.5	OTHER SUBSTITUTION AND ANNELATION EFFECTS.....	29
1.4.0	1,2 AND 1,4-DITHIOCINS.....	38

CHAPTER 2

2.0.0	DISCUSSION AND RESULTS	
2.1.0	THEORETICAL APPROACH.....	54
2.2.0	SYNTHESIS AND INVESTIGATIONS OF STABILIZED THIEPINS AND 1,2-DITHIOCINS.....	64
2.2.1	SULFIDE ADDITION TO ACETYLENS.....	64
2.2.2	SYNTHESIS AND INVESTIGATION OF NAPHTHO[d] THIEPIN, I.....	76
2.2.3	ATTEMPTED SYNTHESIS OF NAPHTHO[2,3-d] 1,2- DITHIOCIN, II.....	92
2.2.4	INVESTIGATIONS OF 1,2,3-TRITHIEPIN, III.....	95
2.3.0	SYNTHETIC APPROACH TOWARDS 4,9- METHANO-6,7- BENZO-1-THIAUNDECA- 2,4,6,8,10-PENTAENE, IV.....	116
2.3.1	SYNTHESIS OF 3,4-BENZCYCLOHEPTATRIENE-1,6- DICARBOXALDEHYDE, 220.....	121
2.4.0	CHEMISTRY OF 1,6-DIETHYNYL-3,4-BENZ- CYCLOHEPTATRIENE, 129.....	144
2.4.1	SYNTHESIS AND INVESTIGATIONS OF THIEPIN IV.....	144
2.4.2	THE OXIDES OF THIEPIN IV: THIEPIN-1-OXIDE, 260, AND THIEPIN-1,1-DIOXIDE 261.....	165
2.4.3	INVESTIGATION OF 5,9-METHANO-7,8-BENZO-1,2- DITHIADODECA-3,5,7,9,11-PENTAENE, V.....	175
2.5.0	ANNELATIONS VIA 3,4-BENZ- CYCLOHEPTATRIENE-1,6- DICARBOX-	

	ALDEHYDE, 220.....	179
2.5.1	SYNTHESIS AND INVESTIGATION OF 3,4-BENZ-1,6-METHANO[10]ANNULENE, VI.....	182
2.5.2	SYNTHESIS OF 9-BENZBICYCLO [5.4.1]DODECA-2,5,7,9,11-PENTAENE, 270.....	196
2.5.3	SYNTHESIS OF BENZBICYCLO[5.4.1]DODECAPENTAENYLUM CATION, 290--AN AROMATIC BRIDGED 10II CATION.....	214
2.5.4	SYNTHESIS AND INVESTIGATION OF HOMOTROPONES 273 AND 283	222
2.5.6	SYNTHESIS OF BENZO-1,6-METHANO[12]ANNULENE, 272.....	245
2.6.0	SYNTHESIS AND INVESTIGATION OF TRIS METHANO[30] ANNULENE, 340.....	263

CHAPTER 3

3.0.0	A GLANCE TO THE FUTURE.....	271

CHAPTER 4

5.0.0	EXPERIMENTAL SECTION.....	276
5.1.0	GENERAL PROCEDURE.....	276
5.2.0	SPECTROSCOPY.....	277

5.3.0	EXPERIMENTAL PROCEDURES.....	280
6.0.0	¹H, ¹³C NMR, MS, AND IR OF SOME SELECTED COMPOUNDS.....	312
	REFERENCES.....	497

List of Tables

Table 1:	Thermal Stability and Benzo-Annellation of Thiepin.....	14
Table 2:	Bond Orders as Measurements of Stability.....	19
Table 3:	Substitution Effects on Benzo[b] and Naphtho[2,3-b] Thiepins.....	22
Table 4:	Oxides and Dioxides of Thiepins.....	32
Table 5:	AM1 Calculated Geometrical Parameters for 61 , 70 , and 72	54
Table 6:	Heats of Formation of 1,2-Dithietane vs. 1,4-Diradical Intermediates.....	57
Table 7:	Heats of Formation of Minima and Transition States.....	60
Table 8:	AM1 Calculated HOMO-LUMO Energies of Selected Vinylsulfides and Useful Dienes.....	114
Table 9:	Aldol Condensations of 1,5-Glutaric Dialdehyde.....	128
Table 10:	Stability of 221 Under Various Conditions.....	142
Table 11:	Stability of Thiepin IV	146
Table 12:	¹ H NMR Data Comparison Between Thiepin 212 and IV	159
Table 13:	Sulfur Extrusion in Various Thiepins.....	161
Table 14:	Sulfur Extrusion Attempts from IV	162
Table 15:	Stability Comparison of Thiepin IV and Its Oxides 260 and 261	166
Table 16:	¹ H NMR Data for Thiepin IV and Its Oxides 260 and 261	167
Table 17:	¹ H NMR Assignment of 280	210

Table 18: ^1H NMR Resonances for 290 as Compared With 270	218
Table 19: ^1H NMR Summary of 228	230
Table 20: ^1H NMR Summary of Ketone 229	232
Table 21: Chemical Shift Summary for 283 and 283a	238
Table 22: Chemical Shift Differences of Bridge Protons.....	241
Table 23: ^1H NMR Chemical Shift of Selected H_α and H_β	243
Table 24: NMR Summary of ^1H , COSY, and NOESY of Isomer 315	252
Table 25: ^1H NMR Resonances for Bridge Protons as Measurement of Relative Paratropicity.....	260

List of Figures

Figure 1: Seven Membered Heterocyclics.....	1
Figure 2: Benzene Oxide (1a)-Oxepin (1b) Equilibrium.....	2
Figure 3: Non-planarity in Oxepin 1.....	3
Figure 4: ¹ H NMR of 6.....	4
Figure 5: Non-aromatic 8 π Boratepin, 7.....	5
Figure 6: Boratepin-Boratanorcaradiene Equilibrium.....	5
Figure 7: Phenothiazine, 8.....	7
Figure 8: Dibenzo[b,f]thiepin 11.....	9
Figure 9: Mechanism of Sulfur Extrusion in Thiepin.....	10
Figure 10: Mechanism of Catalytic Desulfurization.....	12
Figure 11: Simplest Thiepin Synthesized, 32.....	20
Figure 12: A Stable Monocyclic Thiepin, 33.....	21
Figure 13: Murata's Stable Monocyclic, 37, and Schlessinger's Tetracyclic Thiepin, 38.....	25
Figure 14: 2,7-Steric Stabilization of Thiepin 39.....	26
Figure 15: Kuroda's Thiepin.....	41
Figure 16: Stabilization of 42 via Charge Separated Resonances... 2	9
Figure 17: Sulfur Extrusion in 42.....	30
Figure 18: Stabilization of Thiepin-1,1-Dioxide, 48.....	33
Figure 19: (Thiepin)Iron Tricarbonyl, 52.....	35
Figure 20: NMR Parameters as Influenced by Metal Complexation.....	37
Figure 21: ¹ H NMR Parameters of 20 and 51.....	37
Figure 22: 220 as a Building Block for the Synthesis of Thiepin	

IV.....	118
Figure 23: ¹ H NMR of 220	125
Figure 24: ¹ H NMR of 240	138
Figure 25: ¹ H NMR Splitting of the Vinylic Protons in 240	138
Figure 26: 2D COSY Spectrum of IV	148
Figure 27: NOE Values Established for Thiepin IV	149
Figure 28: Geometrical Isomerization of Syn/Anti Forms.....	152
Figure 29: ¹ H NMR Spectra of Syn-247 and Anti-247	155
Figure 30: Cyncloheptatriene as Model of Homoaromaticity; or, Is Thiepin IV Homoaromatic?.....	156
Figure 31: ¹ H NMR of Thiepin IV , Oxide 260 and Dioxide 261	168
Figure 32: UV Absorptions of E,Z-Distyrylsulfide, 106 , Sulfoxide, 262 and Sulfone 263	171
Figure 33: UV Spectra of IV , 260 and 261	172
Figure 34: Mass Spectra of Thiepin IV , sulfone 261	173
Figure 35: ORTEP Drawing of Sulfone 261	174
Figure 36: ¹ H NMR of 270	202
Figure 37: 2D-COSY Spectrum of 270	203
Figure 38: NOE Values and Final Spectral Assignment of 270	204
Figure 39: Splitting Pattern and Coupling Constants for Proton H_{4b}	205
Figure 40: Splitting Pattern and Coupling Constants for Proton H_{4a}	206
Figure 41: Splitting Pattern and Coupling Constants for Proton H_3	207
Figure 42: ¹ H NMR Spectrum of 280	208

Figure 43: 2D-COSY Spectrum of 280	209
Figure 44: ORTEP Drawing of 270	213
Figure 45: Aromatic 6π , 10π , and 14π Charged Annulenes.....	214
Figure 46: ^1H NMR of 290 in CD_3CN	219
Figure 47: Expansion of Aromatic Region in the NMR of 290	219
Figure 48: ^1H NMR of Tropone 273 and Ketones 228 and 229	229
Figure 49: ^1H NMR of 273	234
Figure 50: ^1H NMR of 283	236
Figure 51: ^1H NMR Assignment of Isomer 315	251
Figure 52: ^1H NMR Spectrum of 316	255
Figure 53: ^1H NMR of [12]Annulene 272	256
Figure 54: ^{13}C NMR of Monomer 221 and [30]Annulene, 340	267
Figure 55: ORTEP Drawing of Trimer 340	269

List of Schemes

Scheme 1:	Synthesis of 9	8
Scheme 2:	Sulfur Extrusion from Syn-Benzene Bisepisulfide, 12	11
Scheme 3:	Thiepin-Thianocaradiene Equilibrium in 26 a , 29 , and 9a	17
Scheme 4:	Resonance Stabilizing “Push-Pull” Mechanism in 33	23
Scheme 5:	Sulfur Extrusion from Diels-Alder Adducts of Thiepin 44	30
Scheme 6:	Synthesis of Thiepin-1,1-Dioxide, 48	32
Scheme 7:	Transition Metal Approach for the Synthesis of 49	34
Scheme 8:	Synthesis of 52	36
Scheme 9:	Sulfur Extrusion from 1,4-Dithiocin, 60 , and 1,2-Dithiocin, 61	38
Scheme 10:	Vogel’s Approach Towards 1,4-Dithiocin.....	41
Scheme 11:	Coffen’s Approach Towards 1,4-Dithiocins.....	41
Scheme 12:	Attempted Synthesis of Benzo[d]-1,2-Dithiocin, 70	43
Scheme 13:	Reaction Path for the Extrusion of Diatomic Sulfur from 1,2-Dithiocin 61	61
Scheme 14:	Reaction Path for the Extrusion of Diatomic Sulfur from Benz[d]1,2-Dithiocin 70	62

Scheme 15:	Synthesis of E,Z-Distyrylsulfide, 106	69
Scheme 16:	Debenzylation and Thiolate Trapping with Acetyl Chloride.....	73
Scheme 17:	Synthetic Paths Towards Thiepin I	76
Scheme 18:	Synthesis of Endoxide 123	78
Scheme 19:	Synthesis of 132 via Hydrogenation-Deoxygenation of 123	79
Scheme 20:	Mechanism of Pd-Coupling of Acetylenes to Arylhalides.....	82
Scheme 21:	Lepage's Synthesis of Naphthalene-2,3-dialdehyde, 131	83
Scheme 22:	Synthesis of 130 via Wittig/Fritsch-Butterburg-Wiechell Sequence.....	84
Scheme 23:	Fritsch-Butterburg-Wiechell Rearrangement.....	86
Scheme 24:	Third Approach Towards 130	87
Scheme 25:	Attempted Synthesis of Naphtho[2,3-d] Thiepin, I , via Sulfide Addition.....	89
Scheme 26:	Distyrylsulfides via Wittig-Horner olefination.....	90
Scheme 27:	Attempted synthesis of I via Wittig-Horner Olefination.....	91
Scheme 29:	Attempted Synthesis of II via Disulfide Addition to 130	93
Scheme 30:	Schroth's Synthesis of Trithiepin 164	96
Scheme 31:	Schroth's Synthesis of 1,2-Dithiin.....	99
Scheme 32:	Mechanism of Sulfur Extrusion from 1,2-	

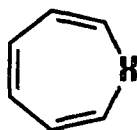
	Dithiin.....	103
Scheme 33:	Synthesis of 1,2-Dithiin, 166.....	105
Scheme 34:	Attempted Synthesis of 1,2,3-Trithiepin III.....	108
Scheme 35:	Two Approaches for the Synthesis of 211.....	119
Scheme 36:	6-Step Synthesis of 220.....	122
Scheme 37:	Synthesis of 3,4-Benzcycloheptatriene-1,6-dicarboxaldehyde, 220.....	123
Scheme 38:	Failed Condensation of 220 with Glutaric- and Succinic Dialdehydes.....	132
Scheme 39:	Reaction of 220 with Hydrazines and Hydroxylamine.....	133
Scheme 40:	Dehydration of 235.....	134
Scheme 41:	Synthesis of 1,6-Bis(β,β -dibromovinyl)3,4-benzcycloheptatriene, 237.....	135
Scheme 42:	Synthesis of 240.....	137
Scheme 43:	Fritsch-Buttenburg-Wiechell Rearrangement of 237.....	141
Scheme 44:	Synthesis of Thiepin IV.....	144
Scheme 45:	Synthesis of 241.....	164
Scheme 46:	Attempted Synthesis of 1,2-Dithiocin, V.....	175
Scheme 47:	Attempted Debenzylation of 361 and 362.....	176
Scheme 48:	Synthesis of Precursor 367.....	178
Scheme 49:	Synthetic Methods Towards Benzo-1,6-Methano[10]Annulene, VI.....	186
Scheme 50:	Synthesis of 291.....	187
Scheme 51:	Thermal Dehydrohalogenation cyclization.....	188

Scheme 52:	1,3-Dithiane Approach Towards VI.....	190
Scheme 53:	Methylation of Bis-Dithiane 295.....	191
Scheme 54:	Forth Approach Towards VI.....	194
Scheme 55:	DDQ Oxidation of 268.....	195
Scheme 56:	Synthesis of Bismethano 270 and 280.....	196
Scheme 57:	Synthesis of Wittig's Benzcycloheptatrienes.....	197
Scheme 58:	Isomerization of 270 and 280.....	201
Scheme 59:	Synthesis of 290 via Hydride Abstraction from 270/280.....	217
Scheme 60:	Synthesis of Homotropone, 288.....	224
Scheme 61:	Synthesis of Homonaphthotropone, 273.....	226
Scheme 62:	Oxidation to Ketones 228 and 229.....	228
Scheme 63:	Synthesis of 283.....	235
Scheme 64:	Synthesis of 316 and 272.....	246
Scheme 65:	Isomerization of 316 via Dianion 313.....	249
Scheme 66:	Oxidation of Dianion 313 to Antiaromatic [12]Annulene, 272.....	250
Scheme 67:	Synthesis of 272 via Bromination/Elimination Sequence.....	254
Scheme 68:	Synthesis of 318.....	257
Scheme 69:	Synthesis of Dibenzmethano[12]Annulene 319.....	259
Scheme 70:	Synthesis of Trimer 340.....	265
Scheme 71:	Attempted Synthesis of Thiophene Trimer, 341.....	270

1.0.0. INTRODUCTION

1.1.0. OXEPIN, AZEPIN, THIEPIN AND OTHER SEVEN-MEMBERED RINGS

A great deal of interest was expressed in the field of seven-membered heterocyclics since the discovery of the tropylium ion. Formally analogues of furan, pyrrole and thiophene and potentially 8π electron systems, isoelectronic with cyclooctatetraene, oxepin **1**, azepin **2**, and thiepin **3** were just the right systems to satisfy the great interest of chemists in the early years of the 1950's. Despite their simple structures, the three parent compounds resisted synthesis for many years. Of the three, the parent thiepin, **3**, is still unknown.



- 1: X=O
- 2: X=N-H
- 3: X=S
- 4: X=B-CH₃
- 5: X=SiRR'

Figure 1: Seven membered Heterocyclics

Little is known about thiepins because of their thermal instabilities resulting in sulfur extrusion. In contrast, oxepin¹ and azepin² have been synthesized and investigated. Several other hetero seven-membered ring systems such as borepin **4**³, and silepene, **5**⁴ have been synthesized recently, as well. Related chemistry is briefly discussed at the end of this section.

Benzene oxide **1a** and the potentially 8π electron antiaromatic oxepin **1b** exist in a valence-tautomeric equilibrium to which both species contribute equally. This system (Figure 2) is classified as a system having fluctuating bonds and for which equilibrium can be shifted from one extreme to the other upon substitution. Nevertheless, it is the benzene oxide component that determines the oxepin chemistry⁵.

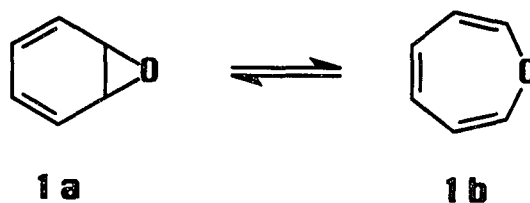


Figure 2: Benzene oxide (**1a**)- Oxepin (**1b**) equilibrium

Effects similar to those influencing the oxepin or cycloheptatriene systems have been detected with the azepin series. No compound having a definite benzene imine structure has so far been detected. Yet, there were several indications of the existence of a valence-tautomeric equilibrium in these systems⁶.

In all cases investigated the oxepins and azepins showed no aromatic stabilization. As an 8π Hückel antiaromatic systems, one may expect large shielding of the ring protons. In fact ^1H NMR studies supported by UV studies indicated a triene type system. Moreover, these investigations indicated that the seven membered ring possesses a non-planar skeleton. In fact, oxepin should have a conformation similar to that of cycloheptatriene and exist in a boat form (Figure 3).



Figure 3: Non-planarity in oxepin 1.

The heterocyclic borepin **4** is of substantial interest as a 6π analogue of the tropylium ion **3**. MO calculations suggested that **4** is only slightly aromatic due to boron's electropositive character

compared with carbon. The ^1H NMR of borepin **6** indicates a strong diamagnetic ring current compared with 4,5-dihydroborepin (Figure 4).

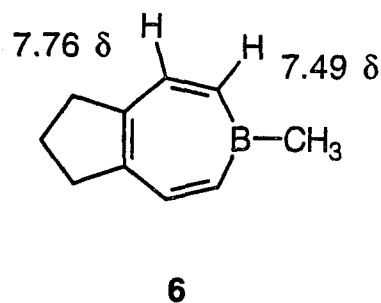


Figure 4: ^1H NMR of **6**

This diamagnetic shift may be attributed to a 6π electron ring current or to a substantial carbon-boron electron donation power which decreases electron density on C_2 and C_7 . Treatment of **6** with methyllithium, produced the Li salt **7**. This formally 8π electron system was found too to be non-aromatic. No valence tautomerization equilibrium with boratanorcaradiene was detected (Figure 5).

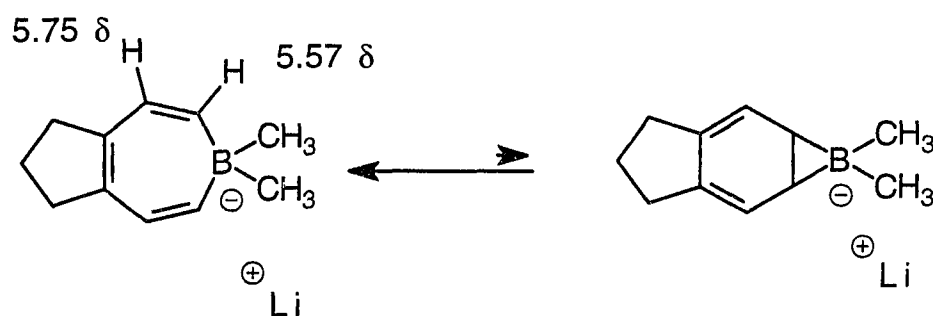


Figure 5: Non-aromatic 8π boratepin, **7**.

However, Schuster⁷ reported the favored equilibrium of boratepin, **7**, (Figure 6) as being the boratanocaradiene form.

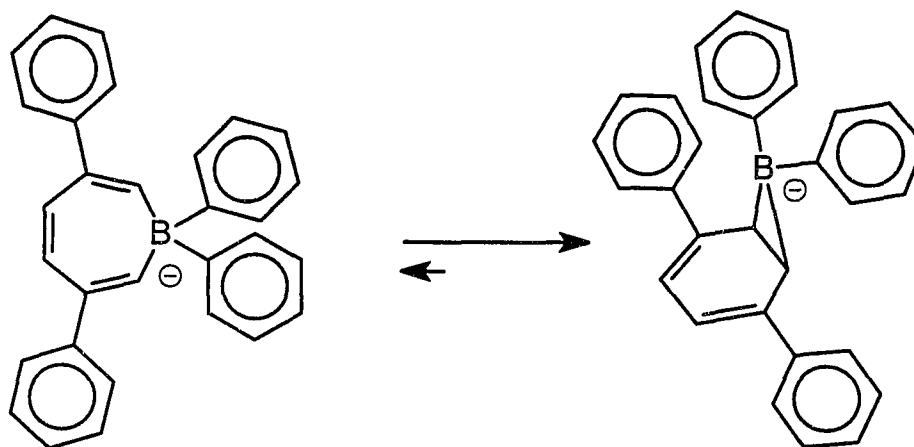


Figure 6: Boratepin - Boratanocaradiene equilibrium.

Factors that effect the oxepin-benzene oxide equilibrium, are expected to affect the thiepin-thianocaradiene distribution at equilibrium. NMR spectral evidence for the existence of the valence tautomeric thianocaradiene form has never been obtained. And so, the existing evidence for this tautomer is based upon the thermal instabilities of the thiepin systems. Thus, it is assumed that where the benzene-episulfide form is present, a spontaneous thermal decomposition involving sulfur extrusion will occur. In other words, while the most common thermal reaction of oxepins involves rearrangements to the isomeric phenols, thiepins appear to aromatize with sulfur extrusion.

1.2.0 THIEPINS

1.2.1 THERMAL STABILITY AND SULFUR EXTRUSION

1.2.2 THE EARLY YEARS

A large number of observations have contributed to the view that a sulfur atom is fairly readily extruded from a heterocyclic if the ring contraction involved leads to an aromatic system. The first report of a thia atom expulsion seems to be Goske's observation that phenothiazine, **8**, and several of its benzo-derivatives extrude sulfur when heated with copper to yield the corresponding carbazoles⁸.

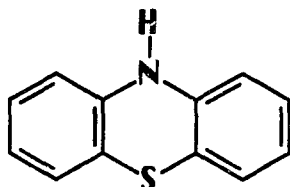
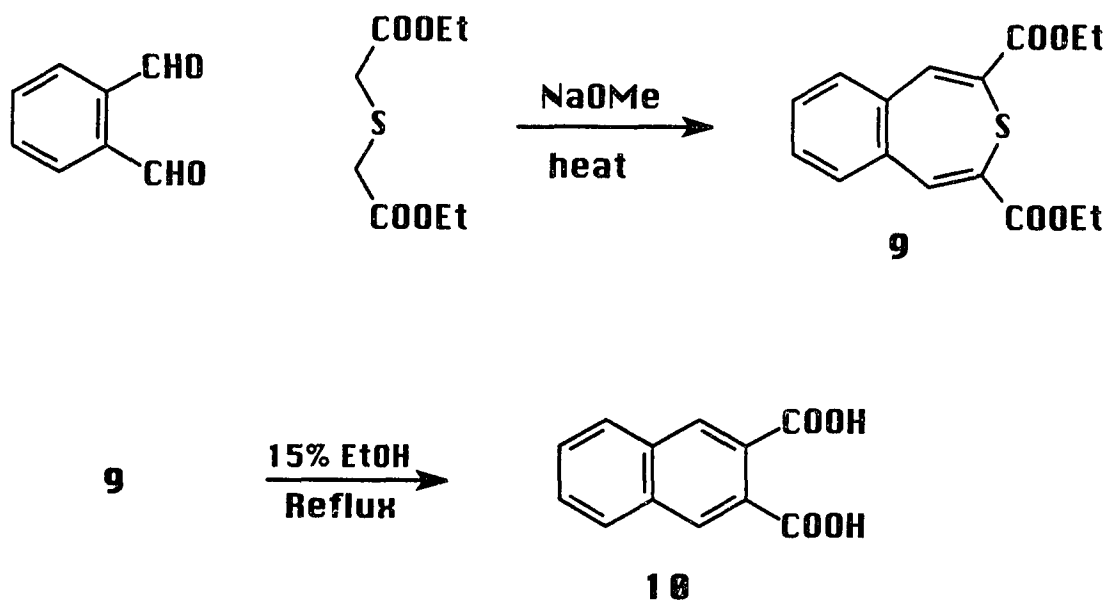


Figure 7: Phenothiazine, 8

A particularly ready extrusion has been observed by G. P. Scott in the then newly explored class of thiepins. 3-Benzothiepin-2,4-carboxylic acid, **9**, was synthesized **9** as shown in scheme 1.



Scheme 1: Synthesis of **9**

Attempts to convert the diacid into series of simple derivatives in refluxing 15% ethanol yielded a white crystalline, sulfur free acid, in quantitative yield. Analysis identified the product as naphthalene-2,3-dicarboxylic acid **10**.

Loudon, Slaon and Summers showed four years later that similar extrusion is observed with derivatives of dibenzo[b,f]thiepin¹⁰ **11**.

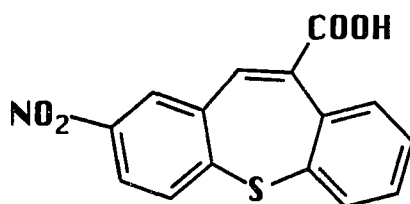


Figure 8: Dibenzo[b,f]thiepin **11**.

When **11** was refluxed in quinoline in the presence of copper, decarboxylation and sulfur extrusion were achieved. However, when **11** was refluxed in the absence of copper, no desulfurization was observed. It was clear then that extrusion of sulfur leading to an aromatic system may be affected by means of ring fusion and substitution.

1.2.3 MECHANISM OF SULFUR EXTRUSION

Extrusion of sulfur is believed to occur by valence isomerization via a disrotatory ring contraction, followed by chelotropic sulfur extrusion (Figure 9).

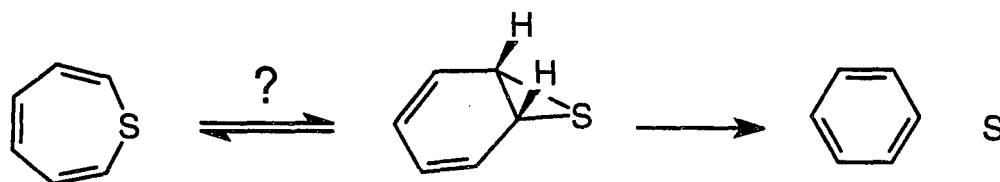
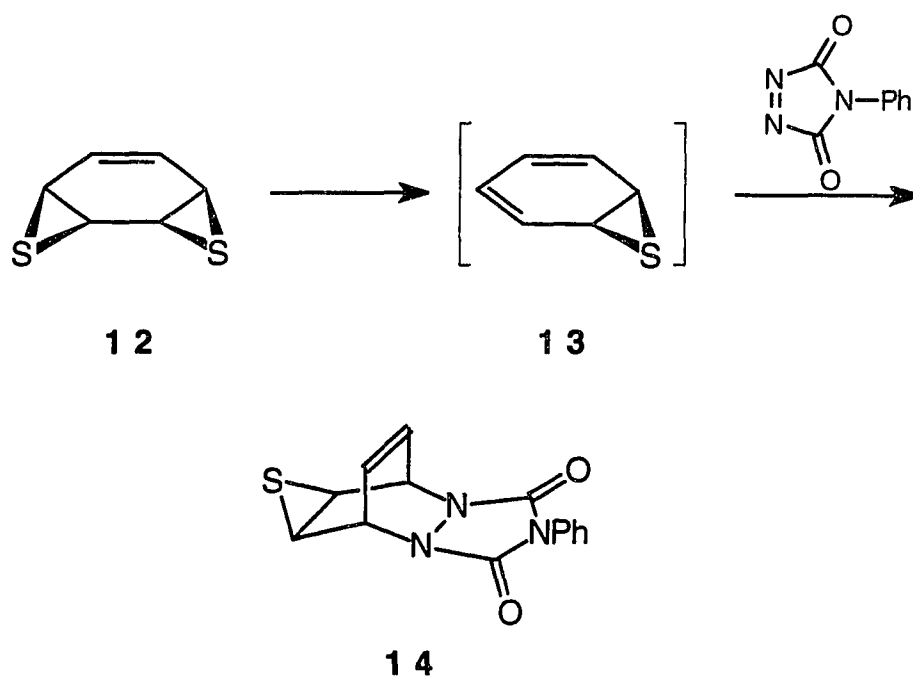


Figure 9: Mechanism of sulfur extrusion in thiepin

In 1974, Vogel *et al* provided the best evidence for the existence of the thianocaradiene form¹¹. Direct synthesis of the first syn-benzene bisepisulfide, **12**, provided insight into its stability and mechanism of sulfur extrusion. When **12** was synthesized in the presence of 4-phenyl-1,2,4-triazoline-3,5-dione (PTD) and was allowed to extrude sulfur (>20°C) adduct **14** was obtained (Scheme 2). Vogel suggested that **14** was formed after an initial sulfur extrusion and the formation of episulfide **13**. That implies that benzene episulfide, **13**, is a long lived species (relative to the rate

of the Diels-Alder addition)--an observation which contradicts any previous attempt to detect and study it.

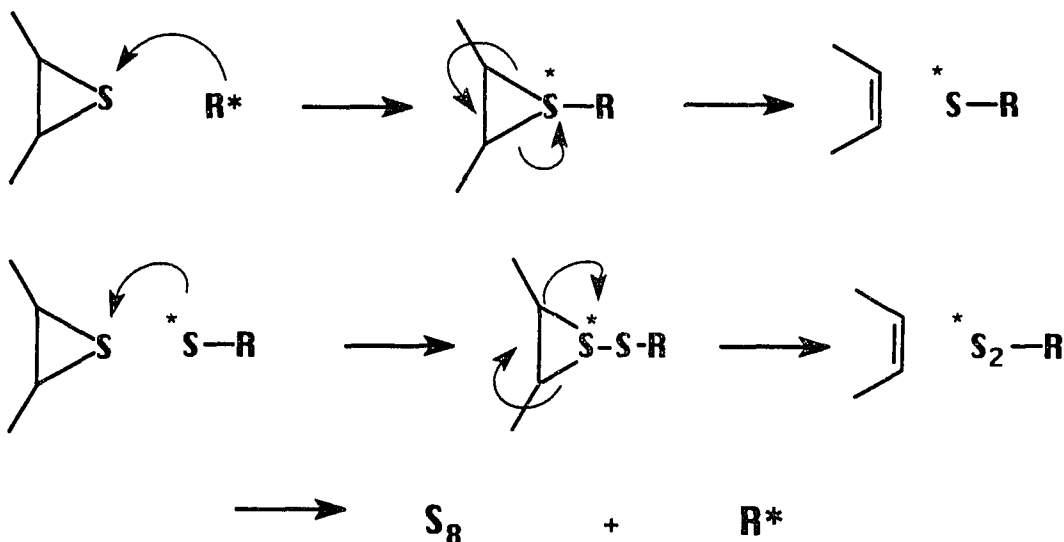


Scheme 2: Sulfur extrusion from syn-benzene bisepisulfide, **12**

However, other routes to the Diels-Alder adduct **14** directly from **12** are not obvious. Other evidence that supports the presence of the benzene episulfide intermediate comes from substitution effects observed to stabilize particular thiepin systems. In cases where episulfide formation is not spontaneous and where its formation is not thermodynamically possible, sulfur extrusion will not occur. When the equilibrium mixture consists of undetectably small

amounts of the episulfide, extrusion may be assisted by the use of tertiary phosphines.

Catalytic amounts of thiolate anions desulfurize phenylated thiiranes at much higher rate than phosphines. The mechanism of this catalytic desulfuration should shed some light on the mechanism of sulfur extrusion leading to aromatization.



R* may be: Radicals, Anions, Tert phosphines

Figure 10: Mechanism of catalytic desulfurization.

The reaction with trace amounts of phenylthiolate, NaSPh, and thiirane proceeds via a chelotropic elimination of NaSSPh.

Disproportionation gives NaSPh back and catenation to S₈. It is plausible that the extrusion of sulfur from an episulfide under such

conditions does not proceed from a three membered ring system but rather via a concerted mechanism directly from the vinyl sulfide fragment itself. This mechanism would explain the observations reported in a few cases where thermal extrusion of sulfur did not proceed in the presence of any amount of nucleophile (catalytic or stoichiometric).

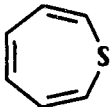
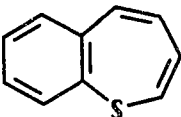
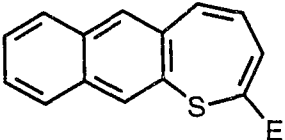
1.3.0 STABILIZING DEVICES FOR THIEPIN

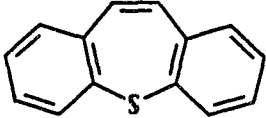
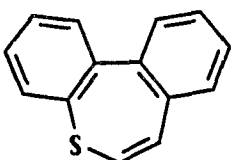
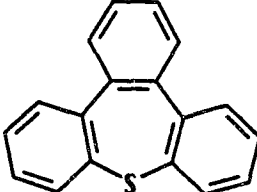
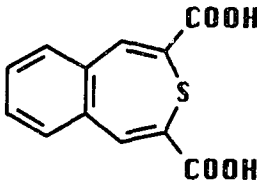
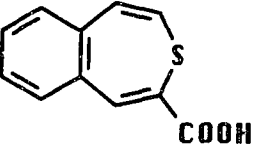
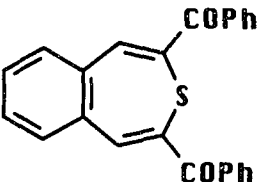
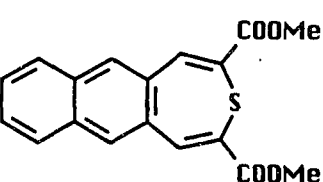
Stabilizing devices for the thiepin skeleton have been developed and used to effect ring contraction. Five such classes are known:

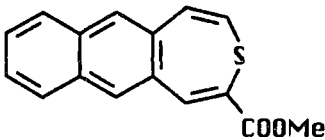
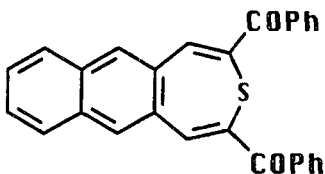
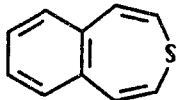
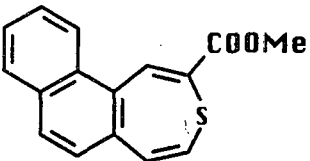
1.3.1 FUSION OF BENZENE RINGS

The stabilizing influence of fused benzene rings on thiepin is evident from a comparison of temperatures at which sulfur extrusion occurs (Table 1).

Table 1: Thermal stability and benzo-annellation of thiepin

#	Thiepin	Conditions for extrusion	Temp °C	
3			unknown	
20			47°	12
21			146° (49 min)	13

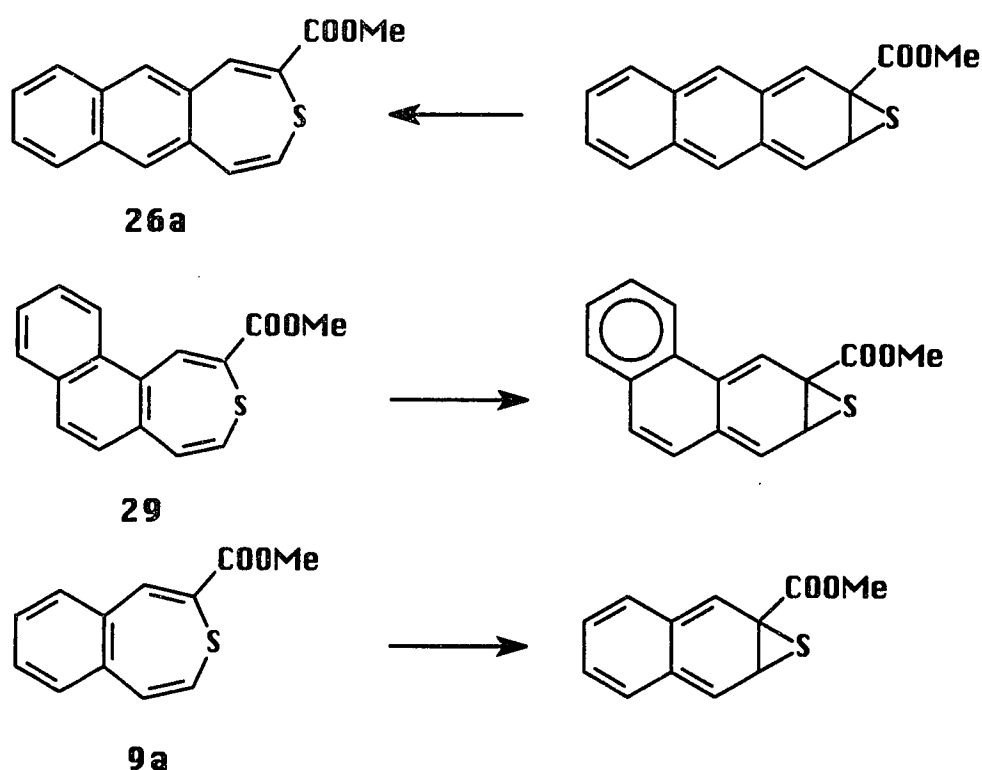
2 2			250°	14
2 3		Refluxing xylene+ Ph ₃ P	Reflux	15
2 4		Copper bronze 5 hours	380°	16
9		15% Ethanol	100°	9
9 a			25°	17
2 5		1:1 dioxane:MeOH	18°	18
2 6		Neat, Sublimation at 0.5 mm	178°	19

26 a			94°	20
27		Neat, Sublimation at 0.5 mm	250°	19
28		neat	-10°	21
29			-27°	22

The increase in thermal stability of the thiepin ring with increasing number of annelated rings is clearly evident. While thiepin itself, **3**, is extremely reactive and has never been detected, benzo [b] thiepin, **20**, has been isolated and investigated (see ref. In Table 1). The dibenzothiepins **22** and **23** along with the tribenzo thiepin, **24**, are thermally stable and extrude sulfur only on thermolysis at high temperatures in the presence of catalysts such as triphenyl phosphine and copper bronze. This high stability is due to a sharp decrease in the characteristic feature of the thiepin ring. The antiaromatic character of this formally 8π system is dramatically reduced and thus lowers the instability of the thiepin ring. This

factor was nicely investigated in the case of **24** where UV studies indicated similarities to a simple o-terphenyl indicating loss of influence of the 8π thiepin ring²³.

Annellation sites of benzene influence the stability of the thiepin ring as well. It is apparent that the benzo [b] thiepin, **20**, is more stable than benzo [d] thiepin, **28**; and in the naphthothiepin series **26a** is more stable than **29**. This may be explained by the formation of the thianorcaradiene intermediate and the level of reduction in aromaticity in the acene moiety.



Scheme 3: Thiepin-thianocaradiene equilibrium in **26a**, **29** and **9a**.

In **26a** the formation of the thianorcaradiene tautomer is much more difficult where a total loss of aromaticity would be involved.

However, in **29** aromaticity would not be completely lost as the thianocaradiene is formed and thus sulfur extrusion resembles that observed for benzo [b] thiepin **9a** (Scheme 3).

In addition to the described differences in benzannelations, Table 1 nicely indicates the thermal stability of the thiepin ring system with increasing aromatic character of the annelated moieties.

Clearly, benzo [d] thiepin **9a**, is less stable than naphtho [2,3-d] thiepin **26a** and by the same criteria, **20** is less stable than **21**. The stability of thiepins is largely dependent on the Hückel bond order of the aromatic bond being annelated with the thiepin system²⁴. Table 2 indicates the half lives of [d] fused thiepins as compared with their corresponding bond orders.

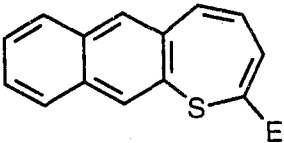
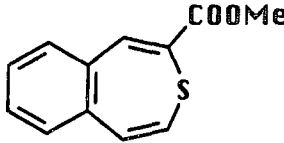
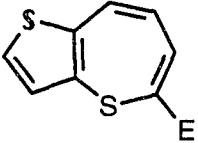
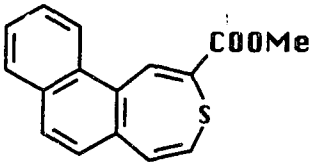
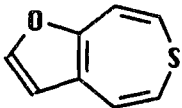
#	Thiepin	Bond Order	Half Life
21		0.60	72 min/94°C
9a		0.67	57 min/25°C
30		0.71	52 min/ -27°C
29		0.73	33 min/ -27°C
31		0.76	19 min/ -27°C

Table 2: Bond orders as measurements of stability.

The increase in the thermal stability is in good agreement with the decreasing bond orders. Furano [3,4-d] and thieno [3,4-d] thiepin are extreme examples of this effect. Naphtho annelations with larger aromatic character decrease the bond order of the C₄-C₅ while

smaller aromatic character in **30** and **31** increases the bond orders and allows facile extrusion.

1.3.2 ELECTRONIC EFFECTS ON SUBSTITUTION

Substituents that are capable of reducing the electron density of the 8π electron system, increase the stability of the thiepin system. As a result, the formal antiaromaticity is reduced. Such substituents allowed the synthesis of many monocyclic thiepins.

The simplest thiepin known to date was synthesized by Murata and was detected in an argon matrix at 10K²⁵.

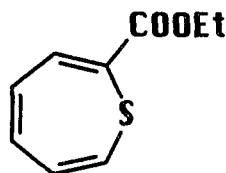


Figure 11: Simplest thiepin synthesized, **32**

The 2-ethoxycarbonyl thiepin, **32**, is more stable than thiepin itself due to the electron accepting effect of the substituent at C₂. In 1972, Reinhoudt and Kouwenhoven²⁶ showed in connection with the synthesis of **33** that its high stability stems from the presence of two methoxycarbonyl groups at positions 3 and 4. These substituents were found to reduce electron density in the thiepin

ring and thus reduce its antiaromaticity.

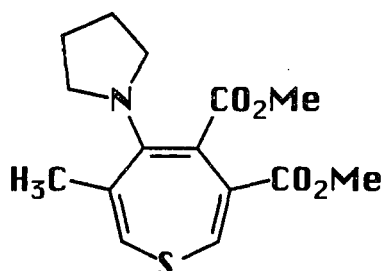


Figure 12: A stable monocyclic thiepin, **33**

Resonance energy calculations on a large number of substituted thiepins using a simple Hückel method predicted that thiepins substituted by electron withdrawing groups will be less antiaromatic than the parent thiepin²⁷. This result supported Reinhoudt's explanation as to the stability of **33**. However, experimental results on benzo [b] and naphtho [2,3-b] thiepins, substituted similarly, were in sharp disagreement (Table 3).

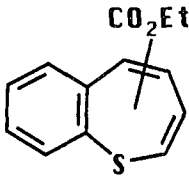
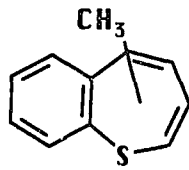
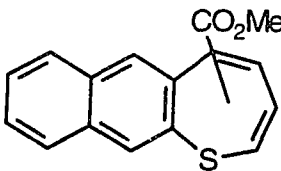
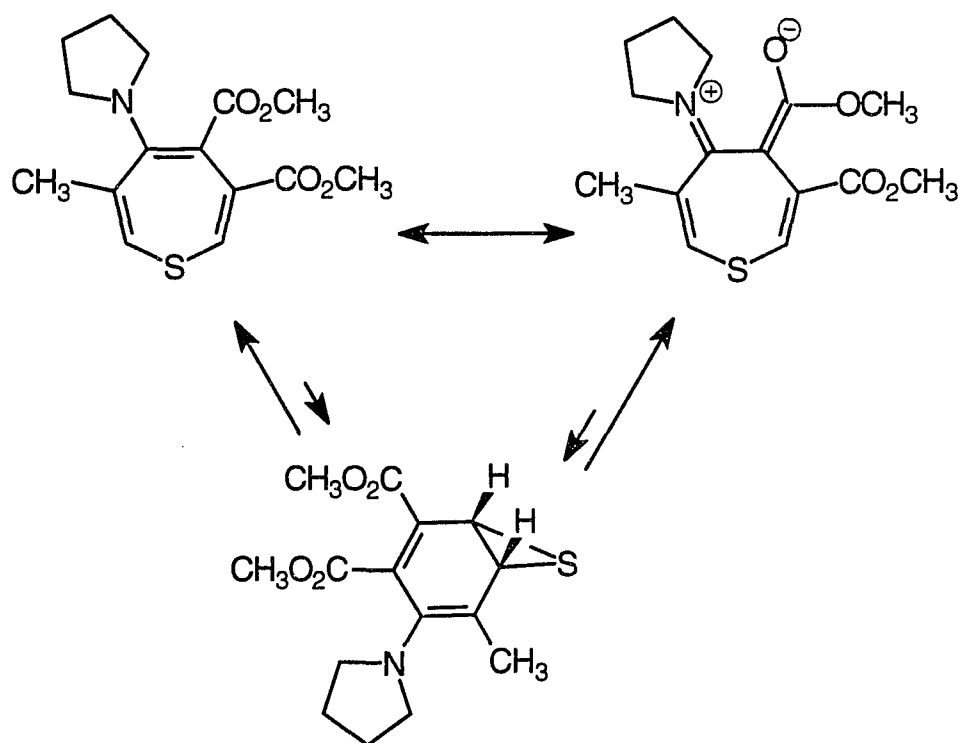
Compound	Temp °C	Half - Life (Min):				
		parent	C ₂	C ₃	C ₄	C ₅
	27°C			16		
	37°C	182			58	69
	47°C	58	352			
	47°C	58		100	62	67
	74°C			159		
	133°C				60	
	146°C		41			

Table 3: Substitution Effects on benzo [b] and naphtho [2,3-b] thiepins

Substitution of an electron donating group stabilizes benzo[b] thiepin in any of the shown cases relative to the parent compound; while substitution of an electron withdrawing group destabilizes it with the exception of substitution at C₂. In addition to these general observations, two specific points are worth making. First, it is clear that substitution at C₂ greatly stabilizes the thiepin system as is evident both by Table 3 and by Murata's synthesis of **32**. Secondly,

substitution of electron donating or electron accepting groups at C₄ or C₅ has a comparable effect on the stability of the thiepin. And so, how does one explain the stability of Reinhoudt's **33**. Murata explains its stability by reduced bond order of the C₄-C₅ bond of the thiepin as a result of a resonance contributing structure as shown in Scheme 4.

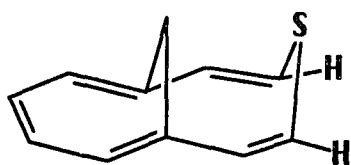


Scheme 4: Resonance stabilizing “Push-Pull” mechanism in **33**.

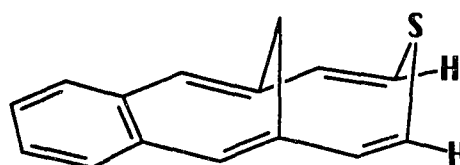
A significant contribution of the resonance form arising from a “Push-Pull” effect of the pyrrolidinyl and the methoxycarbonyl groups, prevents the formation of the thianorcaradiene system and thus avoids sulfur extrusion²⁸.

1.3.3 METHANO BRIDGED THIEPINS

Only two methano bridged thia[11]annulenes are known, **212** and **IV**.



212



IV

Methano-bridged thiepins **212** And **IV** are formally variations on the theme: **212** resembles benzo [d] thiepin while **IV** is similar to its naphtho analogue- naphtho [2,3-d] thiepin. It is the methano bridge that forces the thiepin system into a conformation in which C₁ and C₇ are apart; the bond order of the annelated bond (formally C₄-C₅ of thiepin) is removed, the thia atom is forced out of conjugation and the antiaromaticity is drastically reduced. In that sense, the bridged thiepins **212** and **IV** resemble the highly stable Schlessinger's thieno[d] and furano[d] thiepins.

Thiepin **212** Was synthesized by Vogel and was found to extrude sulfur on heating to temperatures above 50°²⁹. Its stability is indeed attributed to a higher energy barrier for the extrusion as compared with thiepin itself. **IV** was synthesized during this current dissertation project and will be discussed at a later point.

1.3.4 STERIC EFFECTS OF SUBSTITUENTS ON C₂ AND C₇.

Bulky groups on C2 and C7 of the thiepin ring increase its thermal stability by affecting the valence isomerization of the thiepin ring. Bulky groups at these positions force the non-bonding interactions in the thianorcaradiene system to be large and thus disfavoured. The first system to confirm this concept was Murata's 2,7-di-*tert*-butyl thiepin mono ester, **37**²³. Murata based his synthesis on Schlessinger's observations in connection with the synthesis of the tetracyclic thiepin **38**.

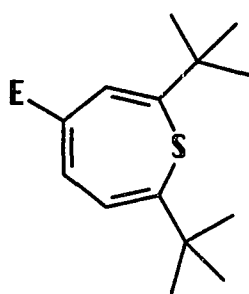
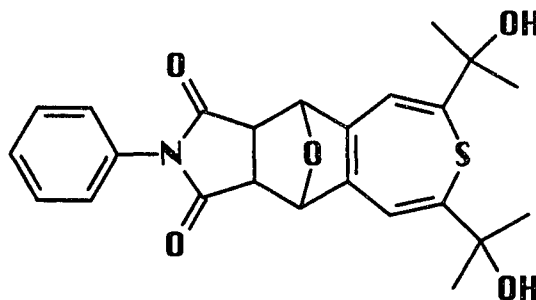
**37****38**

Figure 13: Murata's stable monocyclic, **37**, and Schlessinger's tetracyclic thiepin, **38**.

Schlessinger had reported that when the C₂ and C₇ positions of his thiepin were kept unsubstituted, sulfur extrusion was spontaneous. However, the stability increased when the α -positions were

substituted with isopropyl groups. Here the sulfur atom was still quite readily extruded, yet that was not the case with **38**. Thiepin **38** was found to be highly stable and did not extrude sulfur even on prolonged heating. Murata's thiepin behaved similarly. It proved to be a rather stable system, whereas the 2,7-diisopropyl thiepin was not detected even at -70°C .²³

In 1982 Murata reported the synthesis of 2,7-di-tert-butyl thiepin, **39**. It was found to be similarly stable to the previously synthesized **37** in which an ester group was believed to assist in reducing the antiaromatic character of the ring. With **39**, where such electronic effects are removed, the stability may be attributed solely to increase in energy differences between the ground state of the thiepin form and the thianorcaradiene form (figure 14).

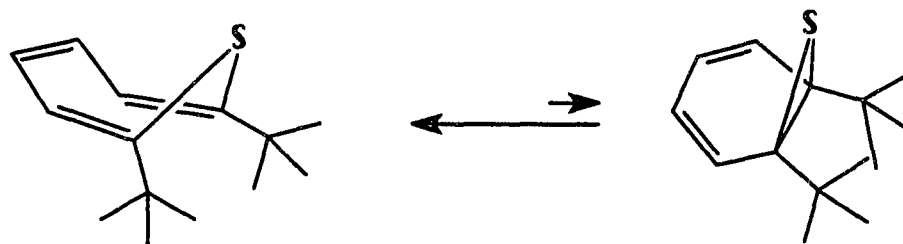
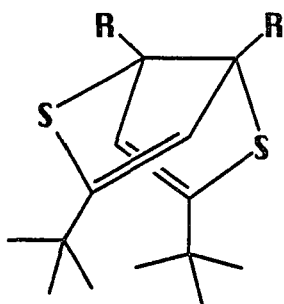


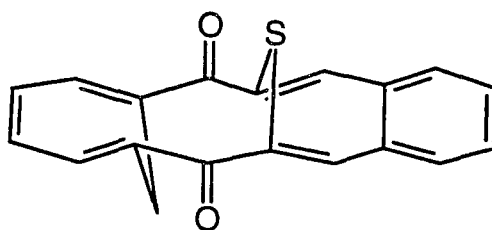
Figure 14: 2,7-steric stabilization of thiepin, **39**.

When **39** was thermolyzed in decaline- d_{18} at 130°C , its half life was measured to be 195 hours. However, thermolysis in benzene- d_6 in the presence of an equimolar amounts of triphenylphosphine at 110°C for

42 hours yielded quantitative amounts of 1,2-di-tert-butylbenzene³⁰. In the absence of triphenylphosphine a second thermolysis product was detected--a disulfurated compound, **40**, believed to arise from a sulfurated thiepin³¹.

**40**

Recently, Kuroda³² *et al* synthesized a representative of the second known class of thiepins stabilized by C2 - C7 carbocyclic substitution. It is the epithia-methano [14] benzoannulene, **41**.

**Figure 15: Kuroda's thiepin 41.**

Compound **41** is a 2,7-disubstituted benzo [d] thiepin with a fixed conformation and thus increased non-bonding interaction which avoids thianorcaradiene formation and sulfur extrusion. The compound is a stable solid which extrudes sulfur upon heating with a half life of 39.6 min at 60°C.

1.3.5 OTHER SUBSTITUTION AND ANNELATION EFFECTS

Thieno [3,4-d] thiepin, **42**, was synthesized by Schlessinger³³ and was found to superficially resemble the benzo [d] thiepin although X-ray structure analysis revealed that the thiepin ring is planar³⁴. The stability of **42** was attributed to contributions from meso-ionic-charge separated resonance structures **42a** and **42b** as shown in Figure 16.

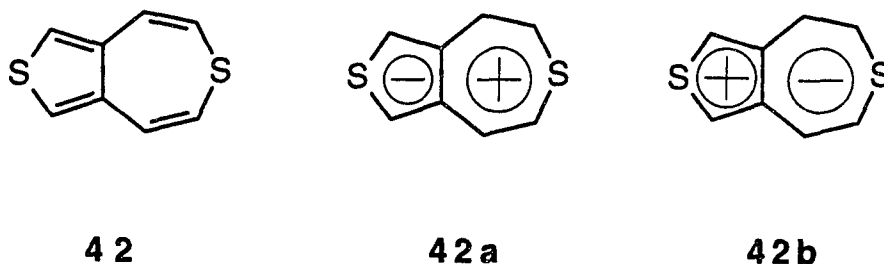


Figure 16: Stabilization of **42** via charge separated resonances

Originally, only “azulene-like” charge separated species such as **42a** were considered. Later, simple Hückel calculations indicated that both **42a** and **42b** could contribute to the stabilization³⁵.

Furthermore, sulfur extrusion from **42** may be a high energy process as a tetravalent sulfur atom is generated in the quinoid portion of the episulfide in **43**.

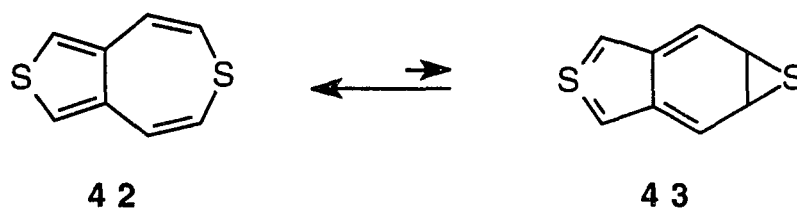
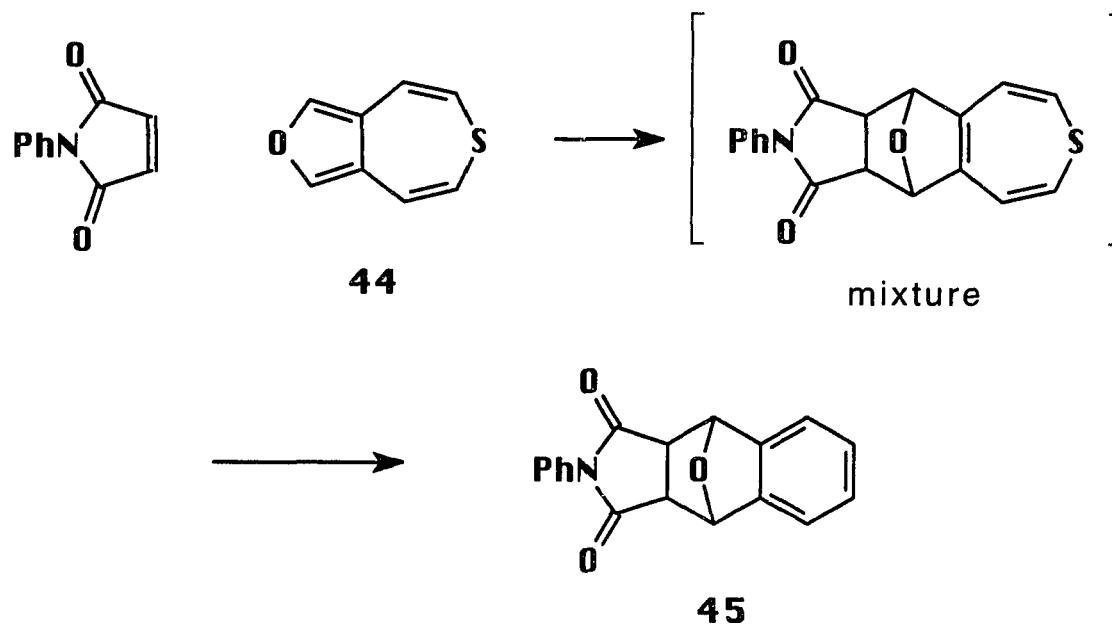


Figure 17: Sulfur extrusion in **42**

Treatment of the furano [3,4-d] thiepin, **44**, with N-phenylmaleimide at room temperature yielded a 3:2 mixture of the exo-endo adducts, **45**, and a complete extrusion of sulfur (Scheme 5).



Scheme 5: Sulfur extrusion from Diels-Alder adducts of thiepin **44**

The obvious ease of extrusion here results from the formation of the parent thiepin with loss of the stabilizing effect that exists in 44³⁶.

Several other 2,7-substituted Furano [3,4-d] thiepins were examined as well. As previously discussed in part D, these were found to be much more thermally stable as the size of the substituents increased.

Another method of controlling the sulfur extrusion in the thiepin system is the oxidation of the sulfur atom into sulfoxide or dioxide analogues. Several derivatives of thiepin-1,1-dioxide including the parent benzo [b] and benzo [d] thiepin 1,1-dioxides have been synthesized^{37,38}. In all cases the thermal stability of these thiepin dioxides is greatly increased (Table 4).

Unlike thiepin-1,1-dioxides, thiepin-1-oxides are very labile systems. For example, benzo [b] thiepin **20** decomposes at 47°C with a half life of 84 minutes where as the sulfone is stable in refluxing ethanol³⁹. The corresponding sulfoxide, however, was found to be less stable than **20** itself and decompose at 20°C with a half life of 45 minutes. A more remarkable example is the synthesis of thiepin-1,1-dioxide by Mock in 1967³³.

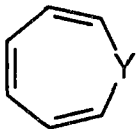
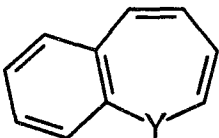
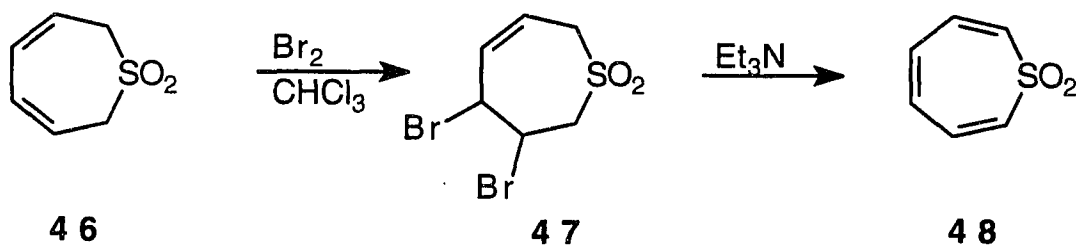
	thiepin	Half Life			
		parent	oxide	dioxide	ref
3 ; Y=S 48 ; Y=SO ₂		Un-known	Un-known	3 hrs/ 100°C	33
20 ; Y=S 49 ; Y=SO 50 ; Y=SO ₂		58 min/ 47°C	<1 hr/ 13°C	No extrusion	34, 40, 41 42

Table 4: Oxides and dioxides of thiepin

1,6-Addition of sulfur dioxide to cis-hexatriene afforded **46** which was then treated with excess bromine in chloroform and converted to the dibromide **47**. Treatment of **47** with two equivalents of triethylamine afforded the first thiepin-1,1-dioxide **48**.



Scheme 6: Synthesis of thiepin-1,1-dioxide, **48**.

Compound **48** is fairly stable and decomposes to benzene with extrusion of sulfur dioxide at 100°C with a half life of 3 hours. This remarkable stability as compared with the unknown thiepin itself is attributed to the controversial concept of d-orbital participation. On this basis, one may assume a ground state participation of structures such as **48a**, **48b**, and **48c** as shown in Figure 18.

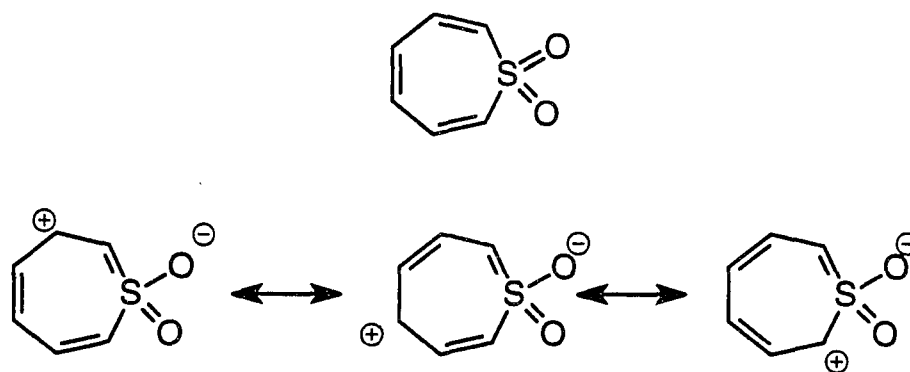
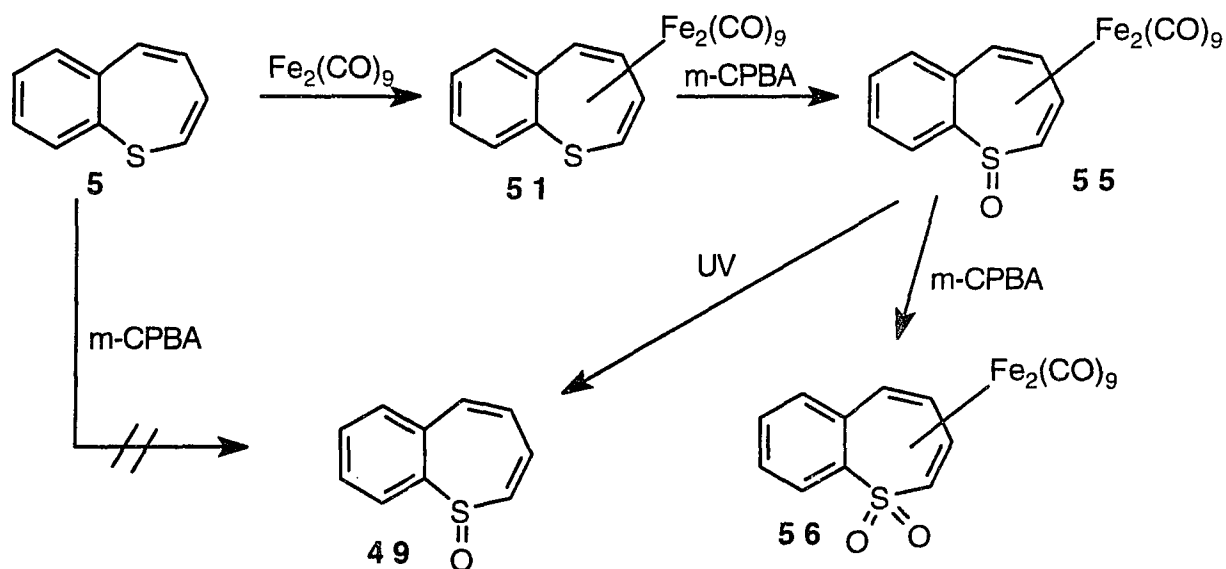


Figure 18: Stabilization of thiepin -1,1-dioxide, **48**

The full understanding of this effect is still missing. The oxidation of the sulfur atom into the corresponding sulfoxide or sulfone did not succeed in every case. Oxidation of Vogel's thia [11] annulene, **34**, failed. Only unidentified mixtures were obtained.



Scheme 7: Transition Metal approach for the synthesis of **49**.

In fact, neither did the synthesis of benzo [b] thiepin-1-oxide, **49**, proceed as expected. Treatment of the parent thiepin, **20**, with *m*-CPBA at 0°C did not produce the desired **49**. This promoted Murata et al to investigate and utilize transition metal complexation for the synthesis of **49**. This method turned out to be a novel method for the synthesis of not only **49** and its oxides but the parent thiepin, **3**, in its complexed form (Scheme 7).

The ability of transition metals to stabilize labile systems such as cyclobutenes⁴³ and norcaradienes⁴⁴ by complexation has allowed the isolation and investigation of these systems. Two thiepin systems were stabilized by such complexation, isolated and investigated. The first was **49**. Compound **55** was decomplexed by irradiation as a dilute THF solution at -50°C . Attempts to utilize ceric ammonium nitrate (CAN) as a decomplexation agent yielded sulfur oxide extrusion. The second isolation of labile thiepin as an iron carbonyl complex was published two years later by the same group. (Thiepin) iron tricarbonyl, **52**, was synthesized by Murata and demonstrated thiepin as a highly stabilized ligand⁴⁵.

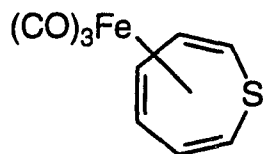
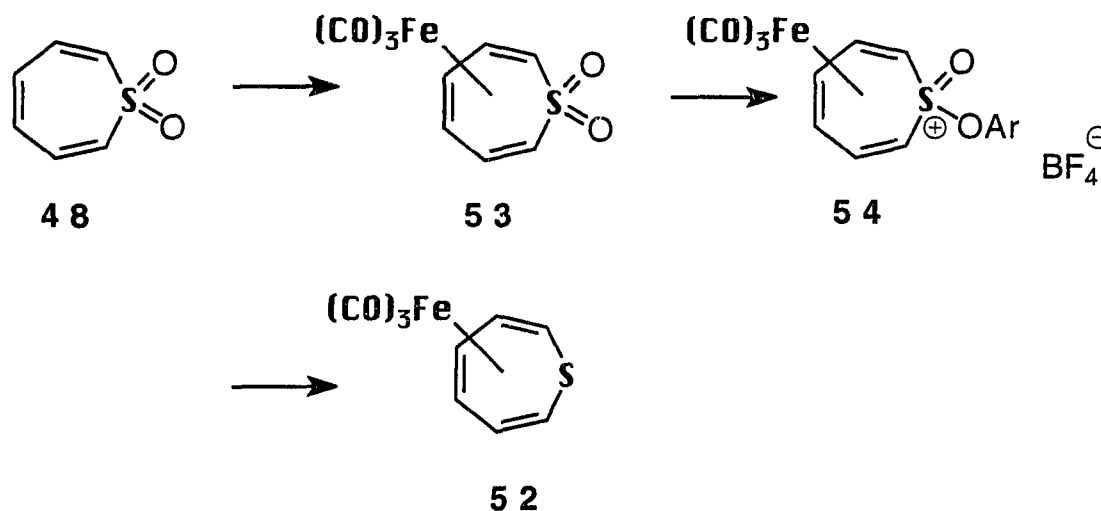


Figure 19: (Thiepin) Iron tricarbonyl, **52**

The synthesis of **52** utilized Mock's Thiepin-1,1-dioxide, **48**, as a building block for the thiepin ring system. Treatment of **48** with $\text{Fe}_2(\text{CO})_9$ in THF at 50°C for 12 hours furnished the iron carbonyl complex **53** (Scheme 8). Reaction of **53** with *p*-toluenediazonium tetrafluoroborate without solvent at 95°C afforded a 1:1 mixture of the stereoisomers of the sulfoxonium salts **54a** and **54b**. These were then reduced to the desired thiepin iron tricarbonyl complex **52** in the presence of SmI_2 -THF complex.



Scheme 8: Synthesis of 52

Attempts to free the thiepin from its complexation at low temperatures by various methods have failed.

Two last points are worth making in regards to metal complexation. First, it was shown in all cases where the iron tricarbonyl-thiepin complex was elucidated by X-ray that the complexation takes place at the diene moiety of the thiepin ring and is of a η^4 type. This type of complexation causes substantial high field chemical shifts for the 2 and 5 positions in **52** and for the benzo [b] thiepin derivatives **51**, **55**, and **56** (figure 20).

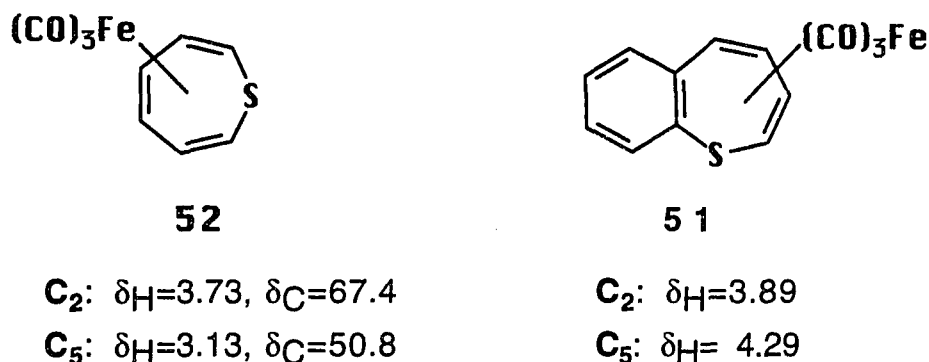


Figure 20: NMR parameters as influenced by η^4 metal complexation

Secondly, no sulfur extrusion has ever been reported to evolve directly from the metal complex. The stability of the metal complexed thiepins seems to be a remarkably useful method of investigation only if decomplexation is possible. In cases such as with **52** where metal decomplexation is not possible, investigation of the ring is altered by effects imposed on by the metal itself. Such differences may be observed by ^1H NMR as shown below.

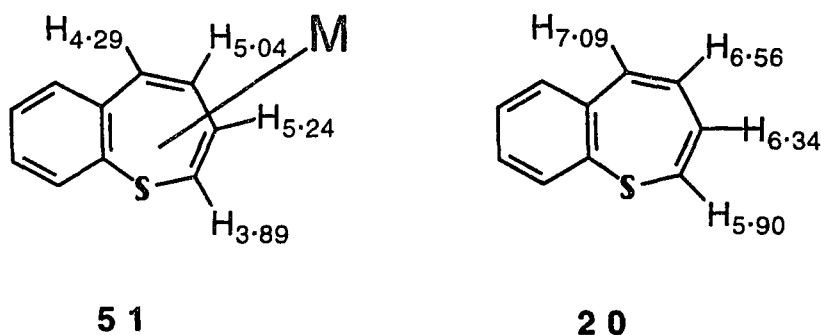
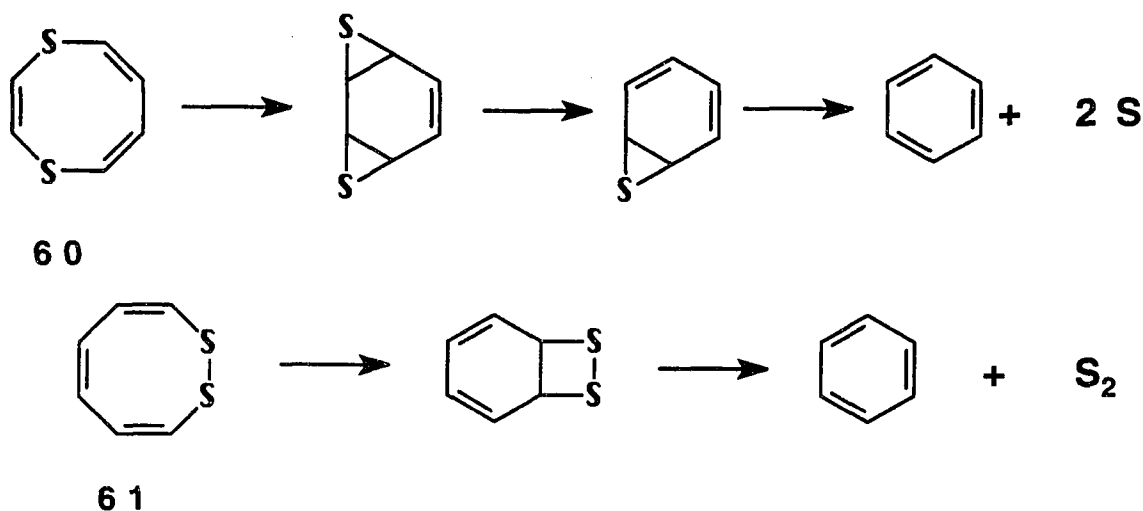


Figure 21: ^1H NMR parameters of **20**⁴⁶ and **51**⁴⁷.

1.4.0 1,2- and 1,4-DITHIOCINS

Similarly to thiepins, the synthesis of dithiocins have seen only limited success. Sulfur extrusion was observed in all dithiocin synthesis. Two different substitutions of the dithia atoms in the 8 membered ring are possible: 1,4-substitution, and 1,2-substitution. Both formally aromatic systems exhibit a very different type of sulfur extrusion. While 1,4-dithiocin, **60**, extrudes monatomic sulfur units, in 1,2-dithiocin, **61**, diatomic sulfur units are expected at extrusion.

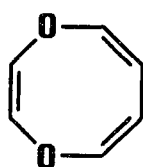
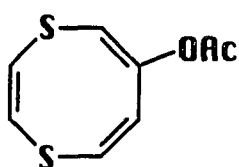
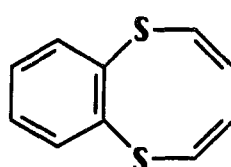
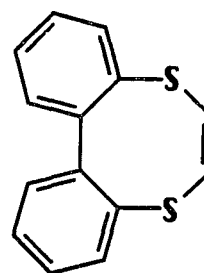


Scheme 9: Sulfur extrusion from 1,4-dithiocin, **60**, and 1,2-dithiocin, **61**.

This major structural difference between the two systems requires different devices for stabilization and most importantly different methods of synthesis.

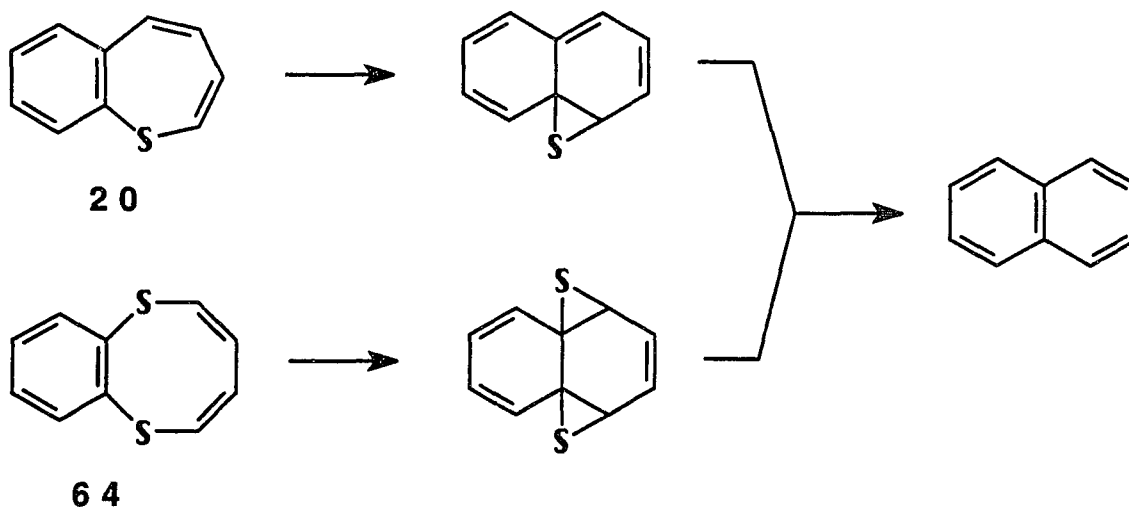
1,4-Dithiocins have been investigated quite extensively as compared with their isomers the 1,2-dithiocins. It was shown by Vogel⁴⁸ and co-workers that 1,4-dioxacin, **62**, undergoes a valence isomerization to a syn-benzene dioxide at 60°. Compound **62** was shown to be an olefinic rather than an aromatic system. Attempts to synthesize 1,4-dithiocin from the syn-benzene episulfide **12** as was synthesized by Vogel and shown earlier led to sulfur extrusion. **63** is the only monocyclic 1,4-dithiocin derivative known to date.

Benzannulation of 1,4-dithiocin provided two known systems: 2,3-benzo-1,4-dithiocin⁴⁹, **64**, and 5,7-dibenzo-1,4-dithiocin⁵⁰, **65**.

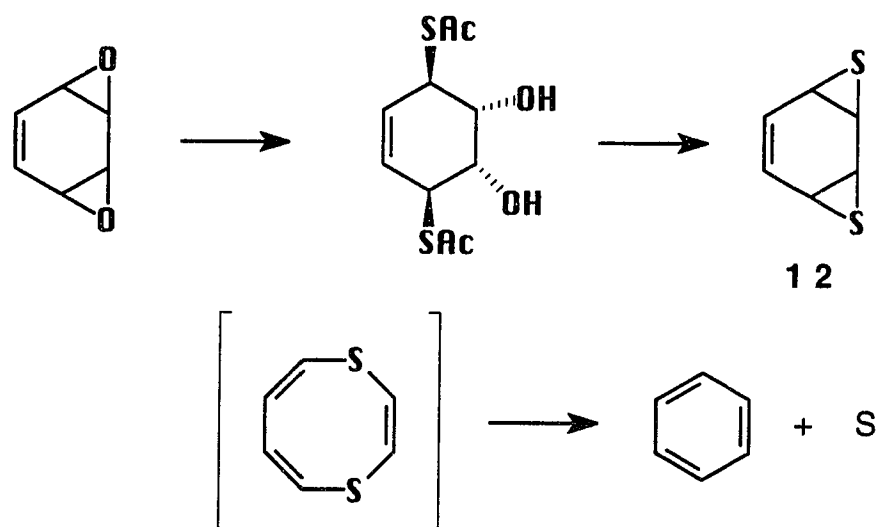
**62****63****64****65**

Both systems were observed to be non-aromatic and to extrude sulfur. **64** Was observed to extrude sulfur on heating to 200°C. The presence of naphthalene as the end product of the extrusion,

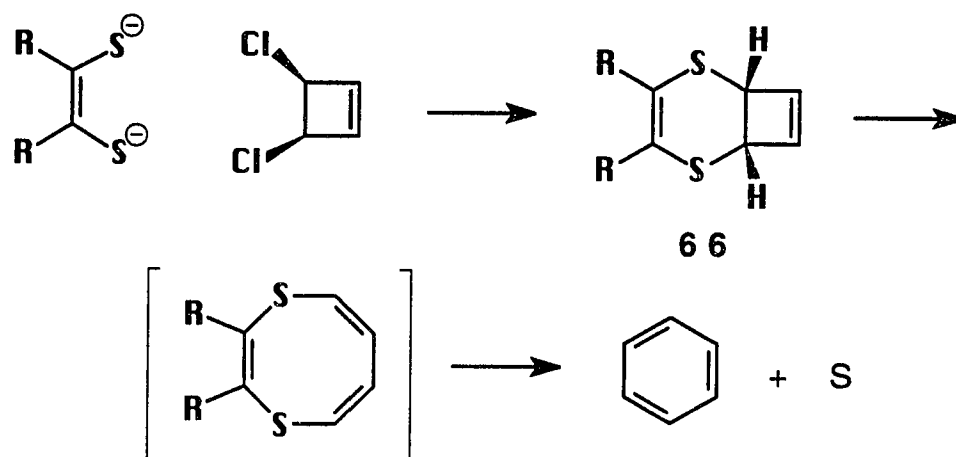
indicated the involvement of the bisepisulfide intermediate. In this regard **64** is more stable than benzothiepin **20** which decomposes neat at room temperature.



Despite the nonaromatic properties exhibited in the 8 membered ring of 1,4-dithiocin, there are two good reasons why dithiocins should be aromatic heterocyclics: a). The known aromaticity of the cyclooctatetraenyl dianion and b). The greater ability of a sulfur atom to replace a C=C double bond than other heteroatoms. Two methods have been devised for the synthesis of substituted 1,4-dithiocins. Vogel⁵¹ utilized bisbenzene episulfide **12** as a precursor for his synthesis. Coffen⁵², on the other hand, utilized the thermolysis and photolysis of dithiabicyclo[4.2.0]octadiene derivatives **66** as an approach towards the labile systems.

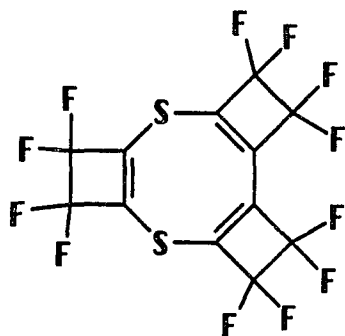
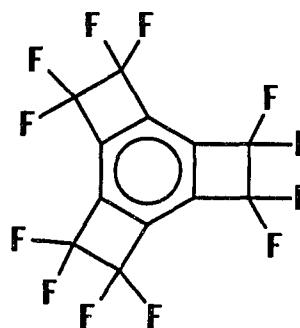


Scheme 10: Vogel's approach towards 1,4-dithiocin

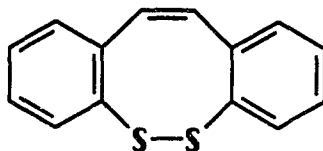


Scheme 11: Coffen's approach towards 1,4-dithiocins

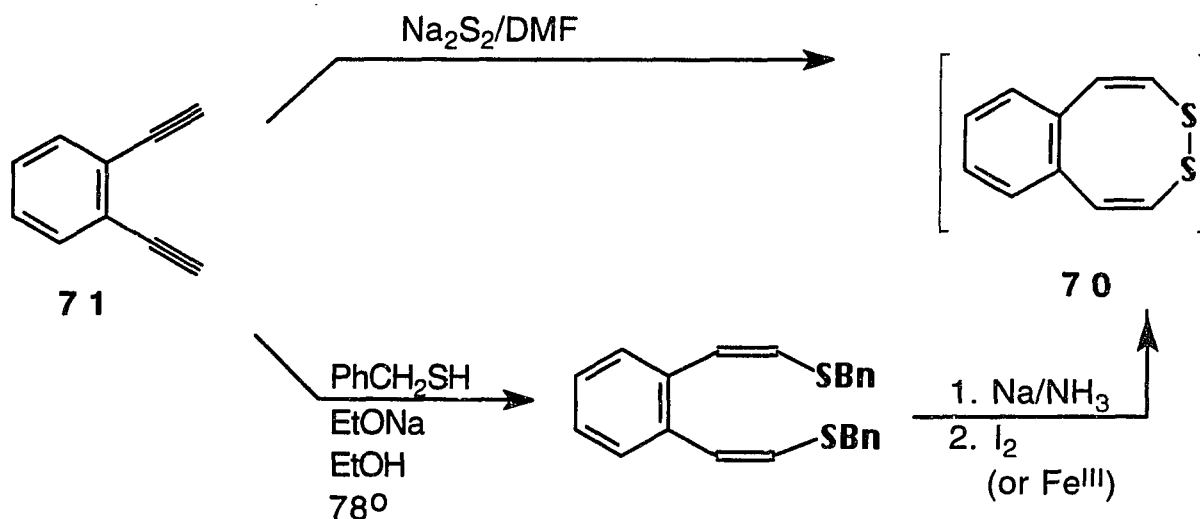
The perfluorinated tetracyclic 1,4-dithiocin, **67**, was produced in a low yield from the reaction of 1,2-dichloro-3,3,4,4-tetrafluorocyclobutene with butyllithium and SCl_2 . Dithiocin **67** is a highly stable solid which shows an ^{19}F NMR similar to dodecafluoro tricyclobutabenzene, **68**, suggesting a ring current in **67**⁵³.

**67****68**

The class of 1,2-dithiocins is known to a much lesser extent. Only 1,2-dithiocin **69** is known⁵⁴.

**69**

Synthesis of benzo[d]-1,2-dithiocin, **70**, was attempted in two various ways starting from o-diethynyl benzene, **71**. The first approach involved the addition of sodium disulfide to a DMF solution of **71**. The second, involved nucleophilic addition of benzylmercaptan to **71**, followed by reductive debenzylation and oxidation as shown below:

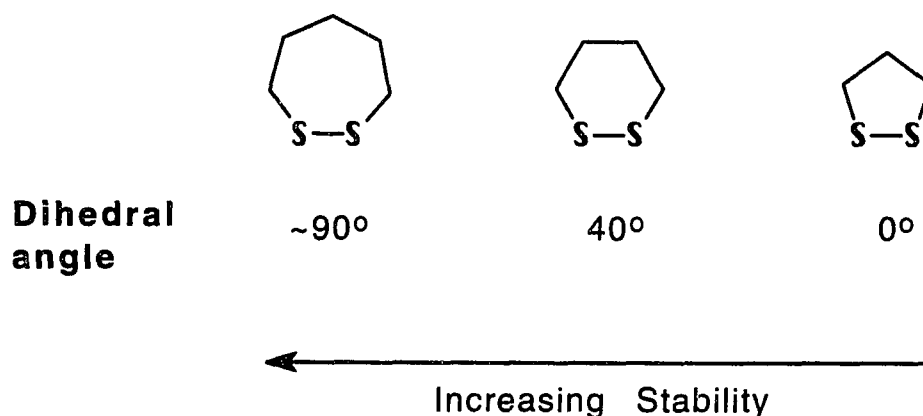


Scheme 12: Attempted synthesis of benzo[d]-1,2-dithiocin, **70**.

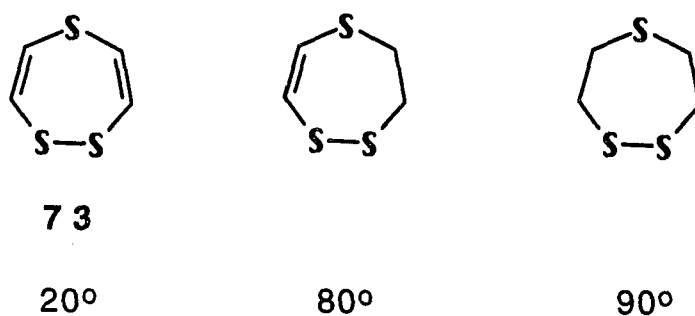
With both routes, aromatization and sulfur extrusion were observed. The apparent instabilities of **70** under high and low temperatures suggested that no aromatic stabilization is present in 1,2-dithiocin. This behavior may be compared with formally antiaromatic thiepins in which similar tendencies were observed. A reason for the unexpected high reactivity of **70** as compared with **64** might be the

reactivity of the S-S bond in 1,2-dithiocins.

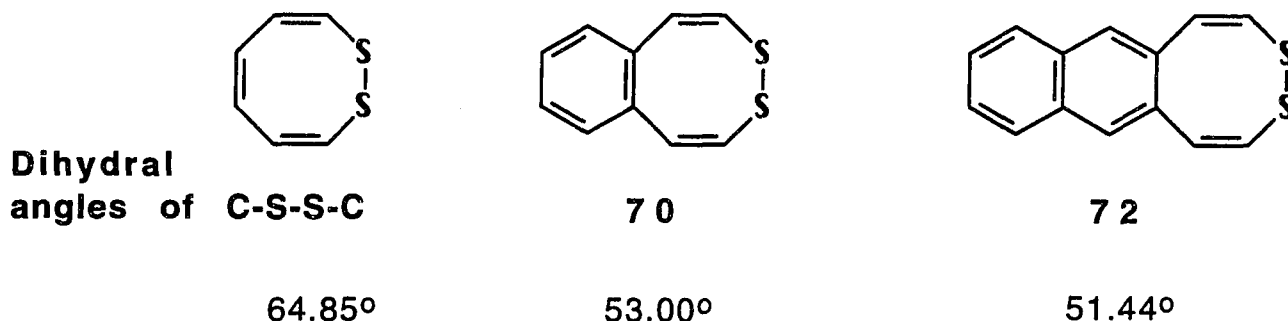
Yamabe⁵⁵ studied the interaction of sulfur lone pairs on the strength of an S-S bond and reported that disulfides having a dihedral angle close to 90° should be less reactive and more stable.



The seven membered ring system is predicted and indeed shown to be most capable of achieving a 90° dihedral angle while the five membered ring is at most only slightly stable. Similarly, Ueng⁵⁶ had shown that the dihedral angles in a fully unsaturated 7 membered trithiepin system **73**, contributes to its instabilities.



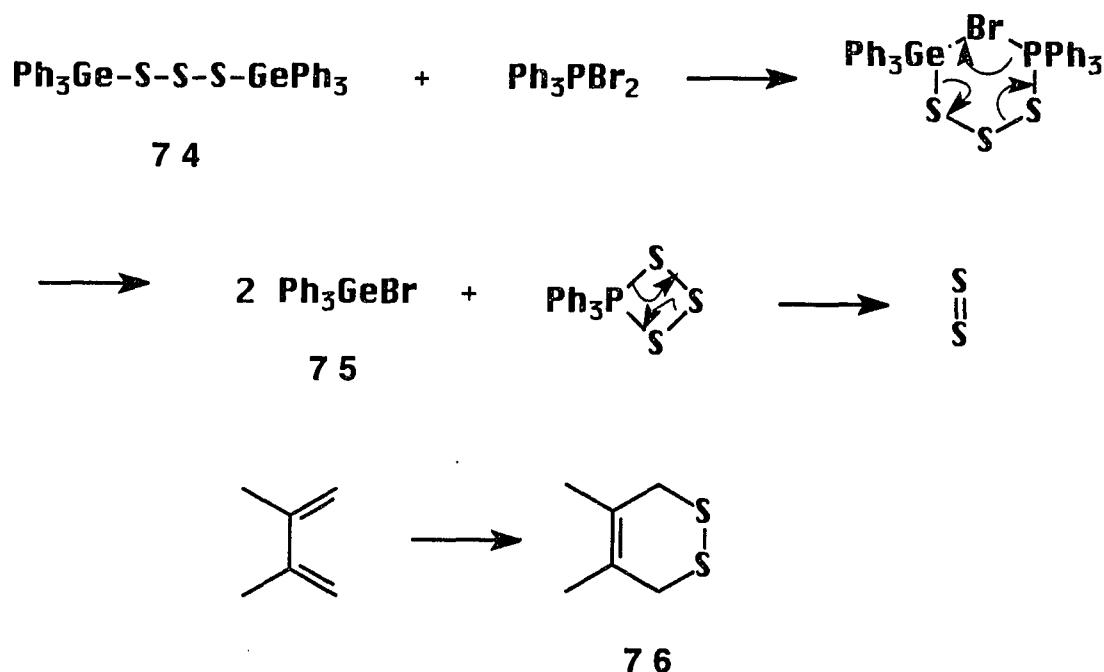
A large dihedral angle is not expected in benzo[d]-1,2-dithiocin, **70**, as compared with 1,2,5-trithiepin, **73**, which may explain the lability of the system. In fact, we carried out AM1 calculations to investigate 1,2-dithiocins and determined the C-S-S-C dihedral angle of **70** to be 53.00°. The corresponding angle in naphtho[d-2,3]-1,2-dithiocin, **72**, is smaller at 51.44° but in parent 1,2-dithiocin the largest at 64.85°.



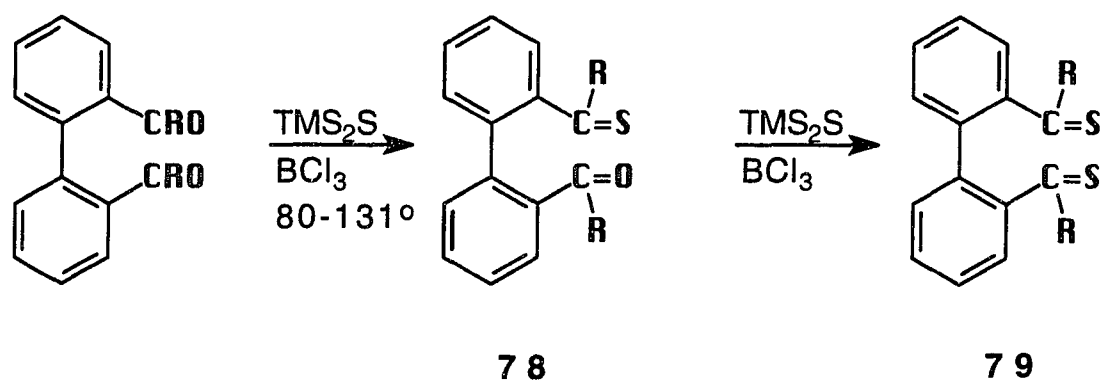
Sulfur extrusion from 1,2-dithiocins is believed to yield a diatomic sulfur unit whose characteristics are under investigation. No direct evidence has ever been obtained for such an extrusion. S₂ extrusion through a benzene dithietane intermediate leads directly to aromatization. In cases where S₂ extrusion may lead to an antiaromatic system, the extruded sulfur unit may be monatomic. Such was observed in 1,2-dithiins (will be discussed later on.) Two important issues arise, therefore: a) the characterization of the diatomic species, and b) the presence of thione-enethiol tautomerism.

Due to the anticipation that singlet sulfur might emulate singlet oxygen chemistry, various groups have been pursuing possible synthetic routes for its preparation. Numerous reports of successful generation of S_2 units from labile disulfides assisted in the study of this species.

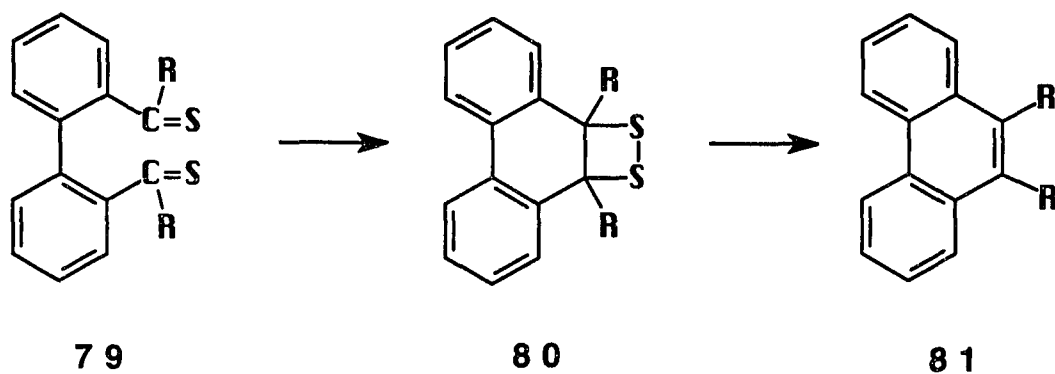
Steliou⁵⁷ generated S_2 units from thermal decomposition of phosphine sulfides made in situ. The treatment of trisulfide **74** with triphenylphosphine dibromide yielded after usual workup quantitative amounts of bromide **75**, triphenylphosphine sulfide and elemental sulfur. However, when the reaction was carried in the presence of a conjugated diene, a Diels-Alder adduct **76** was obtained in variable yields. The formation of **76** was explained through the addition of an S_2 unit to the diene.



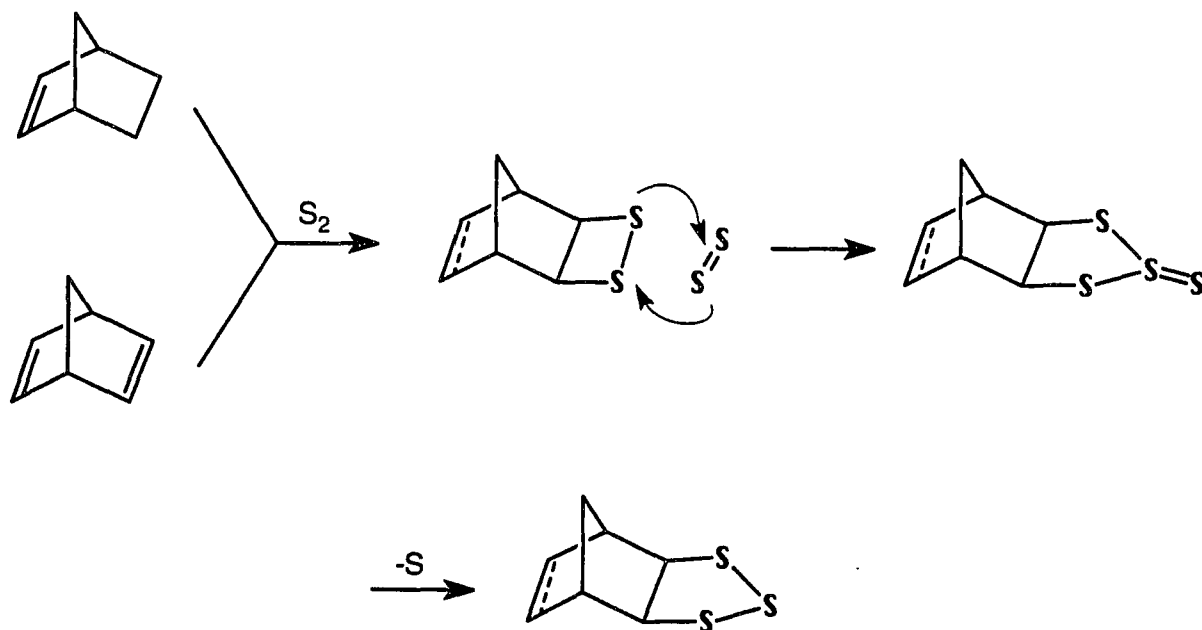
Steliou⁵⁸ continued his investigation of S_2 extrusion and next synthesized precursors to benzene dithietane intermediates. o,o'-Biphenylthione **79** was prepared as shown below.



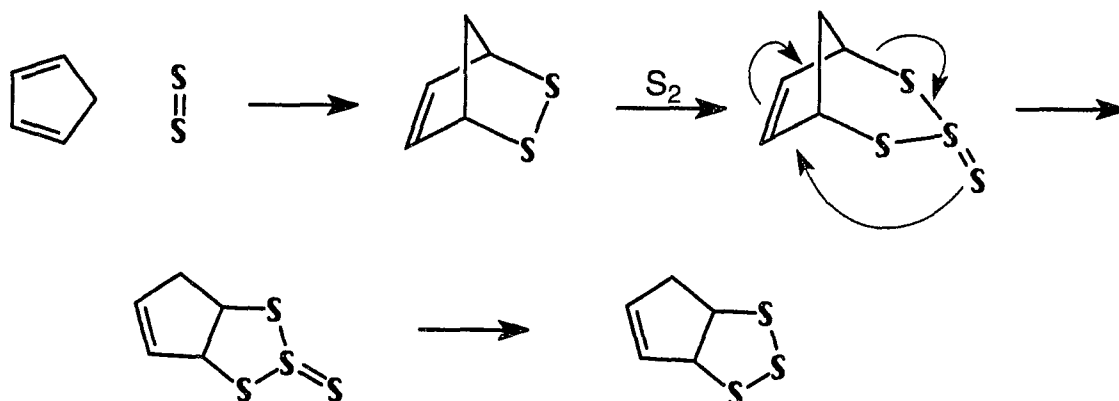
Monothione **78** was found stable. However, upon formation of **79** spontaneous expulsion of S_2 was observed to yield 9,10-biphenyl substituted derivatives, **81**, probably via the intermediacy of dithietane **80**.



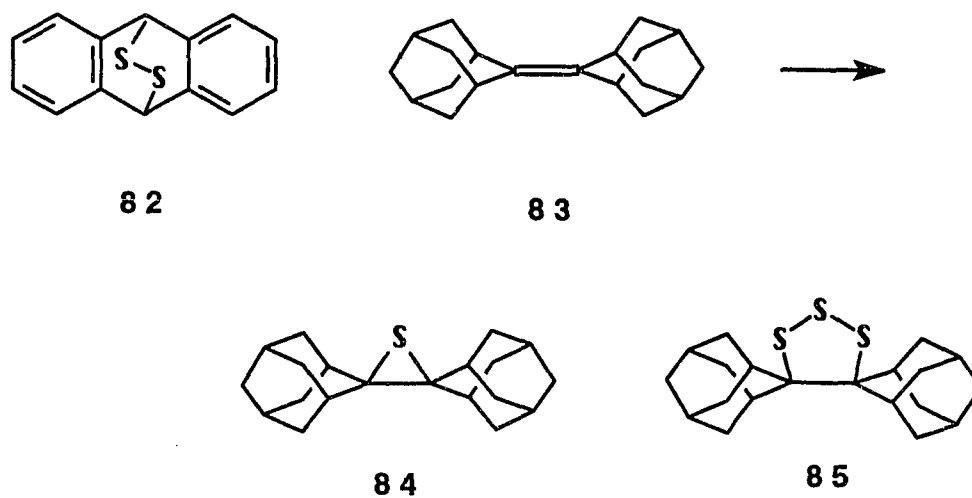
In the presence of a diene, and under the conditions of the reaction, evidence for the formation of diatomic sulfur was obtained by Diels-Alder trapping. Interesting adducts were obtained in high yields when the olefins used for the trapping of the diatomic sulfur units were norbornene and norbornadiene. Both yielded a trisulfide system. This trisulfide is believed to arise from sulfur deposition of a second molecule of S_2 to the highly strained S-S bond of the dithietane precursor intermediate.



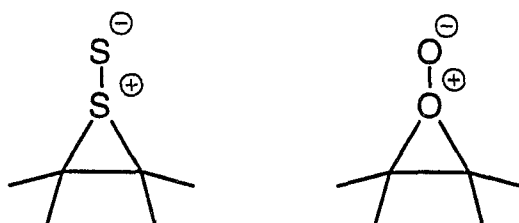
Other Diels-Alder adducts of cyclic dienes and S_2 were reported by Steliou⁵⁹:



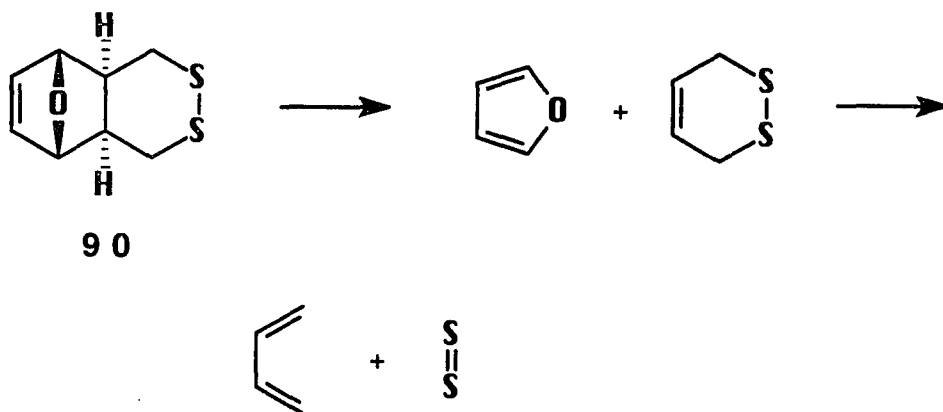
However, when S_2 was extruded from 9,10-epidithio-9,10-dihydro anthracene, **82**, and was trapped by various olefins, the product of addition to biadamantylidene **83**, was the episulfide **84** and not the trisulfide **85**.



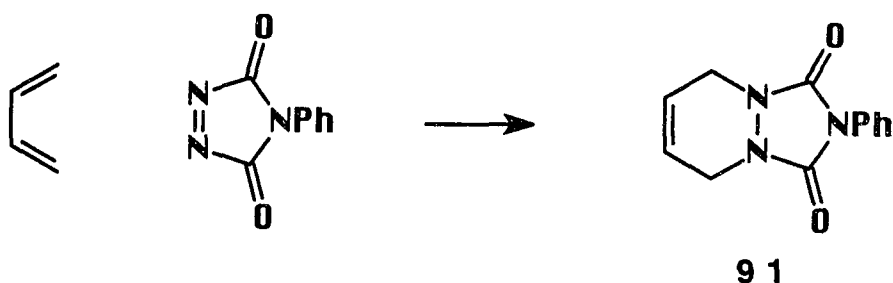
The formation of the episulfide can be understood if singlet sulfur reacts with the olefin to form a thiosulfoxide intermediate, **86**, followed by desulfurization. Such peroxide intermediacy was observed in the reaction of singlet oxygen and olefines.

**86**

Gilchrist *et al* attempted generation of diatomic sulfur from a rather interesting groups of compounds⁶⁰. Structure **90** was synthesized on the basis that it could act as a suitable S₂ source by a double retro Diels-Alder reactions as shown below.

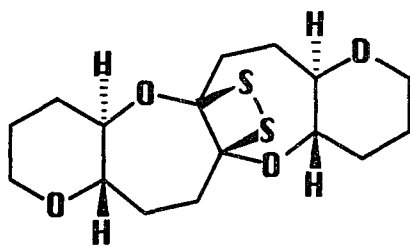
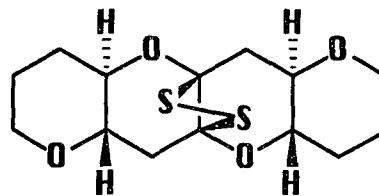


The route of synthesis involved a series of functional group manipulations starting with the Diels-Alder adduct of furan and maleic anhydride. When **90** was pyrolyzed in the vapor phase in the presence of N-phenyltriazolindione, adduct **91** was obtained in 29% yield along with sulfur. The suggested fragmentation can account for the presence of butadiene and sulfur, yet no direct evidence for the presence of S_2 was obtained.

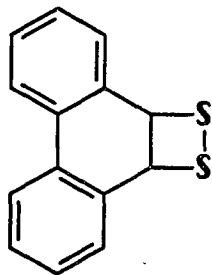
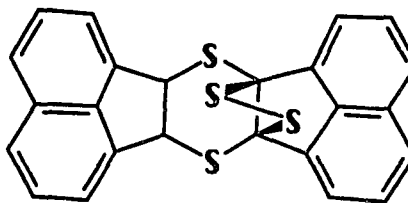


Other methods of S_2 generation have been reviewed in the literature. The importance of these is their application towards the synthesis of 1,2-dithiocins. Both Steliou and Nicolaou carried out series of theoretical calculations to evaluate such S_2 generation process. Nicolaou⁶¹ studied sulfur extrusion from a stable 1,2-dithietane system called dithiatopazine **92**.

S_2 extrusion from **93** was calculated to be 8.0 Kcal/mole more exothermic than **92**; With the latter expelling sulfur with an activation energy of 26.3 Kcal/mole, Nicolaou predicted the expulsion in **93** to be 6-7 Kcal/mole lower.

**92****93**

However, barrier to extrusion in **80** and **94** were found much lower due to resonance stabilization in the hydrocarbon. Compound **80** was predicted to extrude sulfur with ΔH of -37.1 Kcal/mole.

**80****94**

It should be noted that the ground state of S_2 is a triplet in direct analogy to O_2 . Further, the singlet state of S_2 has been measured by Steliou at 13 Kcal/mole above ground state. ΔH_f for an S_2 unit was calculated, however, to be 30.68 Kcal/mole as compared with $\Delta H_f=1.50$ Kcal for $S=O$.

2.0.0 DISCUSSION AND RESULTS

2.1.0 THEORETICAL APPROACH: MECHANISM OF SULFUR EXTRUSION FROM 1,2-DITHIOCINS

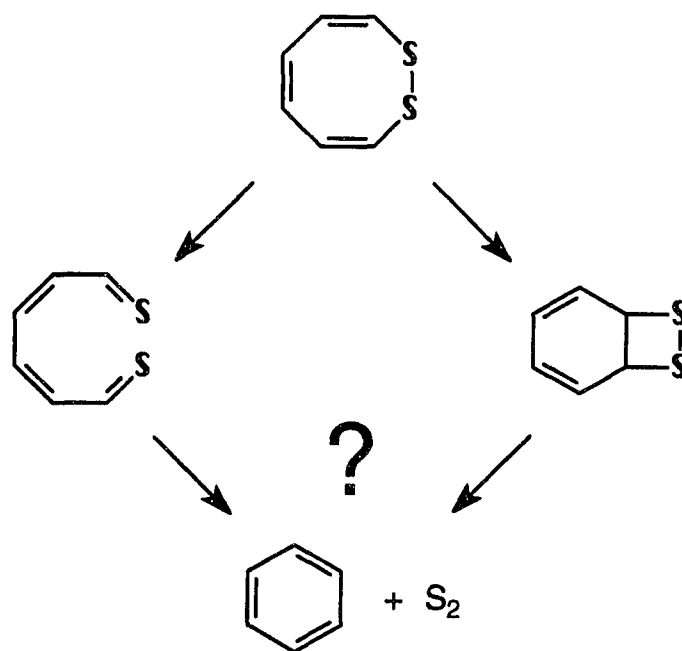
In our investigations towards the synthesis of benzannelated 1,2-dithiocins, we carried out theoretical calculations on sulfur extrusions from parent 1,2-dithiocin, benzo- and naphtho-1,2-dithiocins.

Semiempirical calculations, using AM1 and SAM1, were performed using AMPAC 50 on IBM RS-6000 computers (RISC). The geometries of 1,2-dithiocin **61**, benz[d] 1,2-dithiocin **70**, and naphtho[2,3-d] 1,2-dithiocin **72**, were optimized, saved and further treated (Table 5).

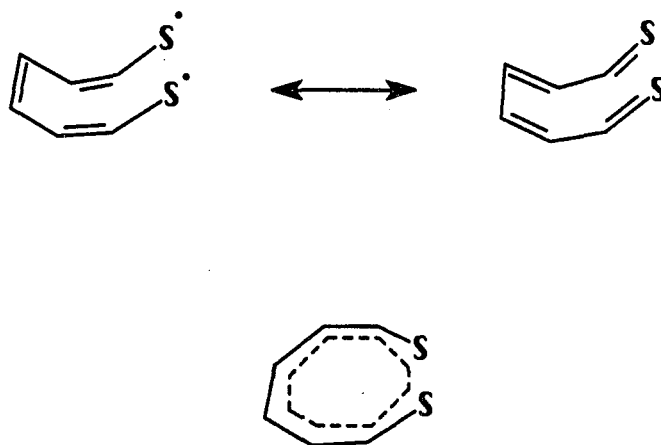
compound	ΔH_f (Kcal)	S-S (Å)	C-S (Å)	C-S-S-C (°)
61	59.24	2.122	1.687	64.85
70	73.16	2.136	1.665, 1.694	53.00
72	92.36	2.138	1.666	51.44

Table 5: AM1 calculated geometrical parameters for **61**, **70**, **72**.

No significant alternations in C-C bonds or ring angles in the annelated systems are observed relative to the parent compound. Notice that heats of formation increase with the increasing number of atoms in the system and that geometrical changes are observed between the parent dithiocin and its annelated forms. Two different intermediates were considered at this point: the traditional dithietane type intermediate and the dithioaldehyde type system.

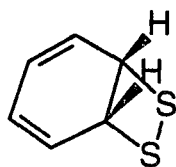


Transition state analysis of sulfur extrusion from dithiocin systems yielded a diradical structure of the form shown next. It is believed that this form may be a combination of a diradical and a dithioaldehyde species. Since at the transition state such equilibrium is not allowed, **96** can be considered as a fair description.

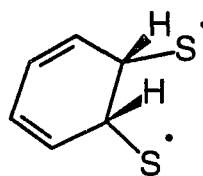


96

The path towards sulfur extrusion is, thus, made more complex. The traditional dithietane intermediate seemed to not fit in any such path. The four membered ring systems were found to be ca. 45 Kcal/mole higher in energy than the corresponding diradical species.



1,2-dithietane

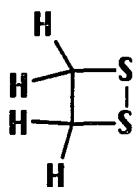


1,4-diradical

compound	1,2-dithietane	1,4-diradical	ΔE
6 1	102.58 Kcal	57.80 Kcal	44.78 Kcal
7 0	131.18	86.38	44.80
7 2	158.46	110.45	48.01

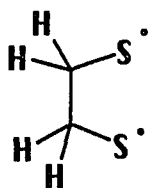
Table 6: Heats of formation of 1,2-dithietane vs 1,4-diradical intermediates.

The intriguing increase in heats of formation in the order of 45 Kcal/mole is quite unclear. To further test this, the model 4-membered ring system was examined.



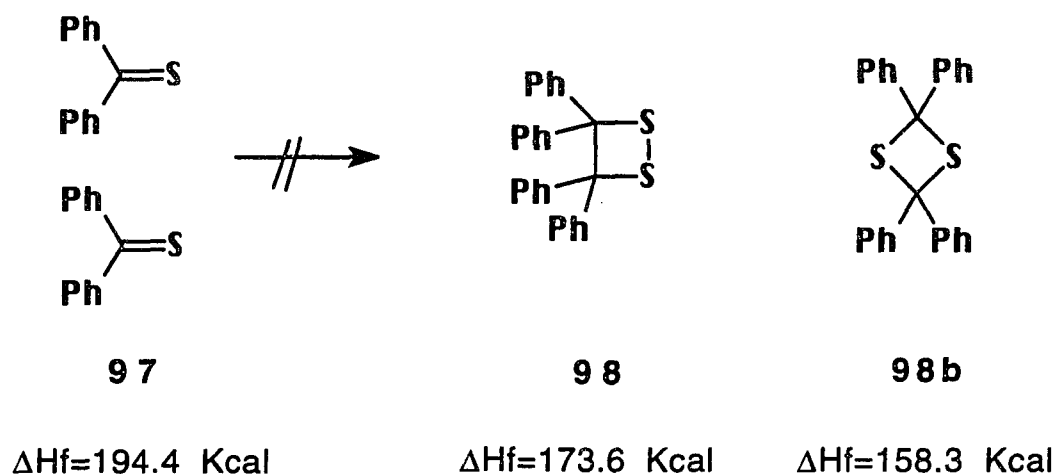
$$\Delta H_f = 71.09 \text{ Kcal/mole}$$

$$\Delta E = 49.39 \text{ Kcal/mole}$$



$$\Delta H_f = 21.70 \text{ Kcal/mole}$$

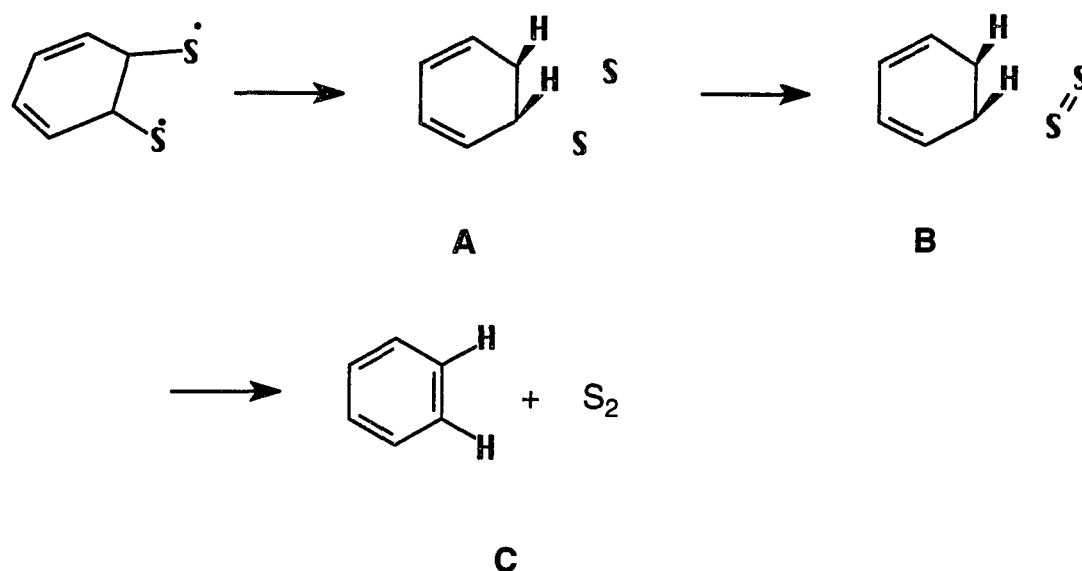
It is clear that this gain in energy is intrinsically related to the 4 membered framework. It may, therefore, be concluded that it has no contribution on or from the annelated segments. Steliou⁶² who investigated similar effects in tetraphenyl 1,2-dithietane **98**, calculated a smaller ΔH_f for **98** than a two thione system **97**.



Steliou took these values to indicate lowered preference of sulfur extrusion in the 1,2-dithietane as compared with the 1,3-dithietane, **98b**, and therefore, assumes the latter to be the corresponding intermediate. On the same basis, diradical intermediates observed in our calculations may be considered as the existing species in the path towards sulfur extrusion. The question now is whether or not the 4-membered ring systems are all parts of the evolution of the minima observed or species on a different reaction coordinate. Clearly, they are not transition states. They may be, however, evolutionary states that proceed or follow the diradical minima.

As it turns out, the position of the dithietane intermediate is not consistent in the systems studied. In the parent compound, the dithietane is only 0.85 Kcal lower than the second transition state while in the benzo and naphtho annelated systems the dithietane intermediates are at minimum 20 Kcal higher than the second TS and at minimum 6 Kcal higher than the first. It seems, therefore, that this dithietane intermediate lies on a different energy path.

The second transition state was identified via the symmetry controlled approach. Initial sulfur extrusion was observed to yield two distinct, non bonding sulfur atoms (stage A). When the C-S distances were continuously increased, S-S bond distances decreased, resulting in the formation of an S_2 species (stage B).



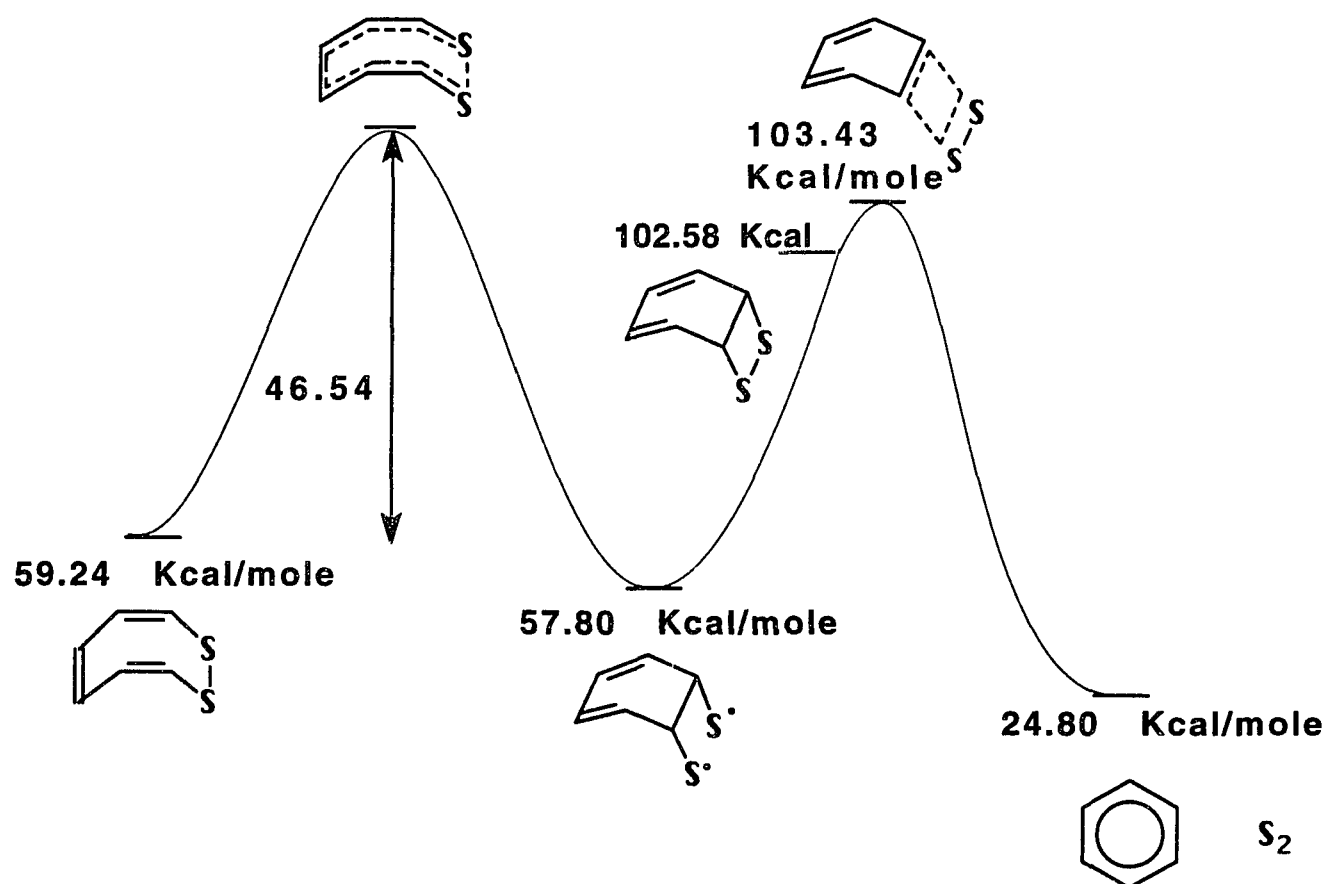
At this point, the 6-membered ring system is still non planar, with the two hydrogen atoms previously vicinal to the sulfur atoms, pointing up above the plane of the 6-carbon skeleton. In stage C, aromaticity is gained with the sulfur unit indefinite distance away.

compound	1,4-diradical	A	B	C
6 1	57.80 Kcal	77.34 Kcal	103.43 Kcal	24.80 Kcal
7 0	86.38	88.85	110.45	40.58
7 2	110.45			54.40

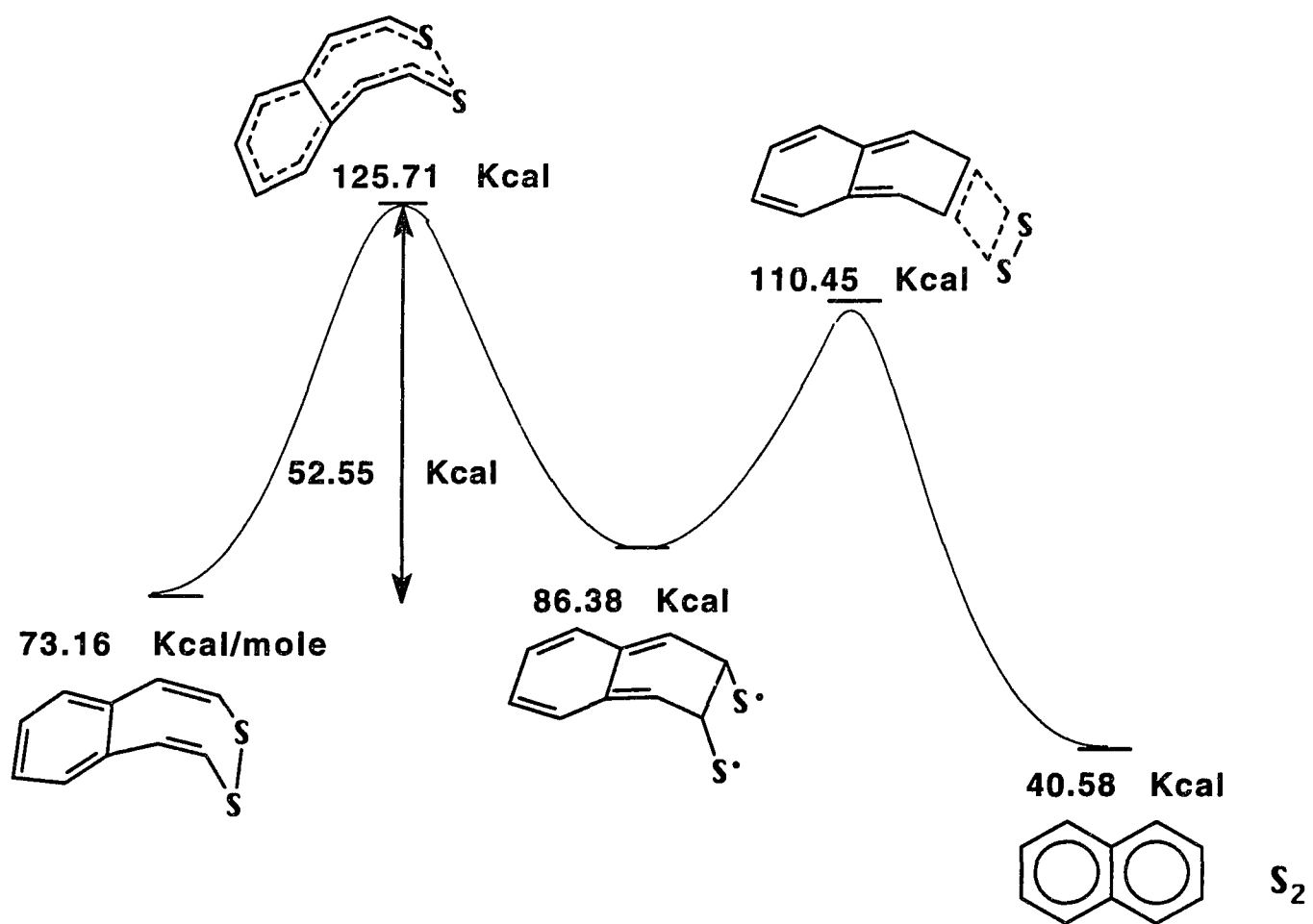
Table 7: Heats of formation of minima and transition states

Structures B were confirmed transition states. That puts them lower than the first transition states of type **96**. The overall reaction profiles for the parent 1,2-dithiocin and benzo[d] 1,2-dithiocin are shown next. As with the first transition state, the second has an intriguing geometry, as well. With two sulfur atoms fully bonded to each other (1.471 Å), the S₂ unit is 2.659 Å (from one sulfur) and 2.904 Å (from the other sulfur) away from the previously bonding carbon atoms. The S-S bond distance in S₂ is calculated to be 1.463 Å which is in agreement with the one obtained for S₂ species at the

second transition state.



Scheme 13: Reaction path for the extrusion of diatomic sulfur from 1,2-dithiocin **61**



Scheme 14: Reaction path for the extrusion of diatomic sulfur from benz[d] 1,2-dithiocin **70**

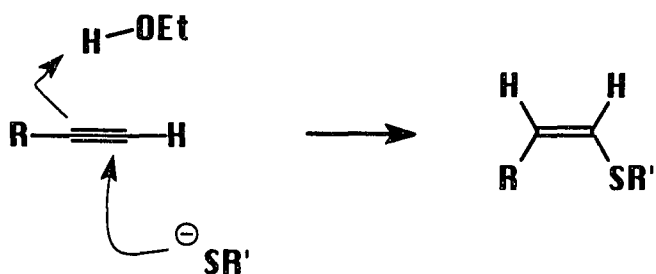
Heat of formation for the S_2 unit was calculated by us to be 63.29 Kcal/mole which is twice as large as the value obtained by Steliou (30.68 Kcal.) The barrier for the first transition state increases with ring annelation as expected due to increase in the energy involved in the orthoquinoid formation as one goes from benzene (46.54 Kcal) to naphthalene (52.55 Kcal/mole) to anthracene (91.81 Kcal/mole). This again substantiates our belief that naphtho[2,3-d]1,2-dithiocin is a good candidate for investigation. The approach towards its synthesis is described in the discussion chapters.

2.2.0 SYNTHESIS AND INVESTIGATION OF STABILIZED THIEPINS AND 1,2-DITHIOCIN.

2.2.1 SULFIDE ADDITION TO ACETYLENES

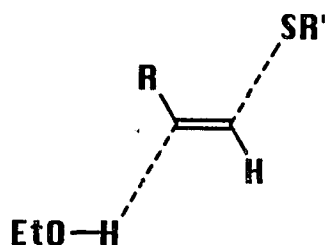
Sulfide addition to mono or diacetylenes has been used for facile synthesis of such systems as substituted thiophens, dithiins and other thiovinyl compounds. We investigated the sulfide addition to diacetylenes as means of ring formation to thiepins, dithiins and dithiocins. Two general methods of addition are known: nucleophilic and free radical mediated addition.

Addition of mercaptans to acetylenes is believed to proceed through an anti addition to the β -position to yield a cis-alkene.

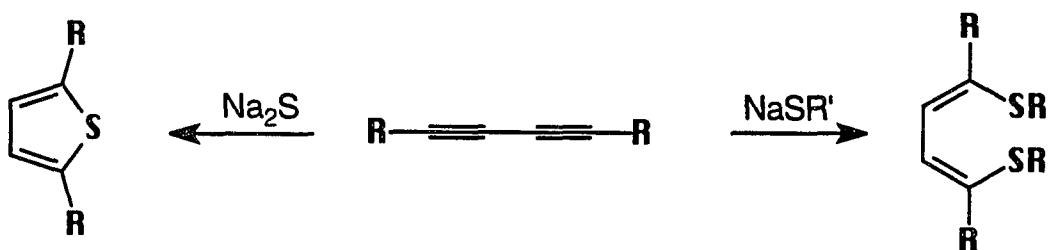


The indicated stereochemistry⁶³ would be expected on the basis that in the transition state the existing negative charge and the electronegative sulfur atom should tend to be apart from each other. Most nucleophilic mercaptide additions to acetylenes proceed rather

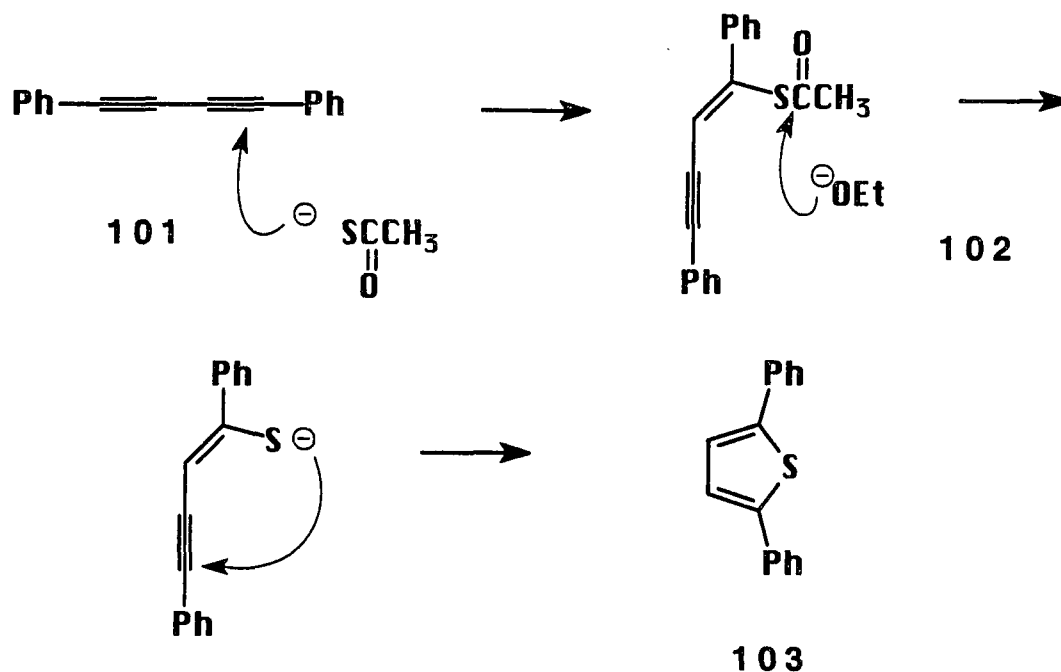
well in alcoholic solutions. The high stereospecificity observed in such solutions was proposed to result from the formation of an intermediate complex, **100**, involving the nucleophile and the solvent.

**100**

Addition of mercaptans to diacetylenes under basic conditions, results in the formation of Z,Z-disubstituted alkenes. However, when sodium sulfide is added, the addition proceeds to form thiophene derivatives.

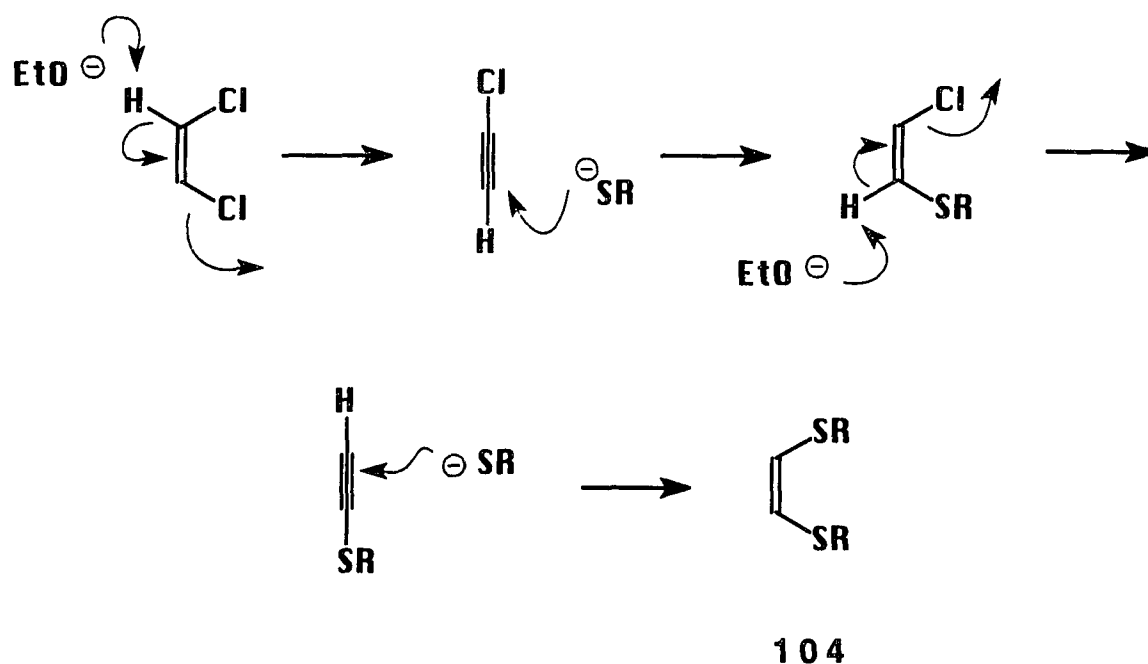


However, we observed that when thiol acetic acid was allowed to add to diphenyldiacetylene, **101**, in the presence of sodium ethoxide, only 2,5-diphenylthiophene, **103** was obtained. The formation of **103** is explained through initial sulfide addition to one acetylene, deprotection of the sulfide by ethoxide ion and intramolecular addition of the formed vinylsulfide to the second end of the diacetylene, as shown below.

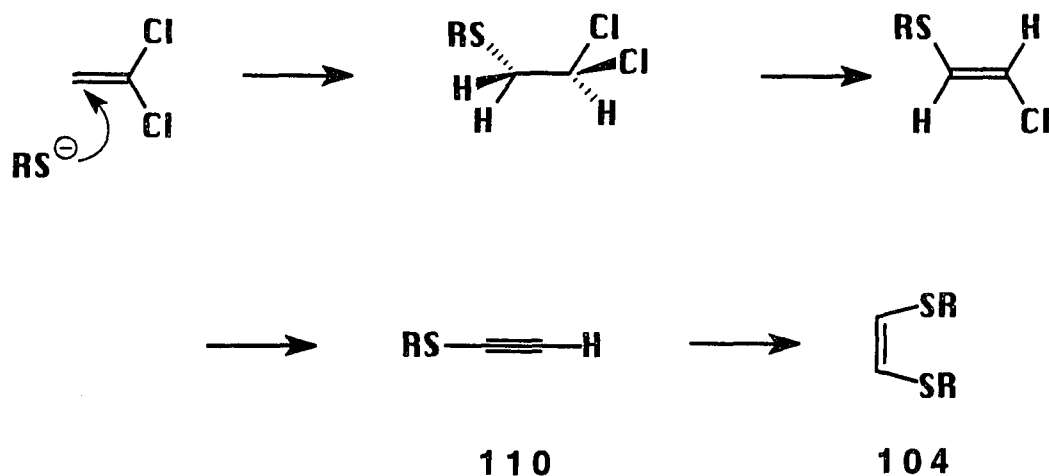


Interception of the eneyne, **102**, was not possible.

One specific reaction has been observed to be solvent selective and proceed in ethanol only⁶⁴. The addition of benzylmercaptane to cis-dichloroethene in ethanol was reported by Schroth to yield the cis-1,2-bis(benzylmercapto)ethene, **104**, in high yield. The reaction was proved to proceed through in situ generated chloroacetylene.

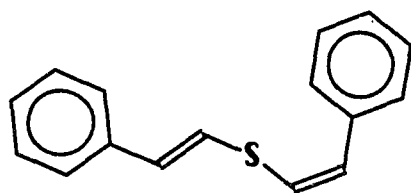
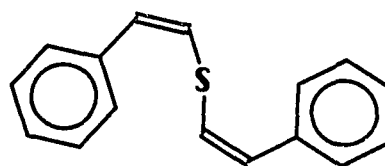


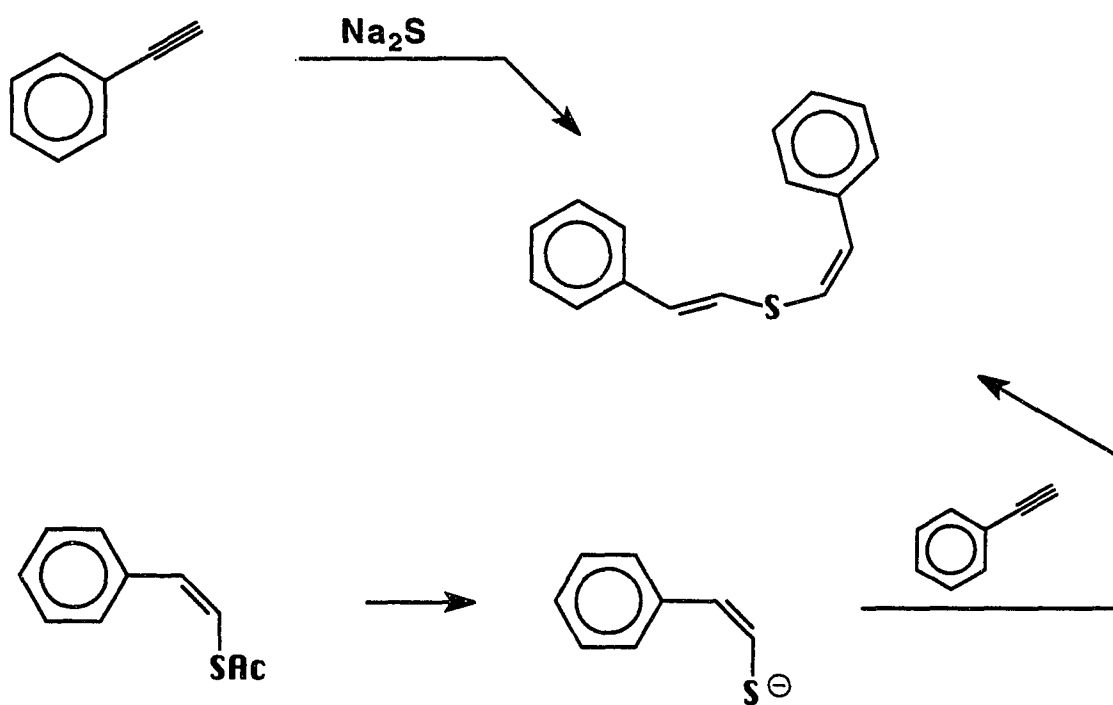
In no other solvent does this reaction work. Similarly, sulfide addition to vinylidene chloride yielded **104**, in similar yields⁶⁵. In this case, however, the orientation of attack by benzylmercaptide ion is due to polarization of the chlorine atoms, thereby facilitating nucleophilic attack at the methylene group.



The second elimination of a chlorine ion and the formation of the thioacetylene, **110**, was observed to proceed sluggishly.

When sodium sulfide was added to an ethanolic solution of phenylacetylene and heated at reflux, none of the Z,Z-distyrylsulfide, **105**, was obtained. E,Z-distyrylsulfide, **106**, was obtained as the sole product in 17.1% yield. Similarly, when vinylsulfide **108** generated from the acetyl **107** was treated with phenylacetylene under identical conditions, **106** was obtained exclusively in similar yields.

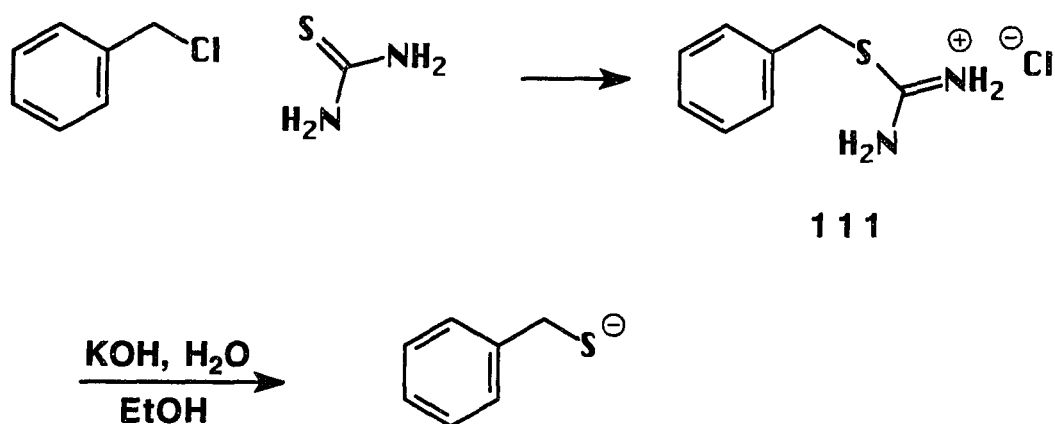
**106****105**



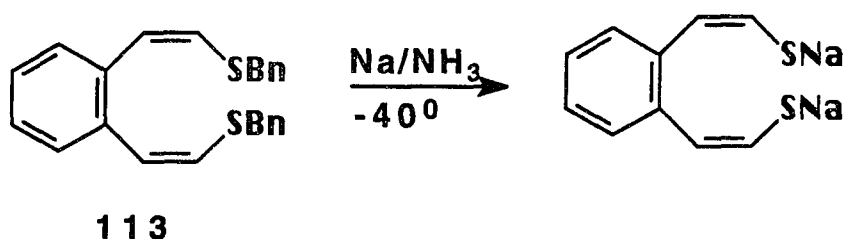
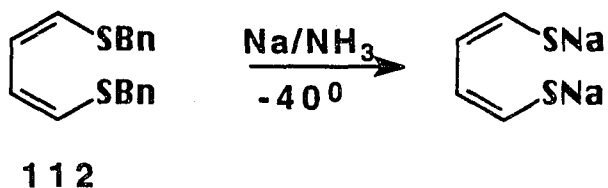
Scheme 15: Synthesis of E,Z-distyrylsulfide, 106

It seems, therefore, that vinylsulfides add to acetylene and reverse the stereoselectivity to yield trans alkenes. This is, to our knowledge, the only non-radical-mediated-sulfide-addition that results in a trans vinylsulfide.

Benzylmercaptan, the most common of the sulfur delivering agents, has been used in the syntheses of Thiarubrines A⁶⁶ and B⁶⁷- a class of naturally occurring disulfide systems exhibiting antiviral and anti HIV activities. The mercaptan may be prepared in situ under basic conditions by hydrolysis of S-benzylisothiuronium chloride salt, **111**. The salt is prepared by nucleophilic substitution of thiourea on benzylchloride in aqueous media.

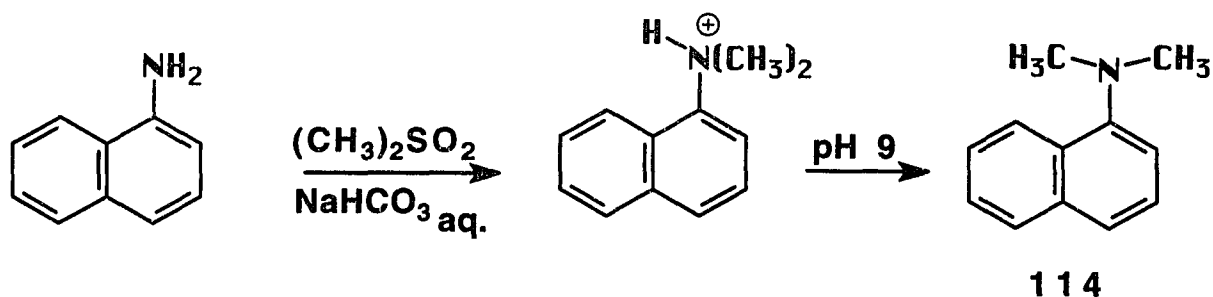


The use of a particular sulfur delivering agent is based on its ability to be deprotected after the sulfur atom has been deposited on the triple bond. Methods for deprotection have been developed quite extensively. Reductive debenzylolation of benzylmercapto vinyl systems such as **112** and **113** was traditionally achieved with sodium in liquid ammonia⁶⁸.



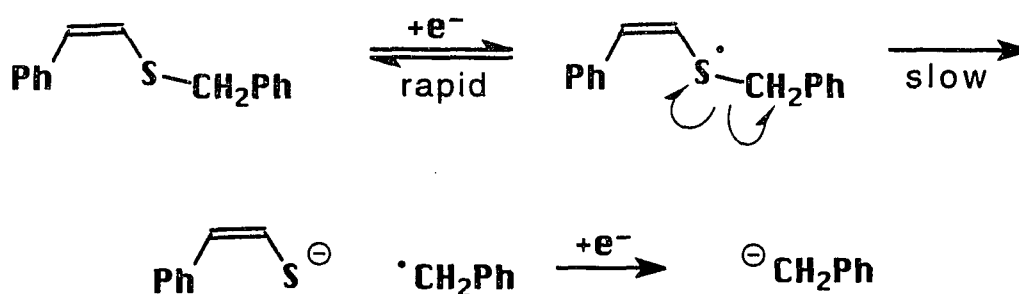
In our hands, such debenzylation failed repeatedly. Block⁶⁹ who faced similar difficulties in debenzylating a 1,2-dithiin intermediate to Thiarubrine B, utilized successfully lithium 1-(N,N-dimethylamino) naphthalenide (LDMAN) as a debenzylating agent.

The precursor, 1-(N,N-dimethylamino)naphthalene, **114**, also known as "Hünig base" is commercially available but may easily be obtained in large quantities and in high yields from methylation of 1-amino naphthalene in aqueous sodium bicarbonate at 0°. Basification to pH 9 and distillation yields DMAN as colorless oil.



Addition of DMAN⁷⁰ into a stirred suspension of lithium metal in THF at -50° yields the radical anion as a deep blue solution which is cooled to -70° and treated with the desired benzylmercaptovinyl compound.

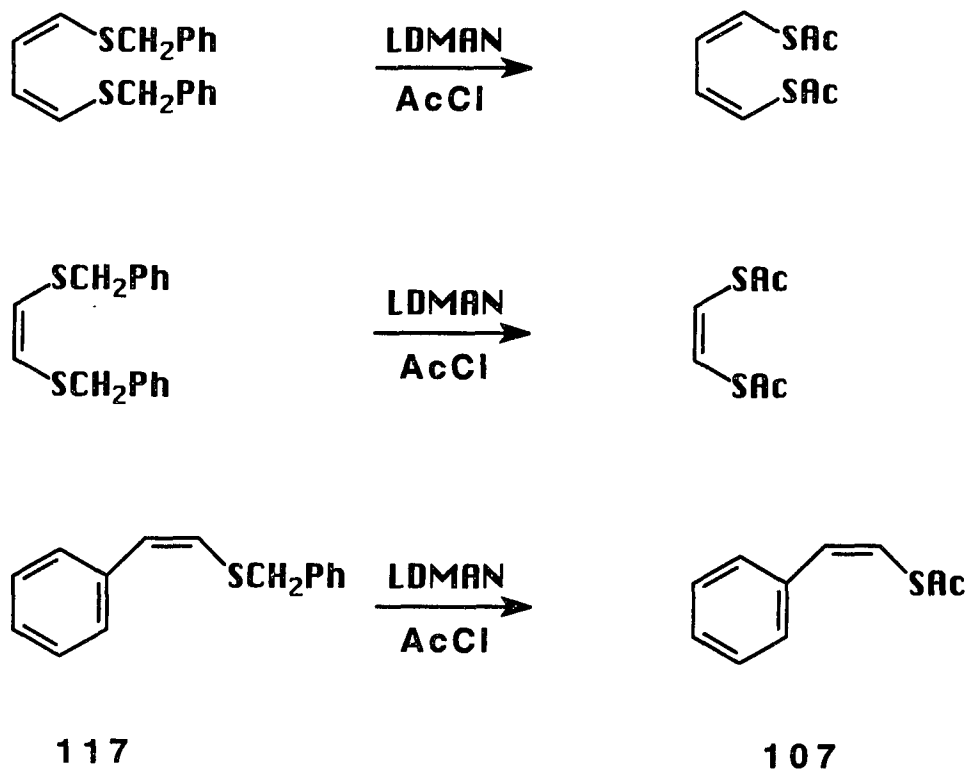
The debenzylation, a reductive lithiation process, via a radical anion is believed to involve an electron transfer to the substrate followed by homolytic cleavage of the carbon-sulfur bond, resulting in the formation of an anionic vinyl sulfide leaving group and a benzyl radical. Reduction follows to yield the carbanion.



LDMAN is by far superior to the widely used lithium naphthalenide in reductive lithiations because it removes the necessity to separate the naphthalene by-product. DMAN may be simply washed out with dilute acid, neutralized and recovered in 85-96% yield.

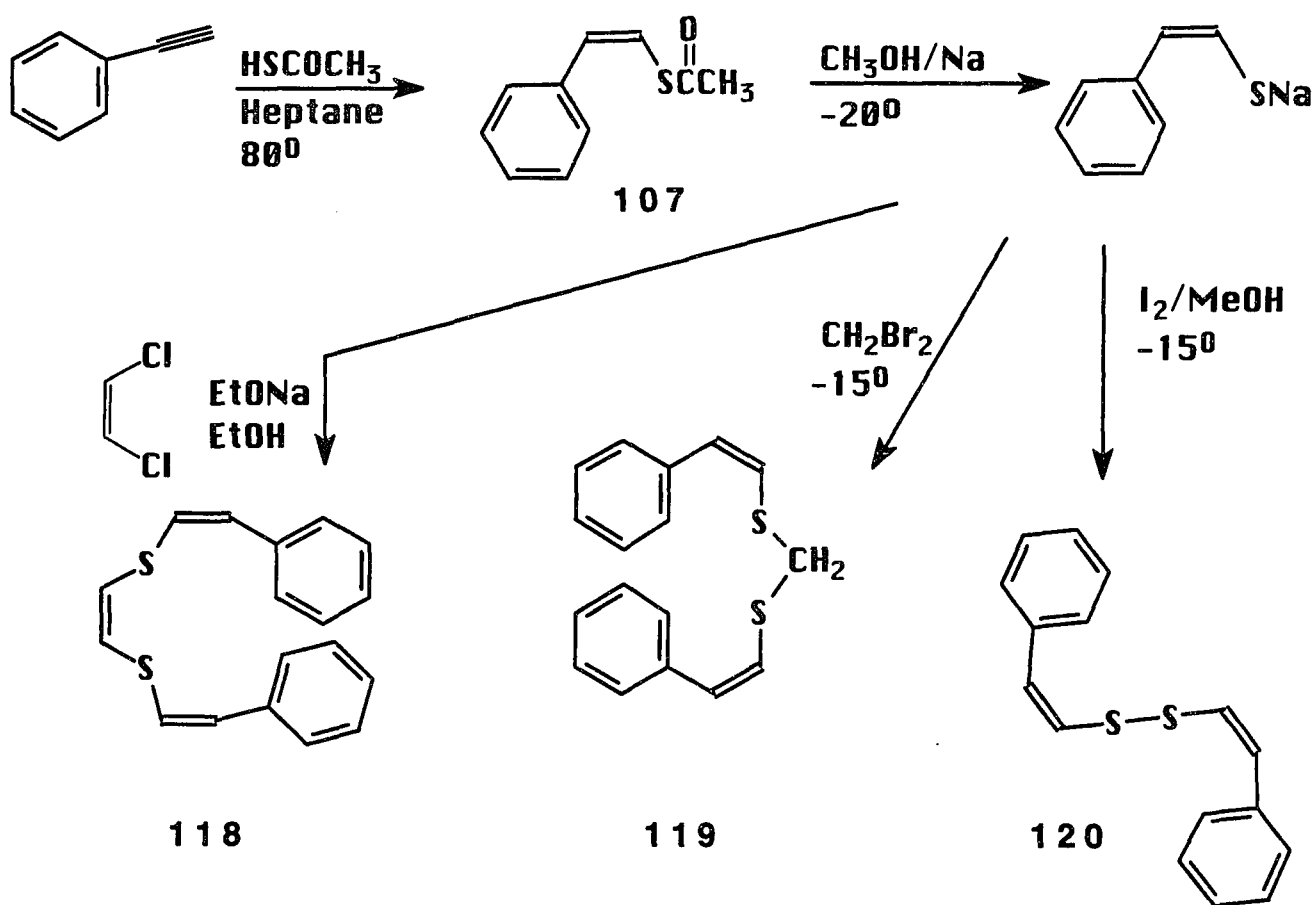
Trapping of the thiolate anion formed after reduction with acetylchloride (or other alkylating agent) yields a stable vinyl-sulfide that may be deprotected in the presence of base.

Debenzylation tests on various mercaptovinyl compounds have been carried out (Scheme 16). With the debenzylation of *cis*-2,3-bis(β -benzylmercaptovinyl)naphthalene, **115**, we encountered some difficulties. Only small amounts of the diacetyl **116** were obtained, in insufficient amounts.



Scheme 16: Debenzylation and thiolate trapping with acetyl chloride

Oswald⁷¹ et al showed that thiol acetic acid reacted with phenyl acetylene at 80° in heptane (5%), under an atmosphere of nitrogen, to yield exclusively the cis-1-acetylmercapto-2-phenylethene, **107**.



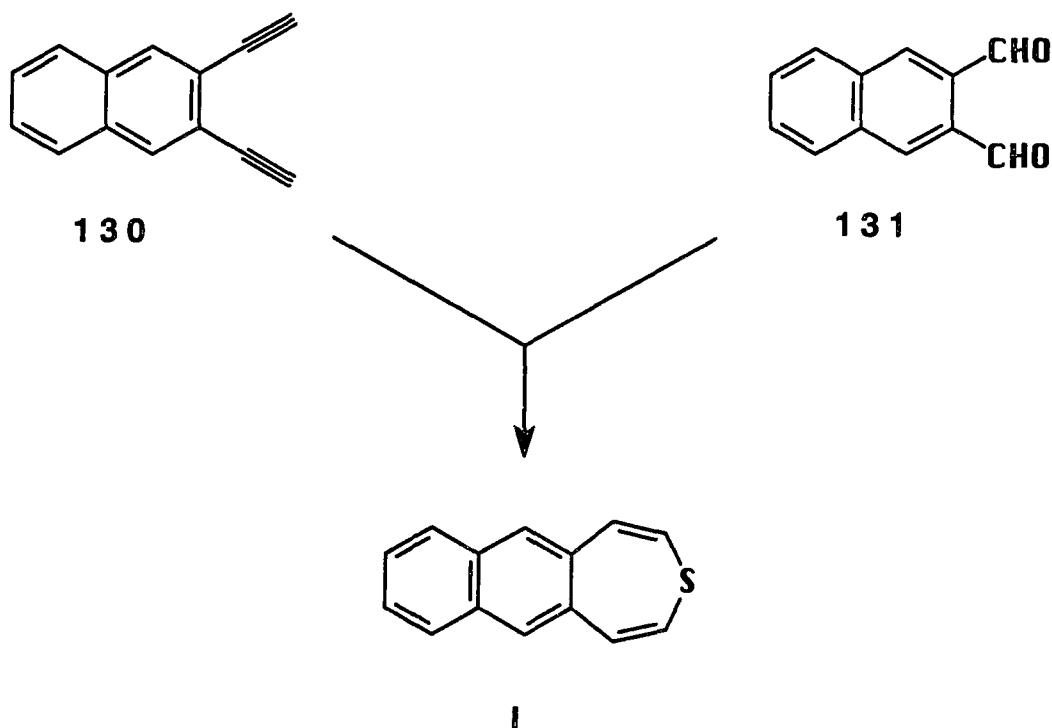
Successful study of the published procedure yielded **107** as a white solid in 42.3% yield. Acetate **107** had earlier been synthesized by LDMAN reductive lithiation of **117**, in two steps in 67.6 % yield. Clearly, with Oswald's free radical approach, such addition obviates

the use of a LDMAN reduction. Further treatment with sodium methoxide in methanol and interception of the anion under various conditions yielded the products, as shown.

Similar reaction of thiolacetic acid with 1,4-diphenyl-1,3-butadiyne did not yield the desired product. Addition to o-diethynyl benzene or to 2,3-diethynylnaphthalene was unsuccessful. None of the starting materials were recovered.

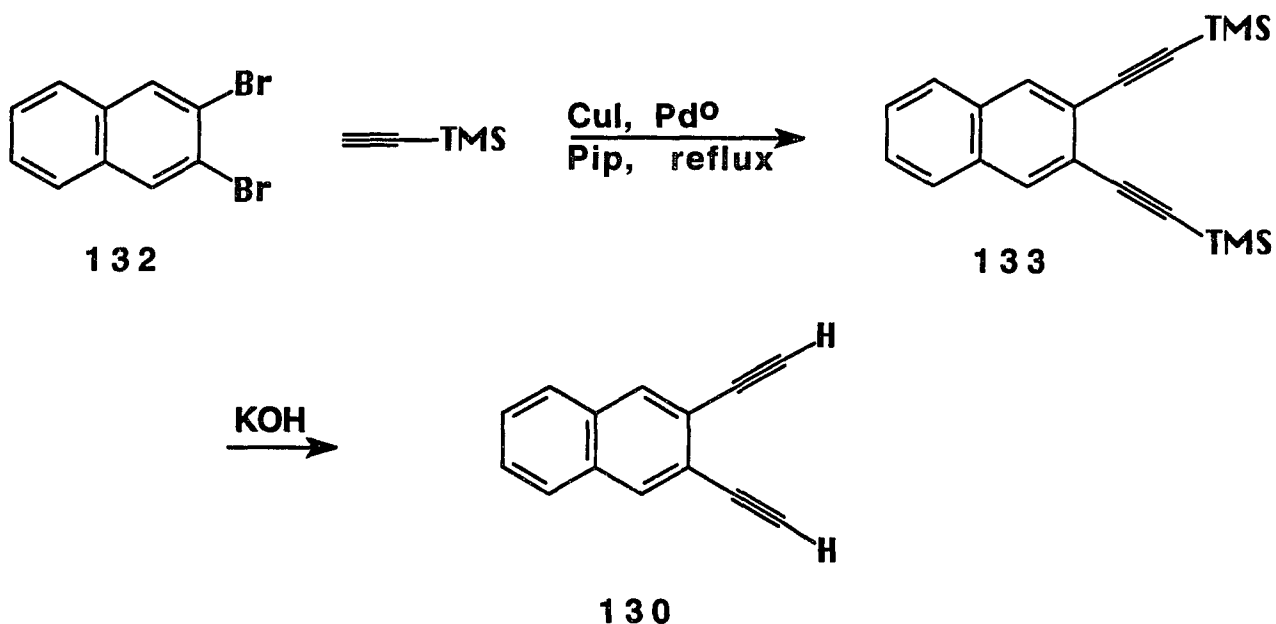
2.2.2 SYNTHESIS AND INVESTIGATIONS OF NAPHTHO
[2,3-d] THIEPIN, I

Two methodologies were considered for the synthesis of **I**. The first, sulfide addition to 2,3-diethynynaphthalene, **130**, and the second a Wittig reaction of 2,3-naphthalene dicarboxaldehyde with thiobis (methyltriphenylphosphonium)bromide, as shown in Scheme 17 below.

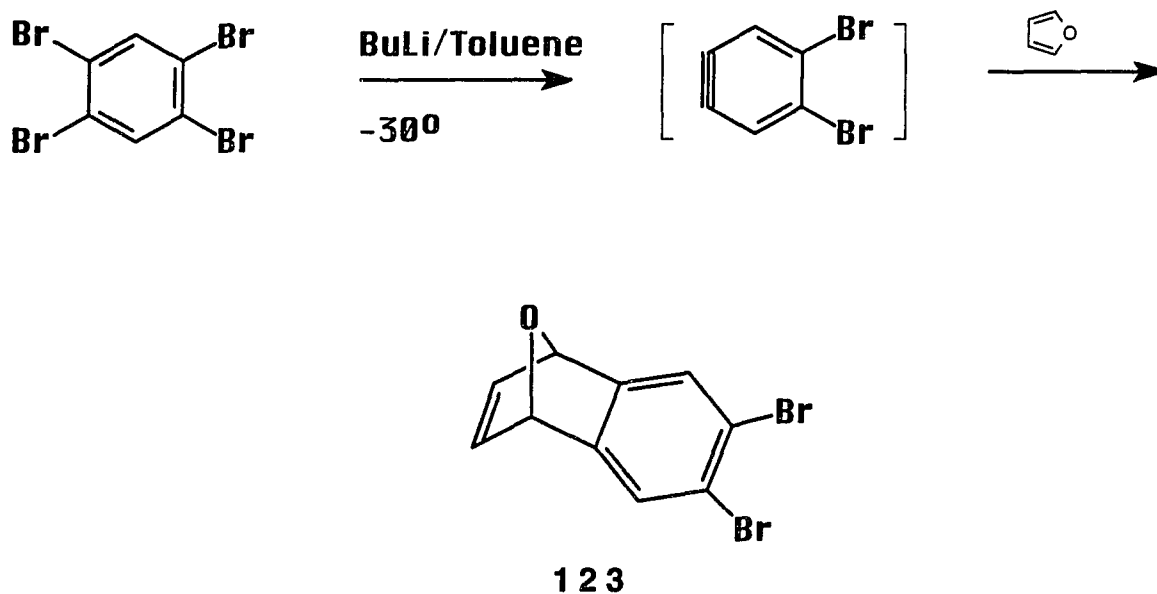


Scheme 17: Synthetic paths towards thiepin **I**

Diacetylene **130** was synthesized in three different ways in variable quantities. The most useful method utilized Pd-coupling of dibromonaphthalene and protected acetylene as shown below.

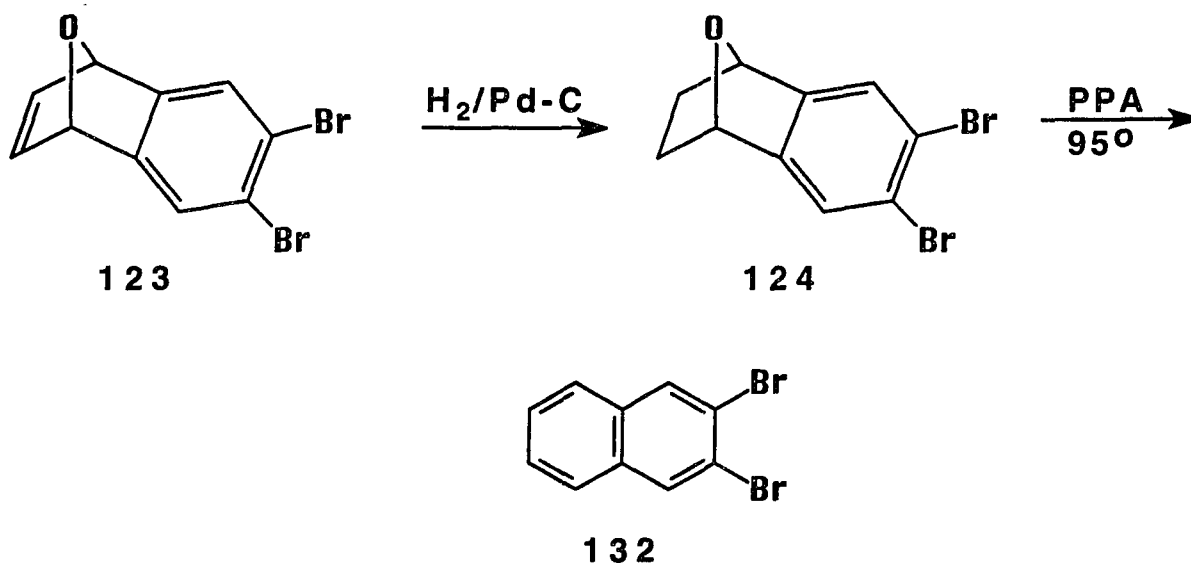


The commercially unavailable **132** was synthesized by Hart's method⁷². BuLi addition to a toluene solution of 1,2,4,5-tetrabromobenzene at -30° in the presence of excess furan, yielded the desired dibromobenzyne adduct, **123**, in 77.3% yield. Deoxygenation and transformation of **123** to **132** was achieved by either of two methods.



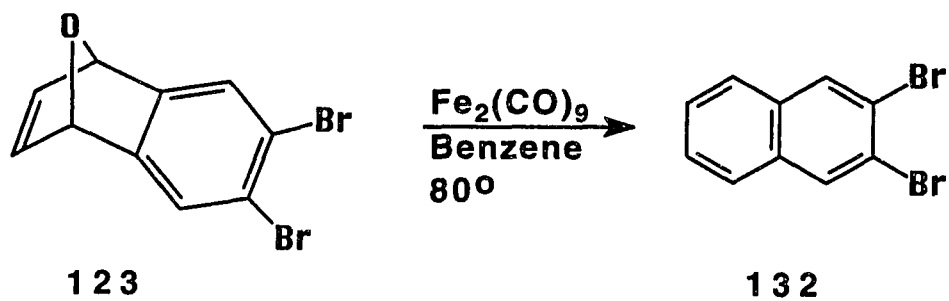
Scheme 18: Synthesis of endoxide **123**

Method a) hydrogenation of **123** to the dihydro compound **124** proceeded quantitatively. Treatment of **124** with polyphosphoric acid at 95° for 15 minutes afforded **132** cleanly in 79.8 % yield (two steps from **123**.)



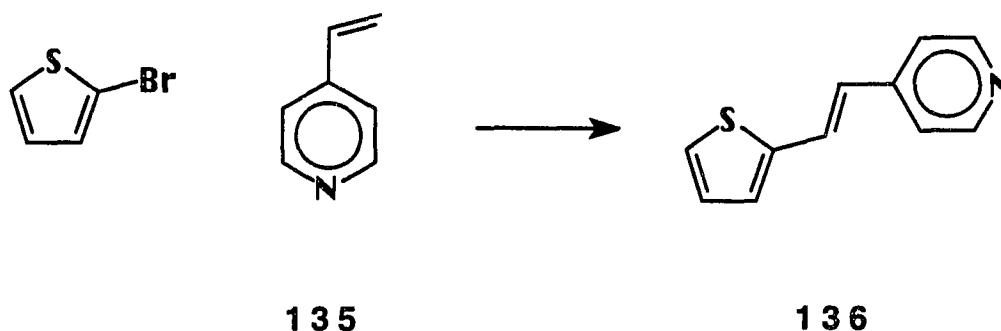
Scheme 19: Synthesis of **132** via hydrogenation-deoxygenation of **123**

Method b) involves the addition of endoxide **123** to a pre-stirred solution of $\text{Fe}_2(\text{CO})_9$ in benzene⁷³ to yield **132** directly in 89.4% yield.



With **132** available, its Pd-coupling with acetylene was examined. Several reports of such coupling reactions have been described in the literature with as many variations in reaction conditions and Pd-type complexes. With its experimentally simple, mild but versatile character, Pd-coupling has become a method of choice to effect a variety of conversions.

Heck⁷⁴ utilized 1% Pd(OAc)₂ and 3% phosphine in triethylamine for the coupling of 2-bromothiophene with pyridine **135** to yield **136** in 57% yield.

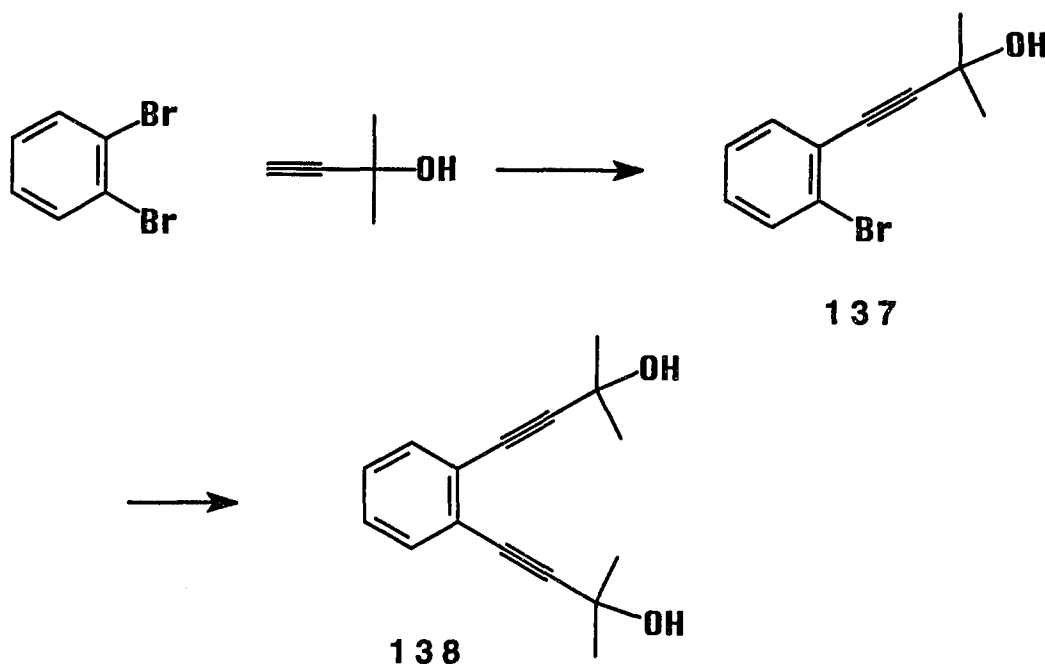


Rawal⁷⁵ utilized the Heck reaction for his synthesis of strychnos family members; while Nicolaou and others utilized Pd-coupling in the synthesis of enediynes such as Calcheamicin₇₁.

Addition of CuI to a mixture of bis(triphenyl phosphine) palladium dichloride and diethylamine solution of iodobenzene and

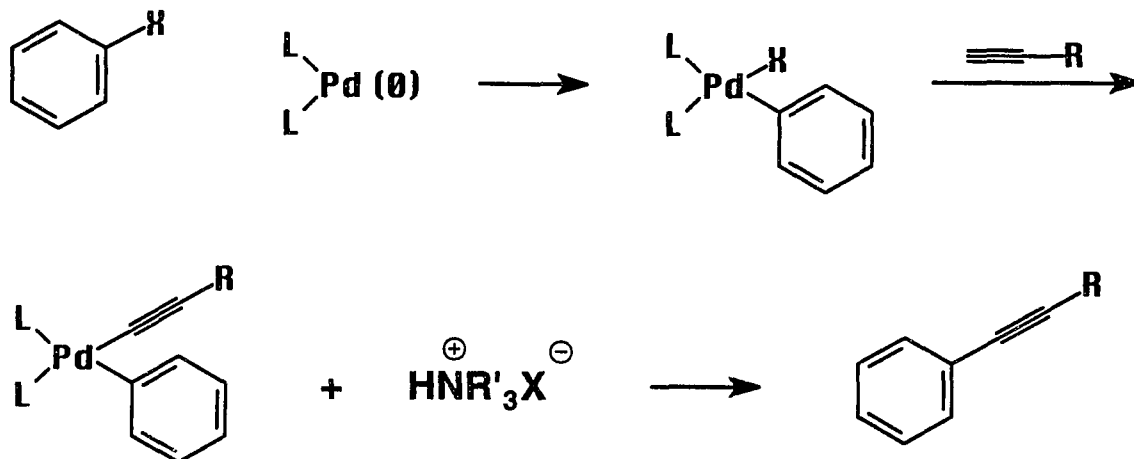
dissolved acetylene gas yielded diphenylacetylene in 85% yield. Similarly, bromoarenes were used to afford such disubstituted acetylenes in high yields. One such report was the synthesis of a large variety of enediynes by Semmelheck⁷⁶. Diethynylarenes were synthesized from the corresponding diiodo- and dibromobenzenes by a facile conversion in the presence of an amine base and tetrakis (triphenylphosphine) palladium catalyst.

Variations in the acetylene protecting groups and palladium complexes proved to effect the extent of coupling. When 2-methylbut-3-yn-ol was used as the acetylene in a coupling reaction with o-dibromobenzene, only small amounts of the bis coupled product, **137**, was obtained⁷⁷. A second coupling of **137** was required to yield **138**.



However, when trimethylsilyl acetylene was used under identical conditions⁷⁸, the bis acetylene product was obtained as the major product in one step.

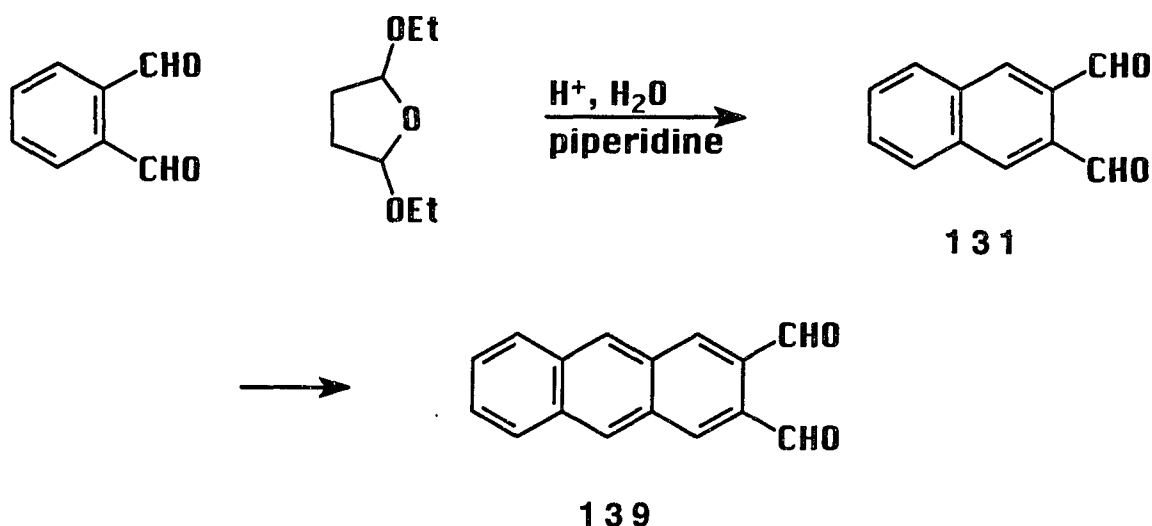
The reaction is believed to proceed through an initial formation of bis(triphenylphosphine)dialkynyl palladium which gives a catalytic species bis(triphenylphosphine)palladium(0). Subsequent oxidative addition of the arylhalide to the Pd(0) species, followed by alkynylation yields the arylalkynyl-Pd complex which easily generates the Pd(0) catalyst and reductively eliminates the coupled product.



Scheme 20: Mechanism of Pd-coupling of acetylenes to arylhalides

Thus, addition of **132** to a piperidine solution containing 6 equivalents of TMSA and catalytic amounts of $(\text{Ph}_3\text{P})_4\text{Pd}$ and CuI yields 2,3-bis[(trimethylsilyl)ethynyl] naphthalene **133**, which is then cleanly deprotected in aqueous KOH in DMF to yield diethynyl **130** in 50% yield (two steps).

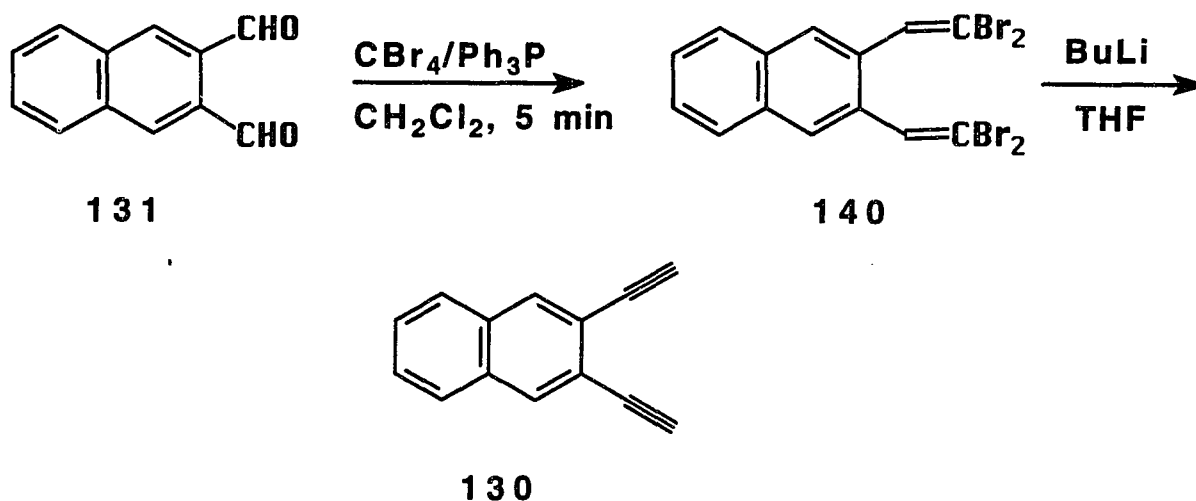
A second approach for the synthesis of **130** utilizes Lepage's aldol condensation of succinic dialdehyde and o-phthalaldehyde⁷⁹. Addition of 2,5-diethoxy (or dimethoxy) tetrahydrofuran to an acidic, aqueous solution generates 1,4-succinic dialdehyde as a labile species. Mixed aldol of the two dialdehydes in the presence of piperidine yields naphthalene-2,3-dicarboxaldehyde, **131**, in a low yield of 19.8%. The product is always contaminated by anthracene dialdehyde, **139**, resulting from a second condensation on **131**.



Scheme 21: Lepage's synthesis of naphthalene-2,3-dialdehyde, **131**

If an equimolar amounts of o-phthalaldehyde and succinic dialdehyde are used, only 4.2% of **139** is obtained. However, if 2 equivalents of succinic dialdehyde are used, **139** is separated as the major product in 28.2% yield along with 2.8% of **131**. The product mixture is easily separated by sublimation.

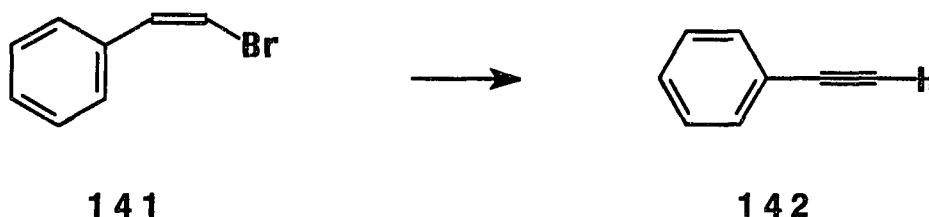
Wittig olefination of dialdehyde **131** with triphenylphosphine-carbon tetrabromide mixture in methylene chloride yielded the tetrabromo compound **140** as a white solid in 56.5% yield⁸⁰. Subsequent treatment of **140** with BuLi in THF⁸¹, followed by acidification yielded the diacetylene **130** in 46.2% yield overall from **131**.



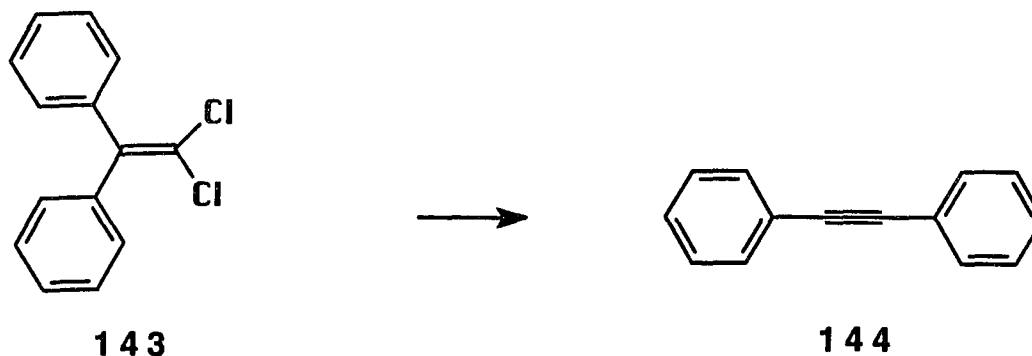
Scheme 22: Synthesis of **130** via Wittig/Fritsch-Butterburg-Wiechell sequence

The aspects of the Wittig type olefination will be discussed at a later point. The BuLi conversion of the bis-dibromovinyl species, **140**, does not follow β -elimination as one would assume, rather follows a carbene insertion reaction known as the Fritsch-Butterburg-Wiechell rearrangement⁸².

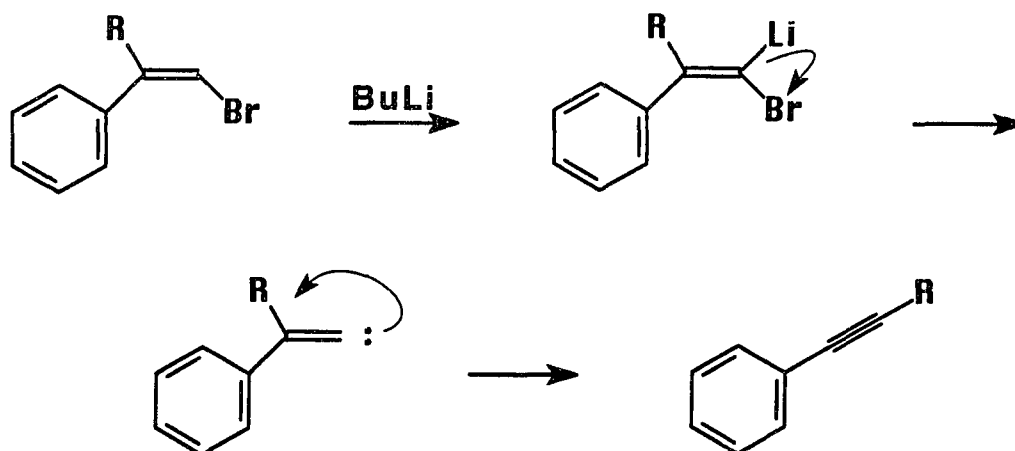
Conversion of a bromovinyl compound such as **141** to an acetylene with t-BuOK is known to follow β -elimination. However, with the greater tendency of metal exchange observed with BuLi, β -elimination is suppressed. When **141** is treated with BuLi or t-BuOK acetylene **142** is recovered.



When diphenylvinyl bromide, **143**, is treated with BuLi, a phenyl shift results in the formation of **144** obtained as the sole product.

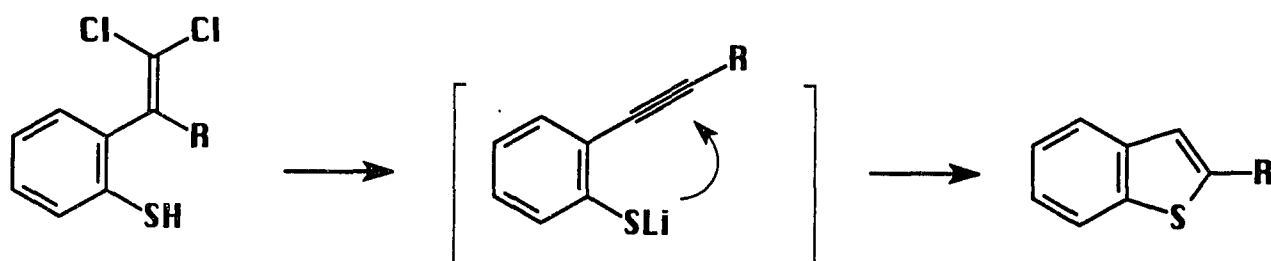


With *t*-BuOK no reaction leading to **144** is observed. It has been determined that metal-halide exchange proceeds to evolve a vinyl carbene which is inserted in a C-H or a C-C bond resulting in the observed acetylene as shown below:



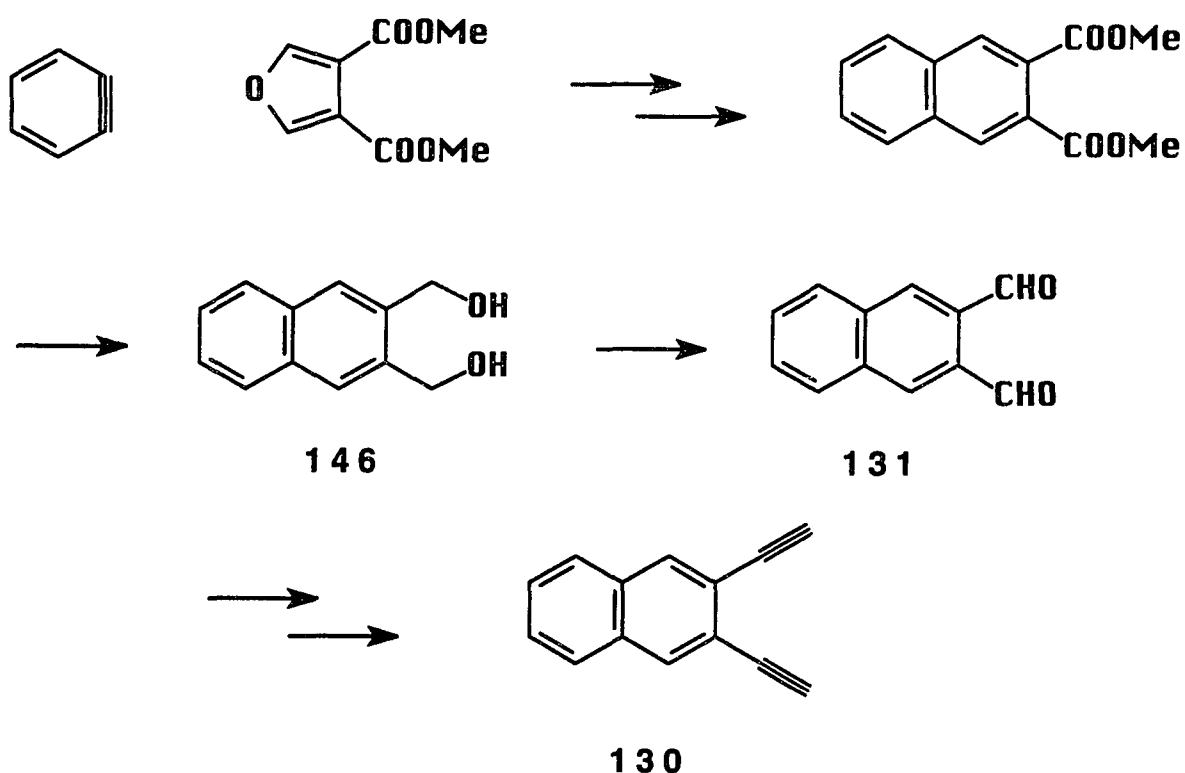
Scheme 23: Fritsch-Butterburg-Wiechell rearrangement.

Recently, such rearrangement was observed in the BuLi reaction of **145**⁸³.



145

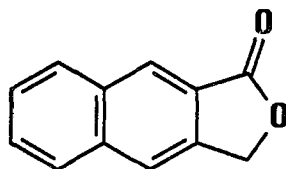
A third synthesis of **130** showed only a limited use due to its lengthy procedure as compared with the two methods previously discussed. The overall approach is shown below.



Scheme 24: Third approach towards **130**

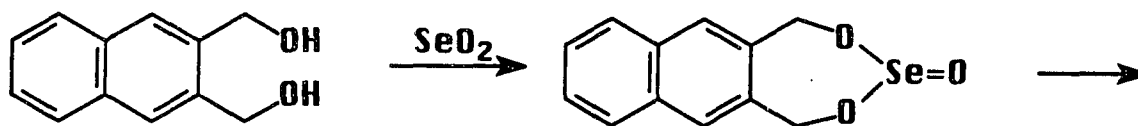
A great deal of functional group manipulation is required with this method. The most problematic step in the sequence is the oxidation of diol **146**. Several oxidations were attempted. The difficulties stem from the proximity of the two alcohols which in most cases

produced a lactone type product, **147**, rather than the desired dialdehyde.

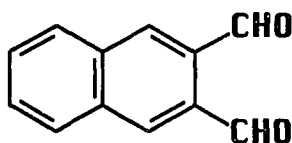


147

Such was the case upon oxidation of **146** with MnO_2 . Only **147** was obtained in 65-70% yield. Attempts to utilize NBS and Br_2 as an oxidant mixture, yielded only small amounts of the dialdehyde **131**. Oxidation with SeO_2 proceeded through the selenate ester which was heated at 110° then sublimed to yield the dialdehyde **131** in quantitative yields.

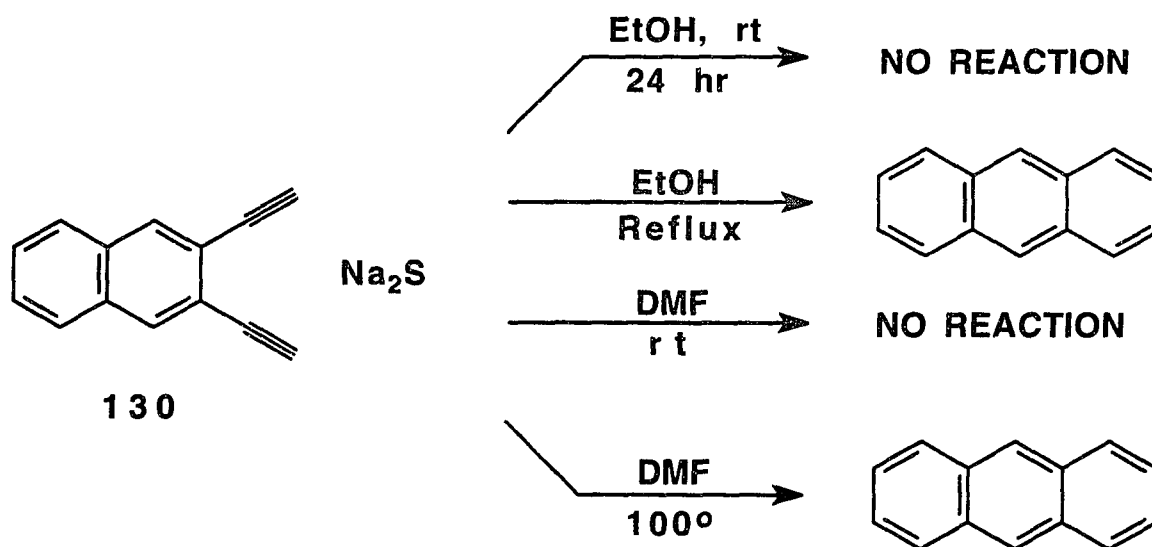


146



131

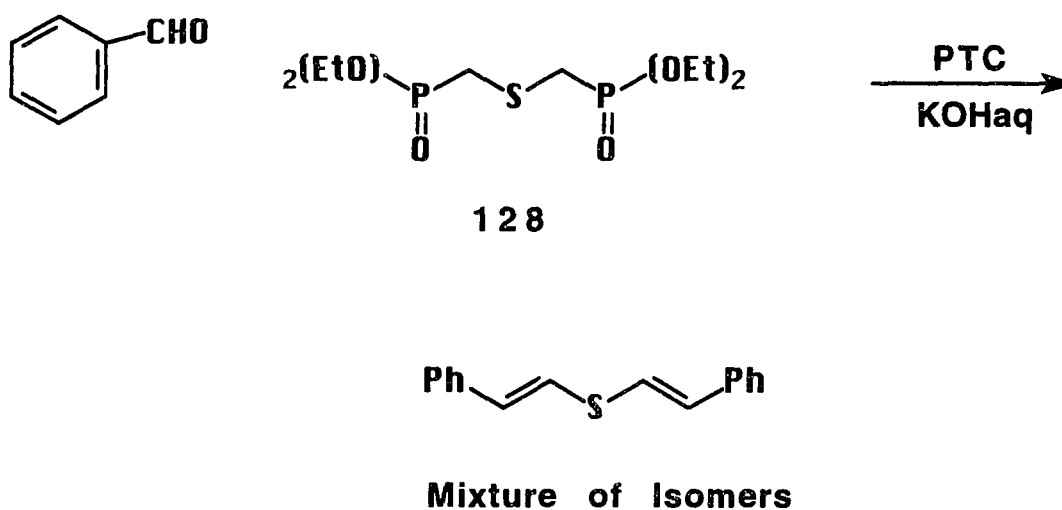
With **130** available, sulfide addition was attempted. Addition of sodium sulfide to the diacetylene **130** was carried out under different conditions.



Scheme 25: Attempted synthesis of naphtho[2,3-d] thiepin, **I**, via sulfide addition

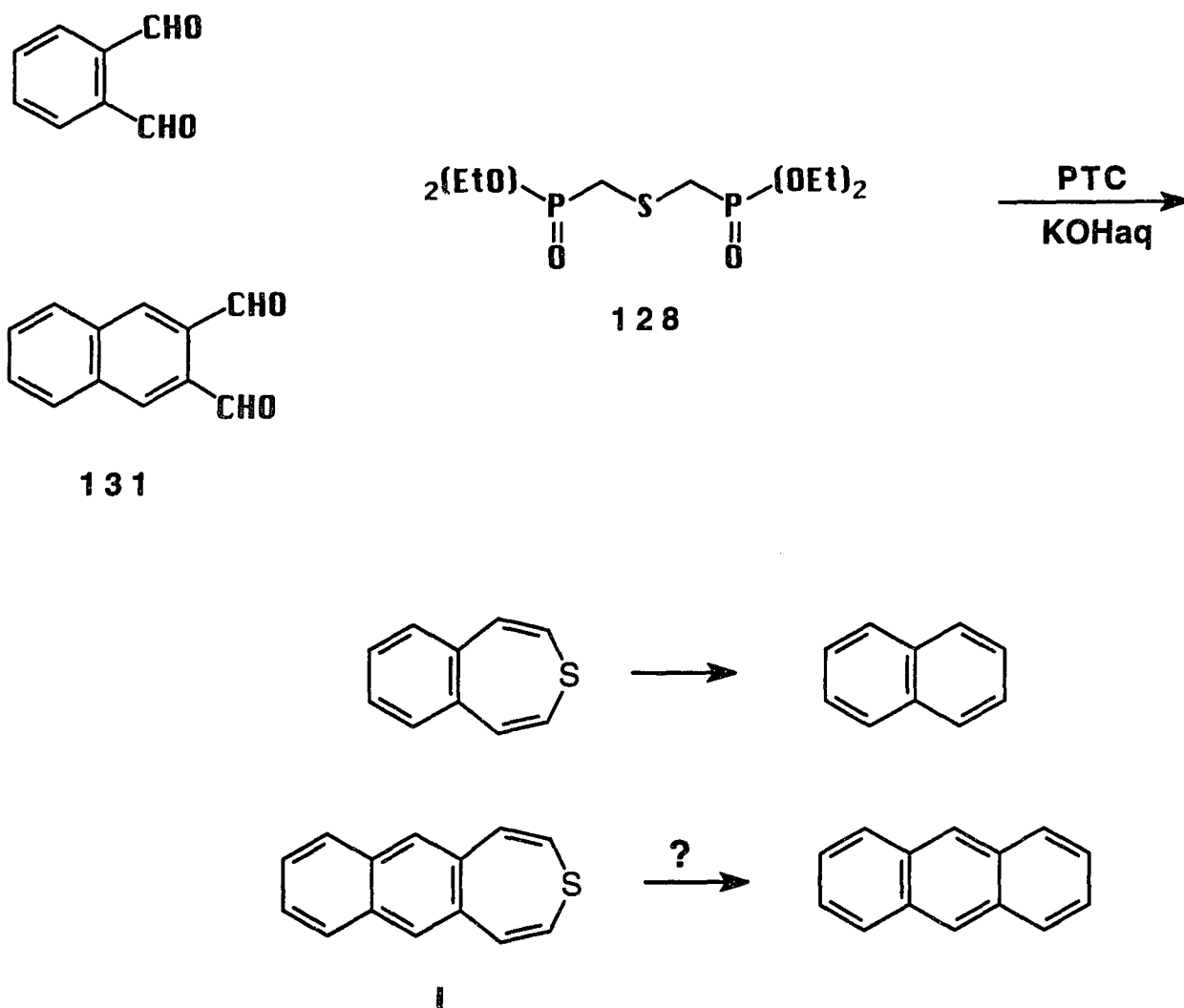
In no case was **I** detected. The production of anthracene and elemental sulfur are believed to evolve from the decomposition of **I**, as was earlier discussed. It seems, however, that refluxing ethanol or warm DMF solutions, required for the sulfide addition, accelerate and facilitate sulfur extrusion. The synthesis of **I** via a Wittig reaction at low temperatures is examined next.

Wittig-Horner type olefination was examined as a method of generating the ylid at low temperatures. Such reactions have been reviewed in the literature and were found useful even under mildest of conditions. The reaction between benzaldehyde and phosphonate **128** has been reported to result in the formation of mixtures of distyrylsulfides, as shown in Scheme 26 below.



Scheme 26: Distyrylsulfides via Wittig-Horner olefination

The reaction between o-phthalaldehyde and phosphonate **128** was thus attempted in hope that the presence of naphthalene in the reaction product-mixture would indicate successful olefination. However, such an addition did not proceed. Similar attempts with Naphthalene-2,3-dicarboxaldehyde failed as well. In no case did the reaction work. The aldehydes were recovered quantitatively.

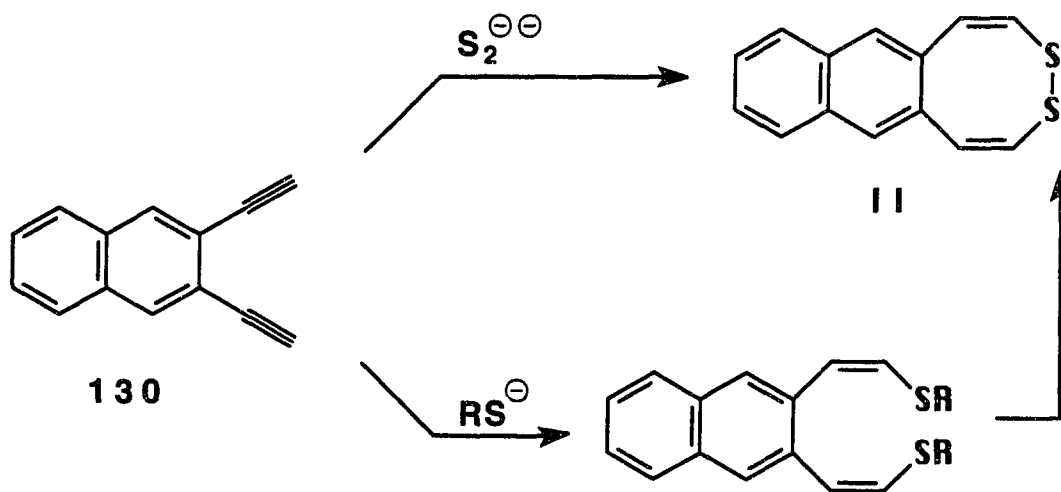


Scheme 27: Attempted synthesis of **I** via Wittig-Horner Olefination.

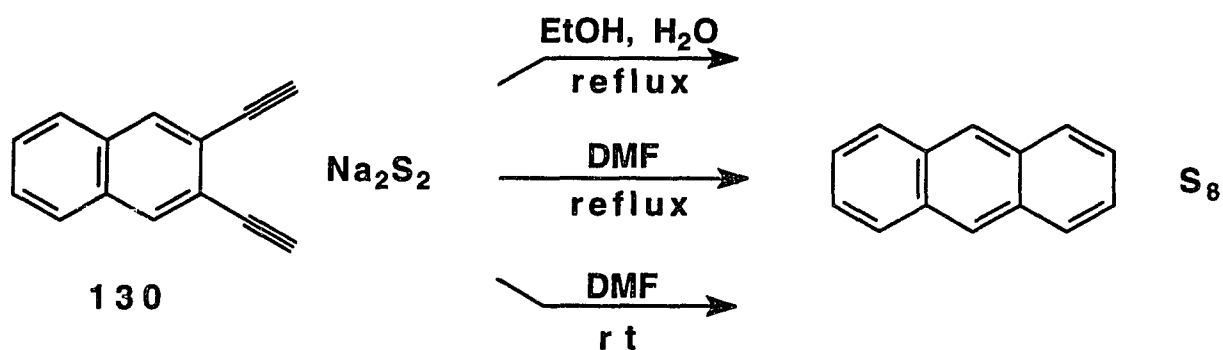
Further attempts to achieve olefination via this route are currently being attempted by varying base and other conditions.

2.2.3 ATTEMPTED SYNTHESIS OF NAPHTHO[2,3-d]-1,2-DITHIOCIN, II.

The general routes devised for the construction of the 1,2-dithiocin system involve the nucleophilic addition of mercaptans to diacetylene **130** discussed earlier.

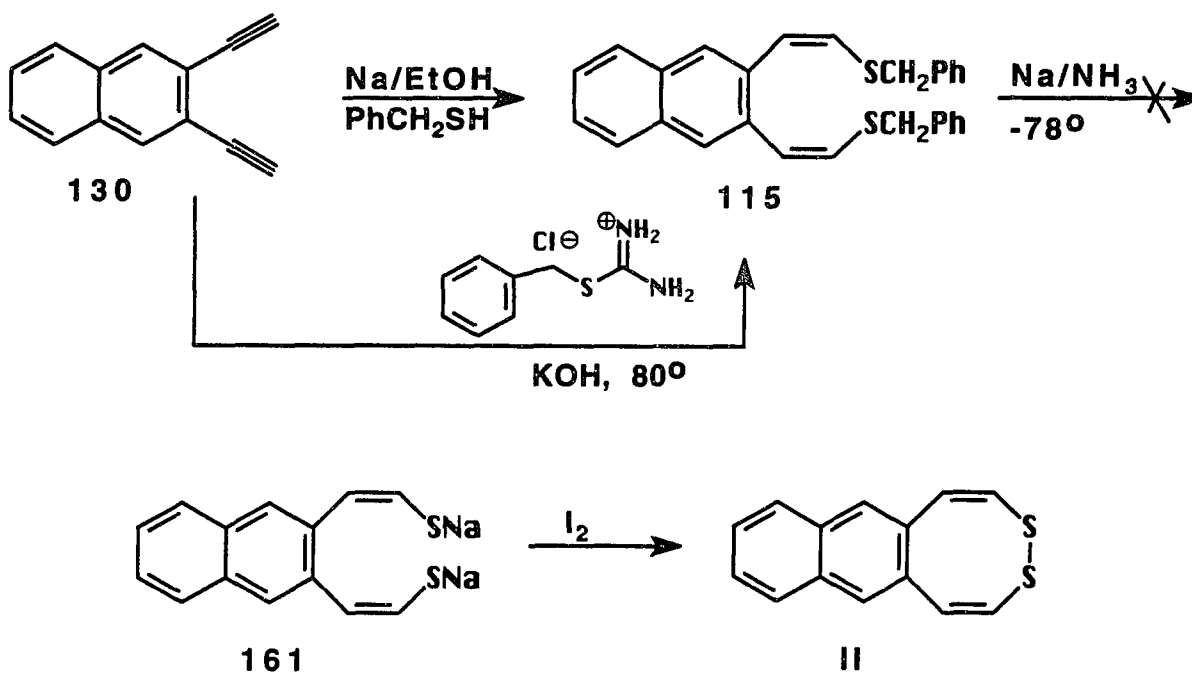


With the failed synthesis of benzo[d]1,2-dithiocin described by Ueng⁸⁴, believed to result from facile sulfur extrusion, we attempted the synthesis of naphtho[2,3-d]1,2-dithiocin, **II**, utilizing similar reaction conditions. Addition of sodium disulfide to **130** under various reaction conditions yielded in all cases anthracene in variable yields.



Scheme 29: Attempted synthesis of **II** via disulfide addition to **130**

The second approach utilized the addition of protected mercaptans to **130**, followed by deprotection and thiol oxidation.

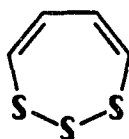
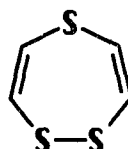


Benzylmercaptan in a sodium ethoxide solution was allowed to react with diacetylene **130** over a period of 3 hours to yield **115** as a white solid in 50.0% yield. ¹H NMR and IR analysis confirmed the presence of only the bis-cis-alkene **115**. Identical results were obtained when **130** was added to an aqueous KOH solution of s-benzylisothioronium chloride salt in ethanol under the same set of conditions. Attempts at debenzylating **115** with sodium in liquid ammonia failed. Similar attempts using LDMAN in THF showed only limited success. Trapping of the dithiolate salt **161** with acetyl chloride failed in most cases. Only minute amounts of the diacetyl compound were recovered.

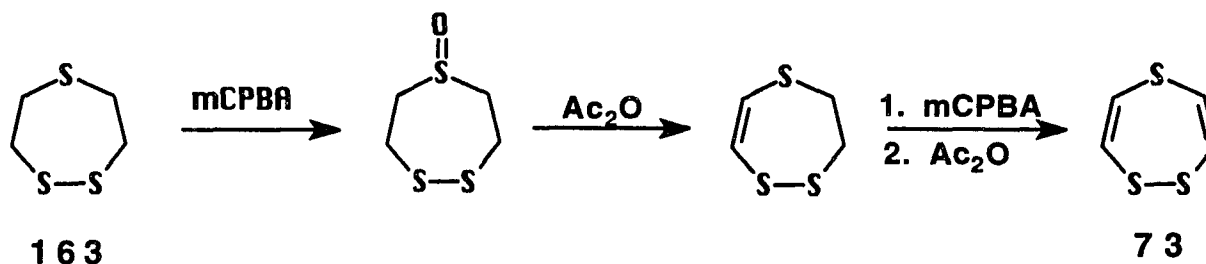
With complications arising in the synthesis of the diacetylene **130**, we decide to discontinue this investigation. Further attempts will be carried out in the future.

2.2.4 INVESTIGATIONS OF 1,2,3-TRITHIEPIN, III

The two trithiepin systems 1,2,3-trithiepin, **III**, and 1,2,5-trithiepin **73**, are potentially 10π aromatic heterocyclics.

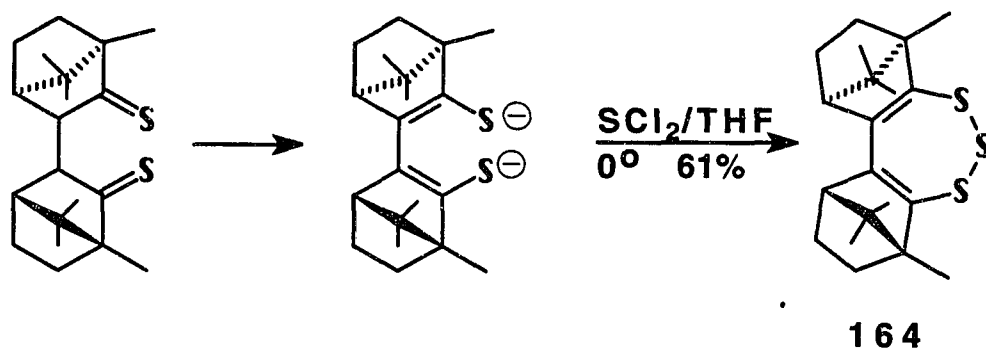
**III****73**

Zahardnik⁸⁵ predicted on the basis of theoretical calculations that trithiepin **73** may be prepared but **III** probably not. In 1978 Grohmann⁸⁶ et al synthesized **73** via two successive Pummerer reactions on the tetrahydro skeleton 1,2,5-trithiepane, **163**, as shown below.



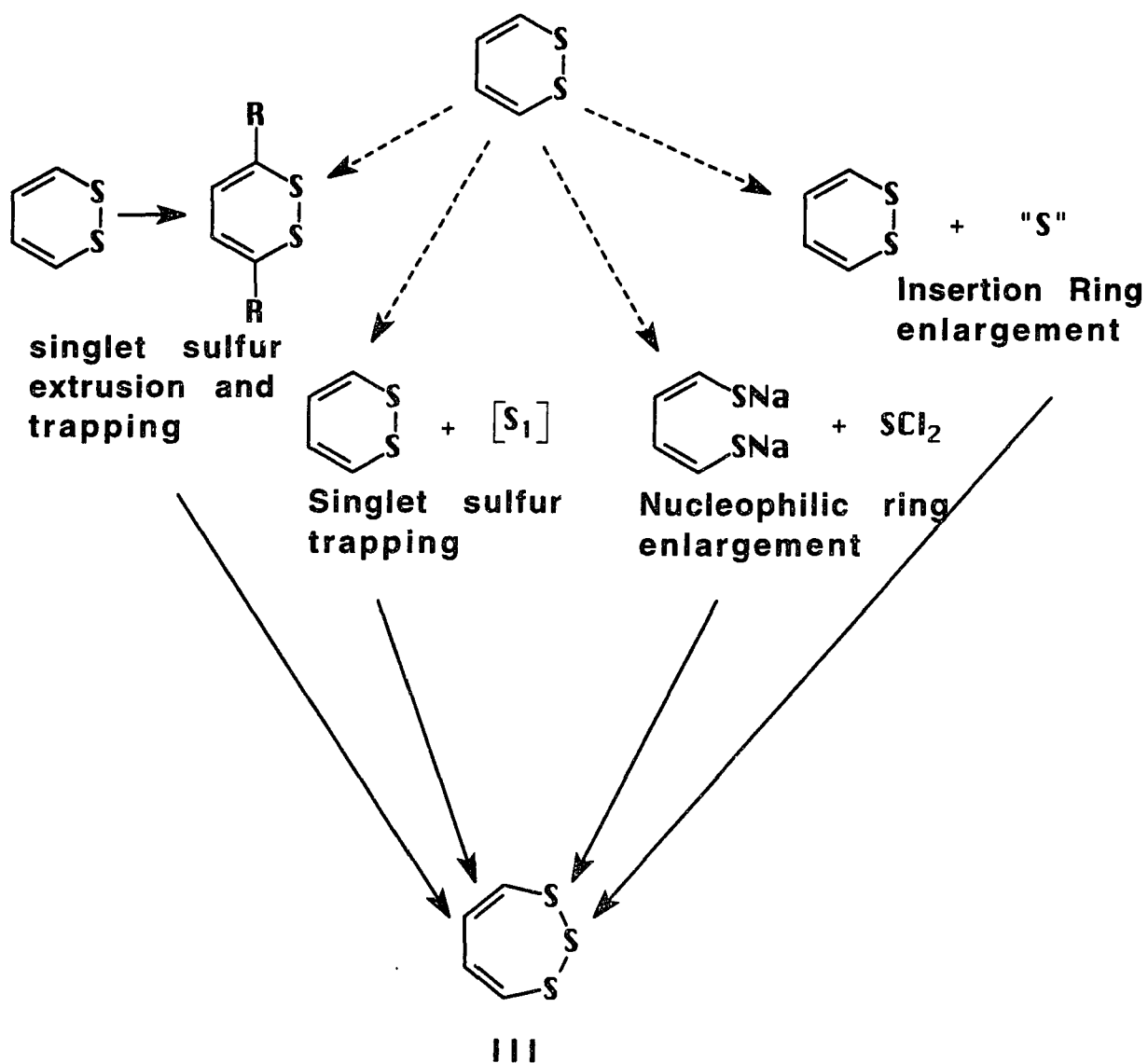
Other substituted 1,2,5,-trithiepins had been synthesized prior to the synthesis of **73** but no clear structural evidence was provided. In addition, in no case was the aromaticity of the ring system examined. Based on NMR studies, Grohmann determined that 1,2,5-trithiepin, **73**, was aromatic.

No prior synthetic attempts of **III** has ever been reported in the literature. Schroth⁸⁷, however, reported the synthesis of trithiepin **164** which is the only known compound containing the 1,2,3-trithiepin skeleton. Schroth's successful synthesis is shown below.



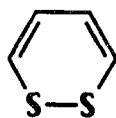
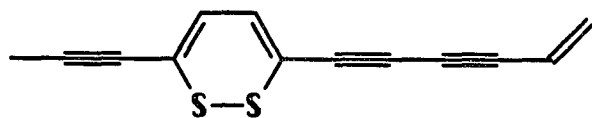
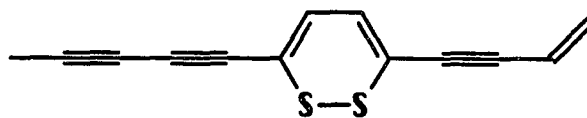
Scheme 30: Schroth's synthesis of trithiepin **164**

Four different approaches to trithiepin **III** were considered, yet only two were carried out: all utilized **1,2-dithiin** as the ring skeleton.

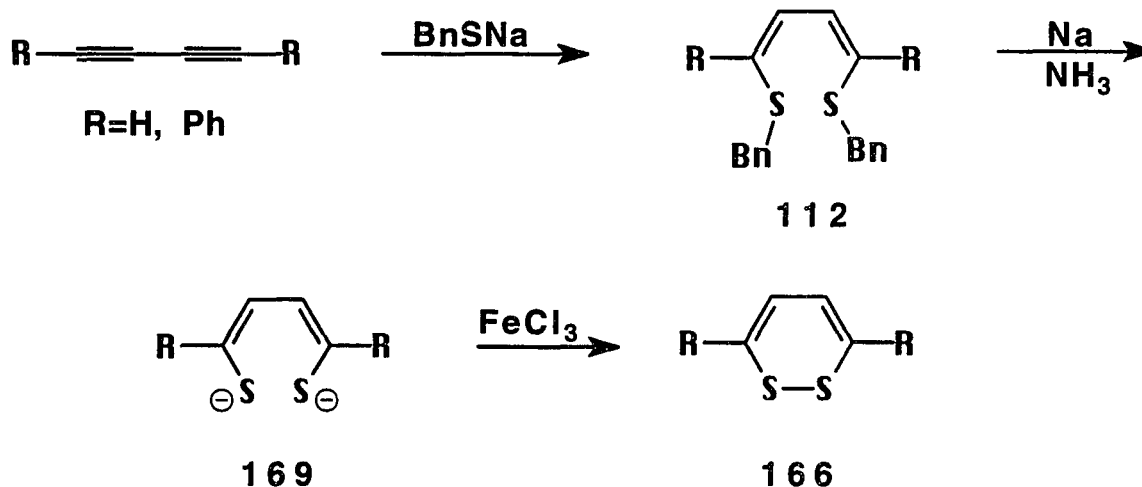


Recently, 1,2-dithiins have attracted great interest due to their biological activity and interesting chemistry. Studies have focused

on their structure, color (1,2-dithiins are red with a UV absorption up to 550 nm, yet have no conventional chromophoric group present), extrusion of sulfur with formation of thiophenes and their promising biological activities⁸⁸. 1,2-Dithiins have been extracted from the roots of *Eriphyllum caespitosum* Dougel and *Ambrosia eliator*, as well as from the leaves of *Aspilia africana*. Thiarubrine A, **167**, a major component of these leaves has shown a great spectrum of antiviral, antifungal and antibacterial activities.

**166****167****168**

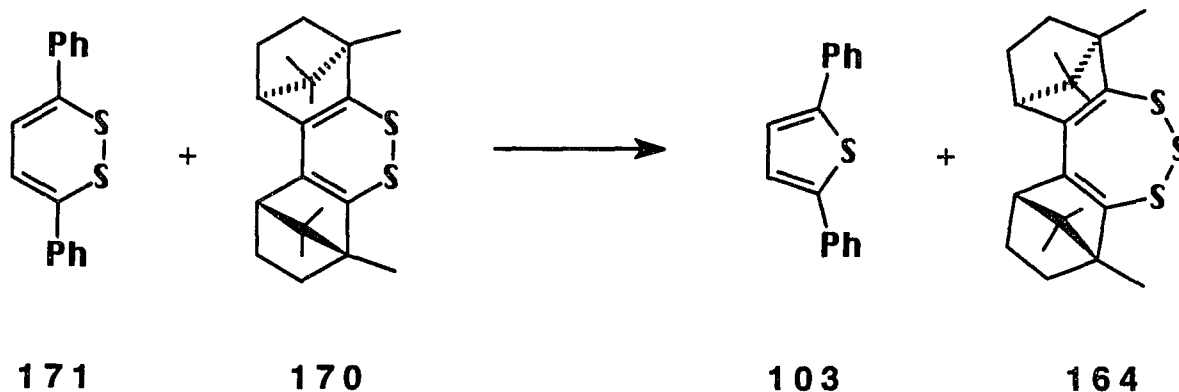
The deep red, highly reactive **166** has been prepared by Schroth utilizing benzylmercaptan addition to butadiynes.



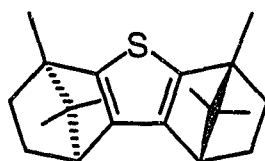
Scheme 31: Schroth's synthesis of 1,2-dithiin

Various 3,6-disubstituted-1,2-dithiins have been studied and synthesized using this method. So far, 10 naturally occurring polyacetylene derivatives of **166** have been isolated and identified. A limited number of syntheses of simple 1,2-dithiins have been reported. At ambient temperatures and in the presence of light, these extrude sulfur with the formation of thiophenes. Such was the observation with Thiarubrines A, B and Schroth's **170**. The extrusion of sulfur from **170** was observed and studied by trapping of the sulfur atom.

Sun lamp irradiation of **170** in methylene chloride with equimolar amounts of 3,6-diphenyl-1,2-dithiin, **171**, yielded 2,5-diphenylthiophene, **103**, and 1,2,3-trithiepin **164** in quantitative yields.

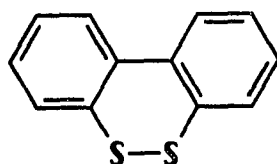
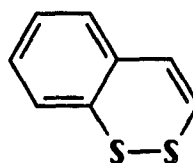


No thiophene analogue **172** was observed in the product mixture.



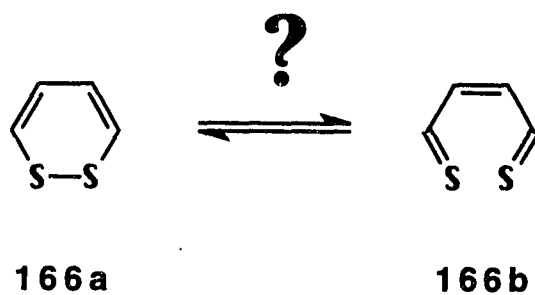
172

Sulfur extrusion from **170** was successful only when heated at 250° in the presence of copper. Similar tendencies of sulfur extrusion were observed with dibenzo-1,2-dithiin, **173**, and benz-1,2-dithiin, **174**.

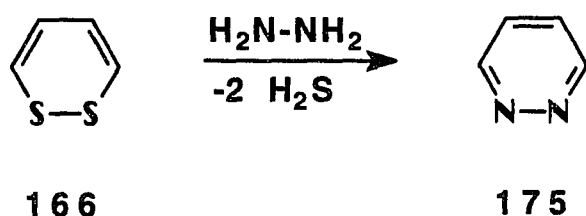
**173****174**

In neither case was sulfur extrusion achieved with ease. Dithiin **170** was, thus, found to prefer sulfur insertion to trithiepin **164** over sulfur extrusion to **172**.

The mechanism responsible for sulfur extrusion from a 1,2-dithiin system, seems to be different from those observed with thiepins or 1,2-dithiocins. With 1,2-dithiin the issue of a butadiene bridged disulfide versus a dithione valence tautomer is of great importance.

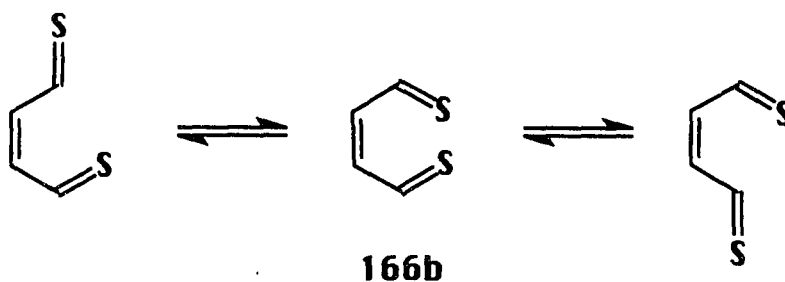


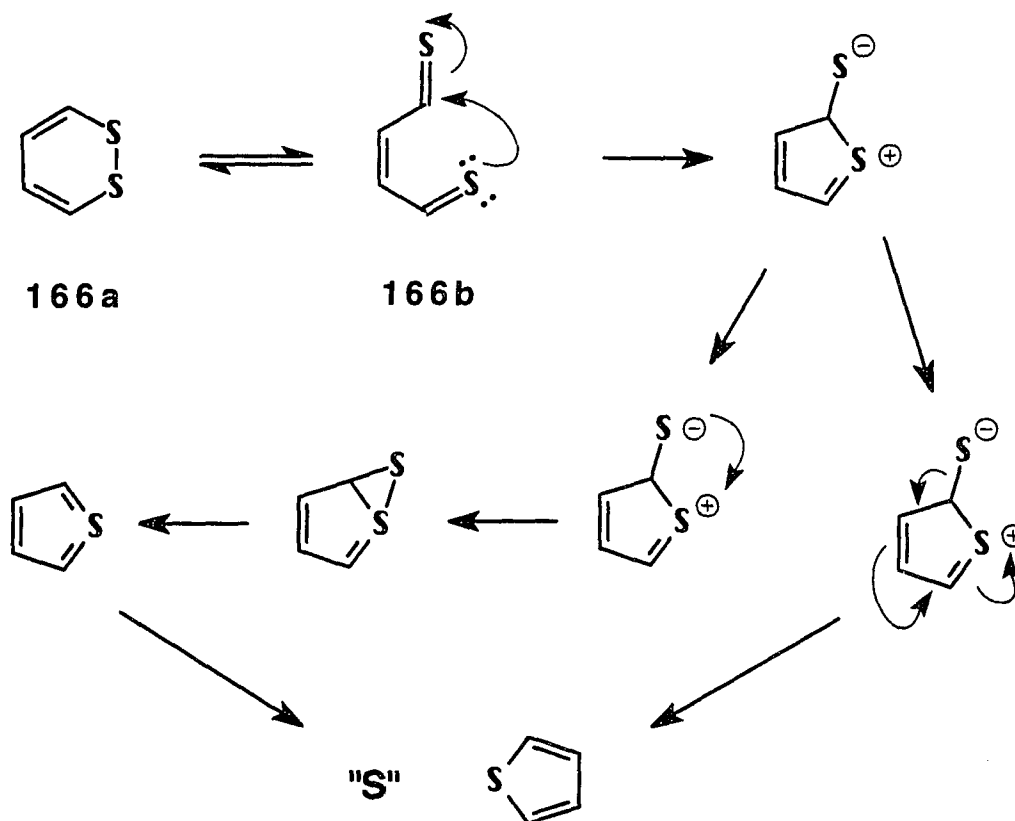
Beginning with the Schroth synthesis of the parent 1,2-dithiin the reaction with hydrazine yielded indications to the presence of tautomer **166b**.



In fact, the extrusion of sulfur from **166a** is believed to proceed via its tautomer as shown in scheme 32.

Mann and Fabian⁸⁹ considered the existence of **166b** in their theoretical examination of **166** and found that the 1,2-dithiin ring is more stable than the open chain valence isomeric dithioaldehyde by about 20 Kcal/mole. The barrier of valance isomerization is low enough, however, to allow transformation at ambient temperature. Furthermore, these calculations showed that isomer **166b** is a transition structure between two isomers.

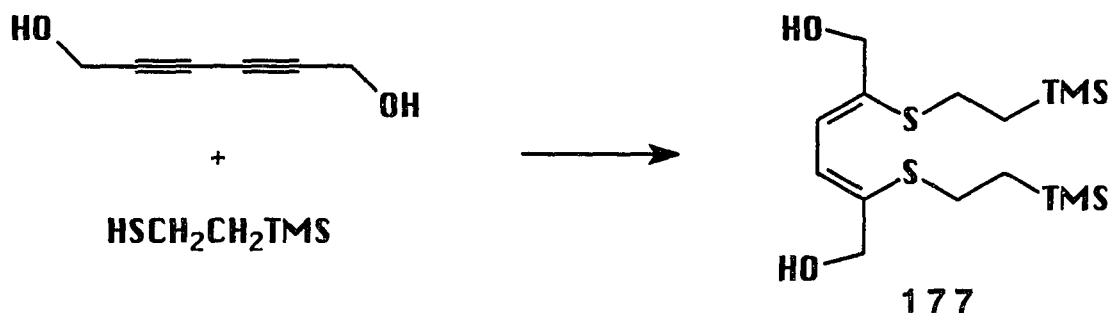




Scheme 32: Mechanism of sulfur extrusion from 1,2-dithiins.

As confirmed by ^1H , ^{13}C NMR and X-ray analyses, derivatives of 1,2-dithiins are cyclic in nature. The 1,2-dithiin ring was found puckered in the crystal and was found to have a CSSC dihedral angle of 55° .

Recently, Thiarubrine A, **167**, has been prepared by Koreeda⁹⁰ and Yang via an 11-step synthesis utilizing 2-(trimethylsilyl) ethane thiol addition to disubstituted butadiyne. Further manipulation of the butadiene **177** yielded **167** in good yields.

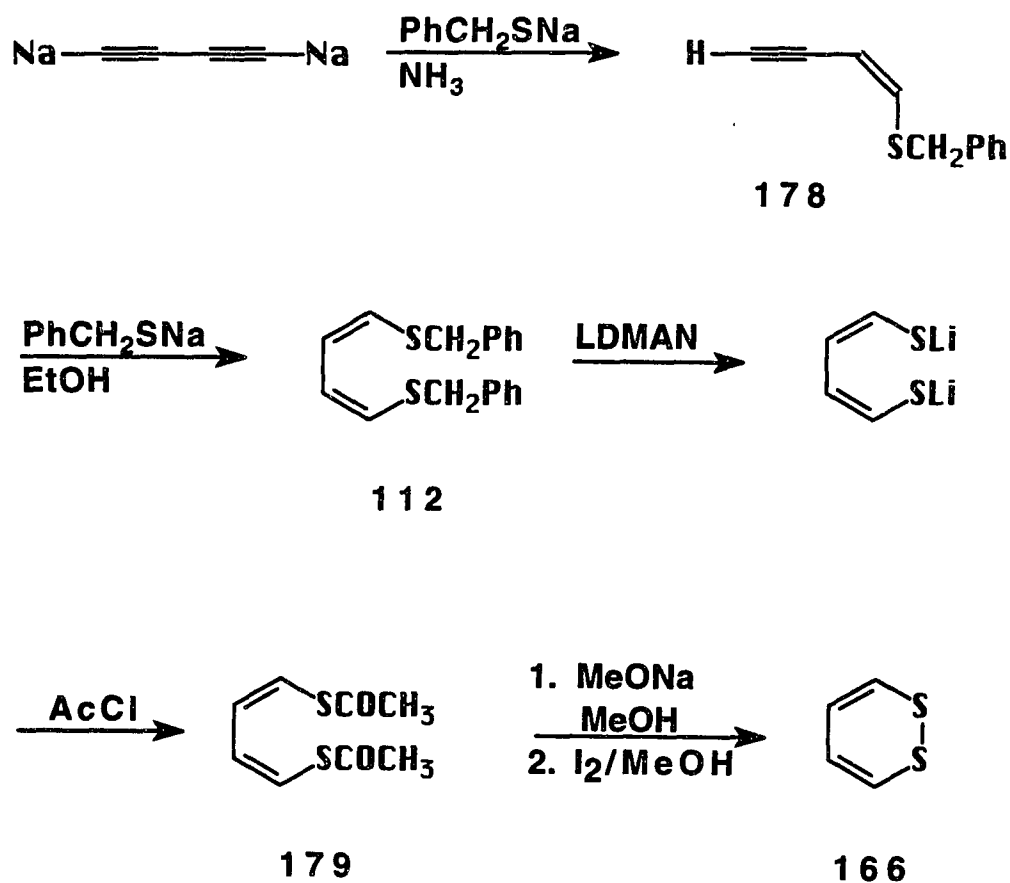


The use of 2-(trimethylsilyl)ethanethiol as a versatile thiol delivering agent is of great synthetic application for it removes the need to use dissolving metals in liquid ammonia. The deprotection of the thiol group by a fluoride ion proceeds readily at room temperature.

Thiarubrine B was synthesized by Block who utilized Schroth's method for the construction of the ring skeleton **168**. However, unlike Schroth use of sodium in liquid ammonia for the reductive debenzylolation of the benzyl protecting group, Block utilized LDMAN.

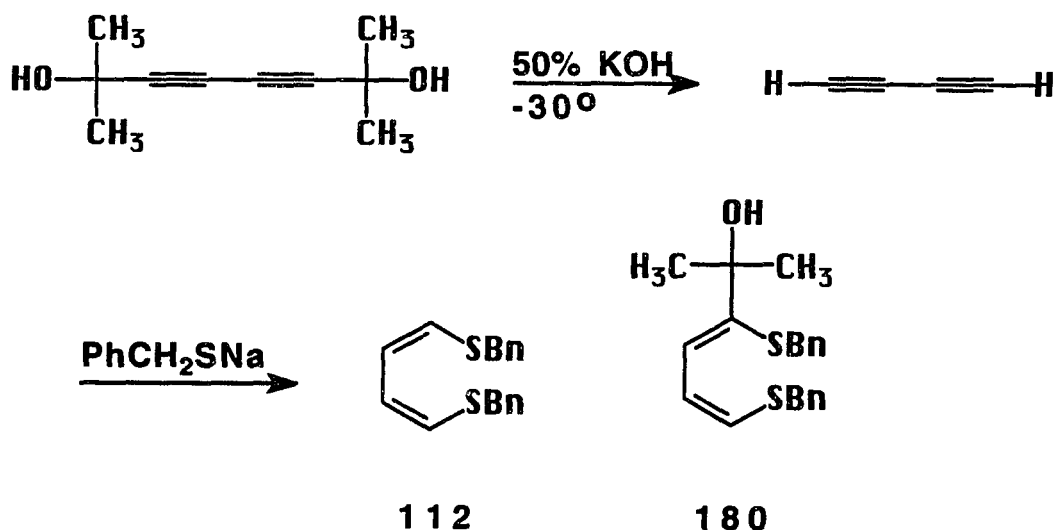
Our approach towards the 1,2-dithiine skeleton was identical to that of Block's. Diacetylene (1,3-butadiyne) was prepared by β -elimination of 1,4-dichloro-3-butyne with sodium amide at -40° . Addition of 2 equivalents of benzylmercaptan afforded a mixture of **178** and **112**. Conversion of **178** to **112** proceeded in refluxing ethanol. Butadiene **112** was then debenzylated with LDMAN as described earlier and then quenched with acetylchloride to yield diacetyl **179** as a white

solid in 79.9% yield. The conversion of **179** to dithiin **166** proceeded via base deprotection and oxidation. The oxidation with iodine was found useful but cumbersome at times. Dithiin **166** could be obtained as a red oil in 77.6% yield.



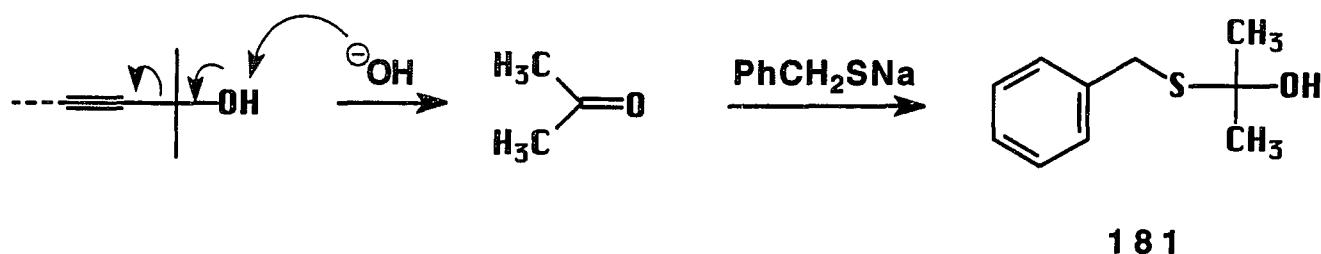
Scheme 33: Synthesis of 1,2-dithiin, **166**

To avoid the use of liquid ammonia as a medium for the formation of the diacetylene we looked into additional methods by which diacetylenes can be synthesized. Addition of 2,7-dimethyl-3,5-octadiyne-2,7-diol (prepared by oxidative coupling of 3-methyl-1-butyne-3-ol) to a stirred, cooled ethanolic solution containing KOH and benzylmercaptan, yielded **180** in 37.7% yield as the major product. **112** Was obtained only in 16 % yield.



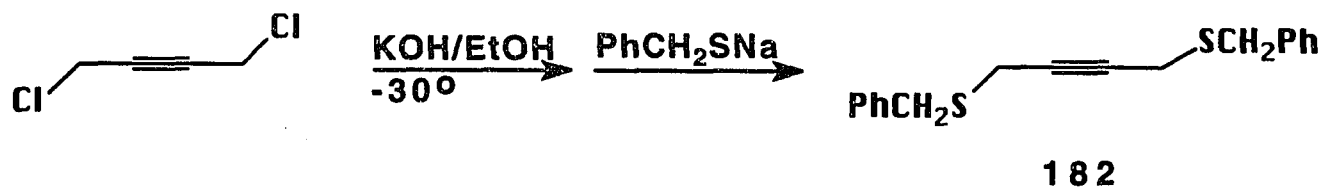
Formation of **180** as the major product indicates only a partial deprotection of the diacetylene and early interception by the mercaptide anion. **180** is a colorless solid which was found to be highly sensitive to traces of acid and decomposed readily in such solutions.

When the addition of the bis protected butadiyne to the above described solution is done at temperatures higher than -20° , diacetylene forms readily and escapes. The benzyl mercaptide remaining in solution, thus reacts with the formed acetone to yield a brown solid characterized as the hemimercaptal **181**.



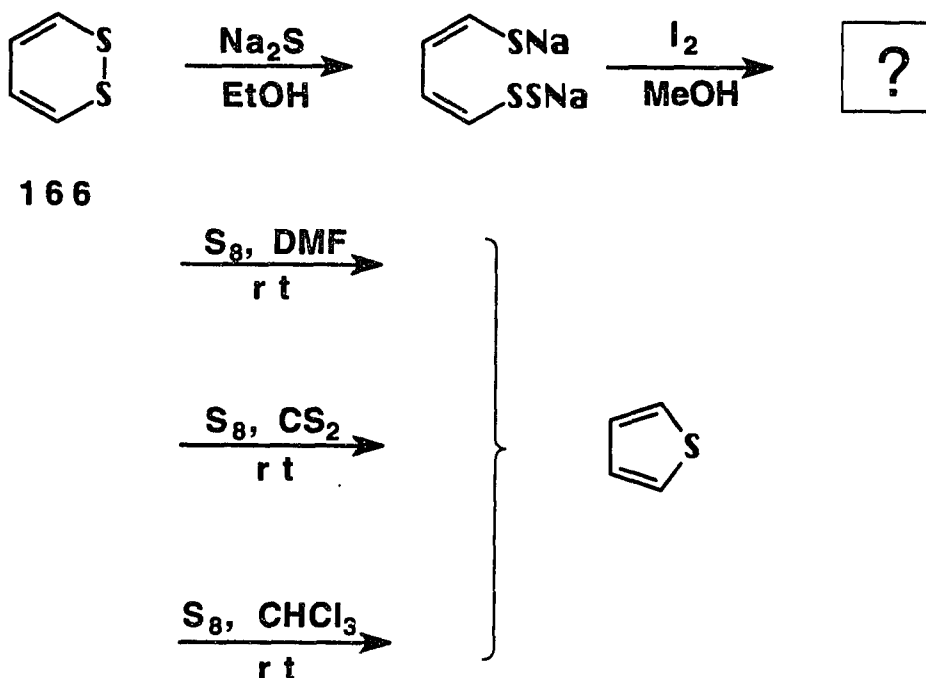
Hemimercaptals such as **181** are ordinarily unstable and only few cases are known. Hemimercaptal **181** showed a shelf life of about two months under inert atmosphere at room temperature. Both spectroscopic and experimental data confirmed the formation of the hemimercaptal.

Addition of 1,4-dichloro-2-butyne to a stirred ethanolic solution at -30° as described above did not yield 1,3-butadiyne as evident from the exclusive formation of the S_N2 product **182** in high yield.



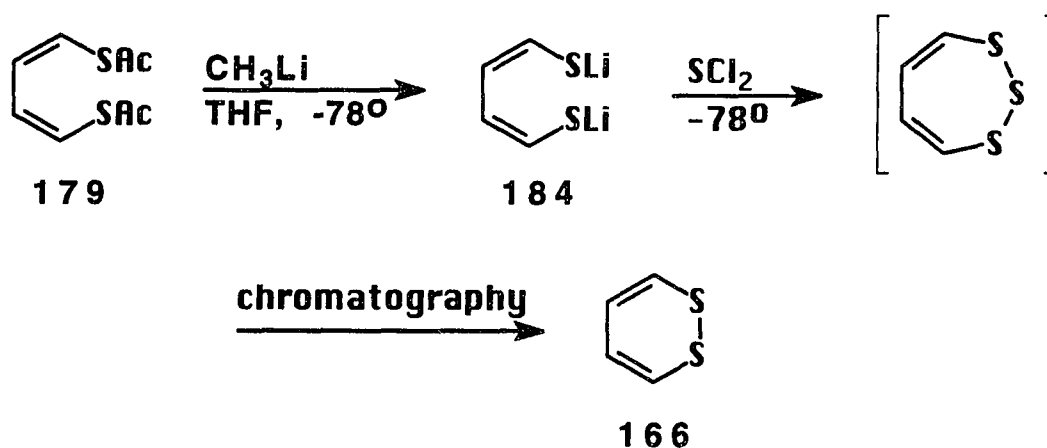
Unlike Schroth our attempts at generating 1,2,3-trithiepin, **III**, were to no avail. This is surprising especially on the basis of Fabian's theoretical results that indicated great agreement between Schroth's 1,2-dithiin, **170**, and the parent 1,2-dithiin, **166**. No indication of increased strain for **170** is given that may explain the observed ease by which it is converted to **164**. However, as was shown earlier, sulfur extrusion from **170** was observed to be difficult while sulfur insertion was achieved with great ease.

Sulfur insertion into the strained S-S bond of 1,2-dithiin, **166**, with sodium sulfide or elemental sulfur under various conditions failed to yield trithiepin **III**, and instead resulted in the formation of thiophene in most cases.



Scheme 34: Attempted synthesis of 1,2,3-trithiepin **III**

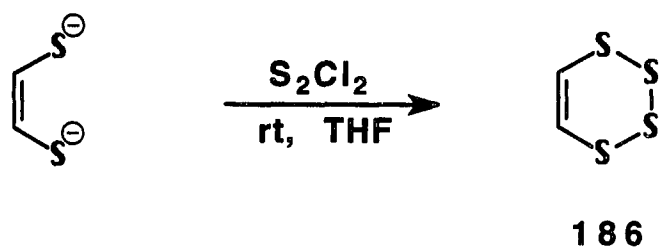
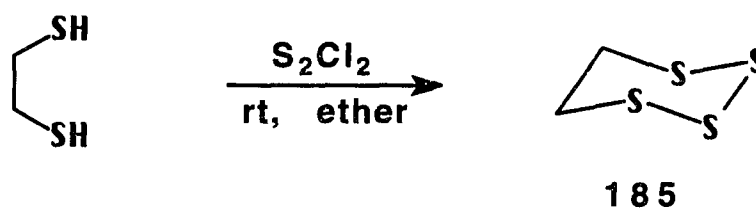
Where sodium sulfide was used followed by iodine oxidation, an unidentified mixture was obtained. Nucleophilic attack of the dithiolate dianion, **184**, generated from the diacetyl **179**, on SCl_2 at low temperatures yielded after chromatography on silica gel the 1,2-dithiin, **166**.



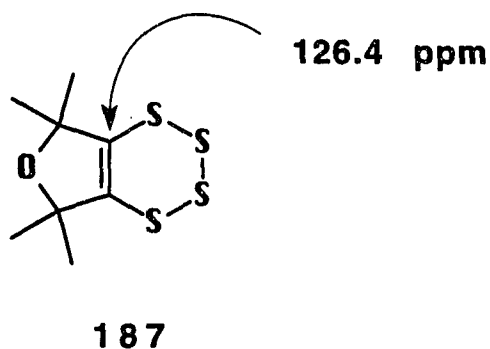
It is possible that the formation of **166** resulted from a sulfur extrusion from **III**. No spectroscopic evidence for the formation of **III** was obtained in the crude mixture prior to chromatography.

Synthesis of tri- and tetrasulfides have been extensively reviewed in the literature. SCl_2 / S_2Cl_2 addition to dithiols has been the method of choice. 1,2-dithioethane added simultaneously with S_2Cl_2 to an ether solution resulted in the formation of a cyclic tetrasulfide, **185**. Similarly, addition of S_2Cl_2 into a THF suspension of cis-disodium dithio ethylene yielded a yellow oil which

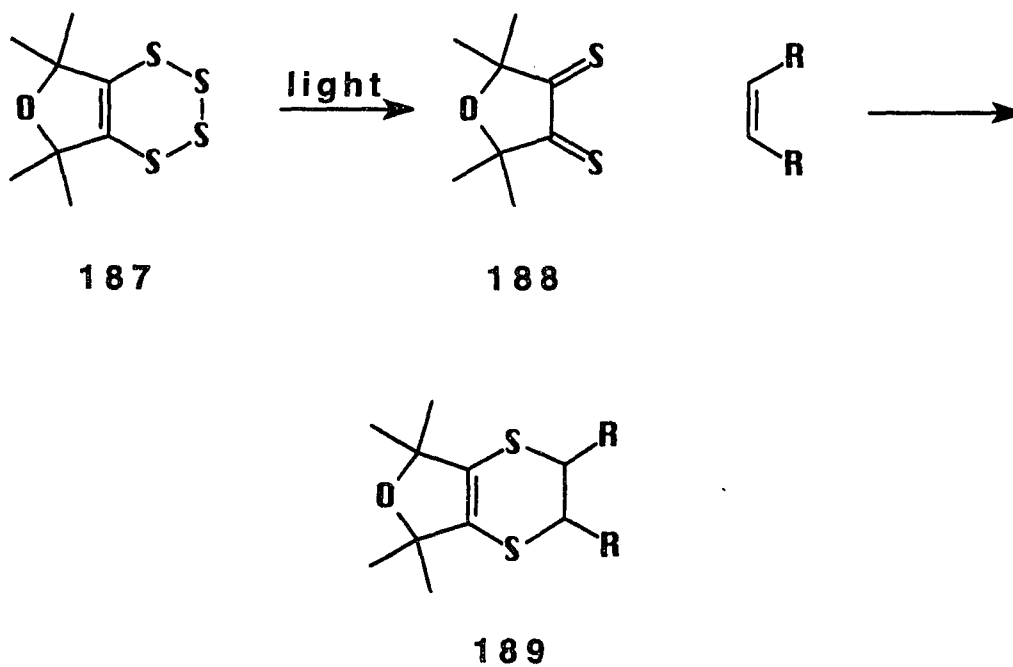
decomposes upon concentration to form S_8 and an unidentified insoluble polymer.



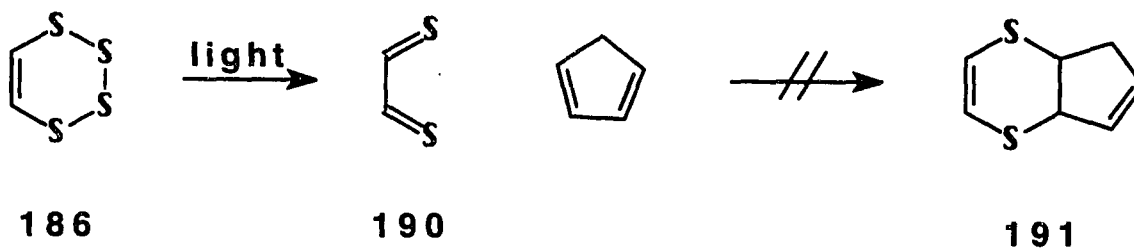
The formed 1,2,3,4-tetrathiin, **186**, is stable in ether for weeks without any noticeable decomposition. Its ^1H NMR shows one singlet at 6.92 ppm and a ^{13}C signal at 119.9 ppm. Ando⁹¹ reported the first stable 1,2,3,4-tetrathiin derivative, **187**, and examined its sulfur extrusion.



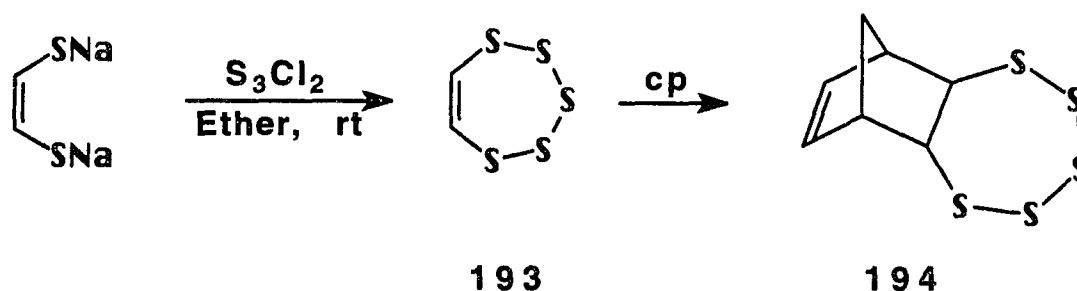
Photolysis of **187** in the presence of olefines gave dihydro-1,4-dithiin, **189**.



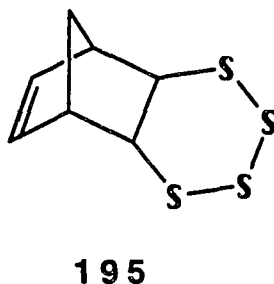
The fused **187** loses S_2 to give the 1,2-dithione, **188**, which reacts with external olefins in a Diels-Alder fashion. Attempts to generate the parent dithione **190** under similar conditions utilized by Ando et al failed.



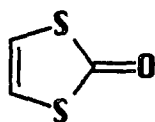
1,2,3,4,5-Pentathiepin, **193**, has been synthesized by Feher utilizing addition of S_3Cl_2 to a freshly made cis-dimercaptoethylene in ether⁹². When **193** was allowed to stir in the presence of cyclopentadiene, adduct **194** was obtained in 30% yield.



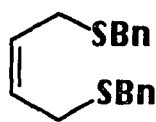
With **186** such an addition to cyclopentadiene failed to yield **195**.



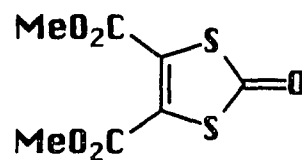
Previously, Grohmann and Ueng encountered similar difficulties in the Diels-Alder additions of various vinyl disulfides such as **196-198** to furan, cyclopentadiene, N,N-dimethyl-1,3-butadiene and other dienes. Mayer⁹³ reported, however, the only such Diels-Alder adduct from the reaction between cyclopentadiene and



196

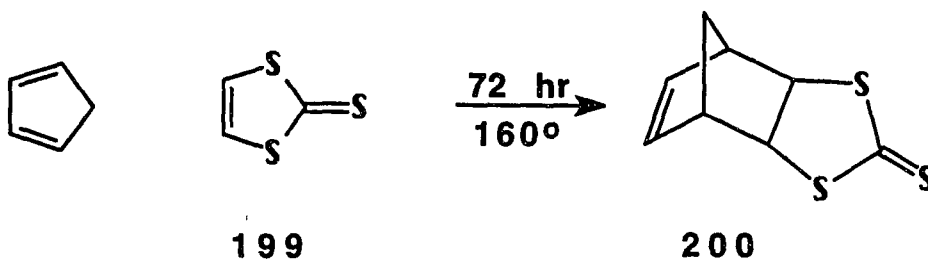


197



198

trithiacarbonate, **199**, which gave only 0.3% of an uncharacterized product.



To examine and evaluate the selectivity observed for this type of a Diels-Alder addition, we carried out a series of theoretical calculations. The HOMO-LUMO energies were all obtained using semi-empirical AM1 calculations (AMPAC 50) on an IBM RS-6000 computers. Values are listed in Table 8 for all dienes and dienophiles examined.

vinylsulfide	HOMO	LUMO
	-8.20083	+0.34054
	-9.01084	-1.37055
	-7.7257	+0.51548
	-7.4345	+0.0864
	-8.8158	-2.6602
	-8.6316	-2.70134
	-9.1088	-0.5428
	-8.4505	-1.2256

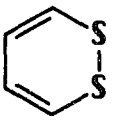
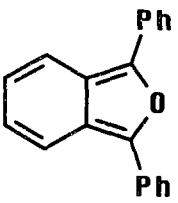
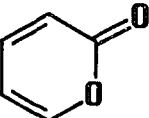
Singlet S=S	-8.46381	-1.17043
Triplet S=S	-12.12465	-4.94517
Singlet O=O	-12.67674	-3.39721
Triplet O=O	-14.87373	-8.03698
	-6.72059	-1.34272
	-7.69508	-1.04386
	-9.07891	+0.48144
	-9.64065	-0.61269

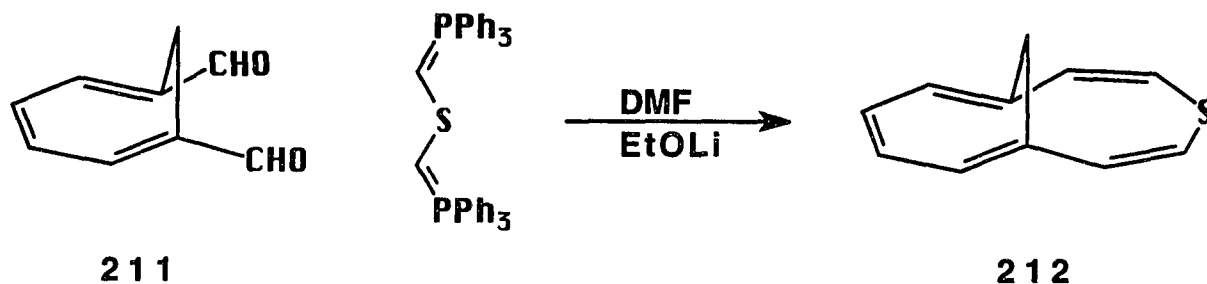
Table 8: AM1 calculated HOMO-LUMO energies of selected Vinylsulfides and useful Dienes.

2.3.0 SYNTHETIC APPROACH TOWARDS 4,9-METHANO-6,7-BENZO-1-THIAUNDECA-2,4,6,8,10-PENTAENE, IV.

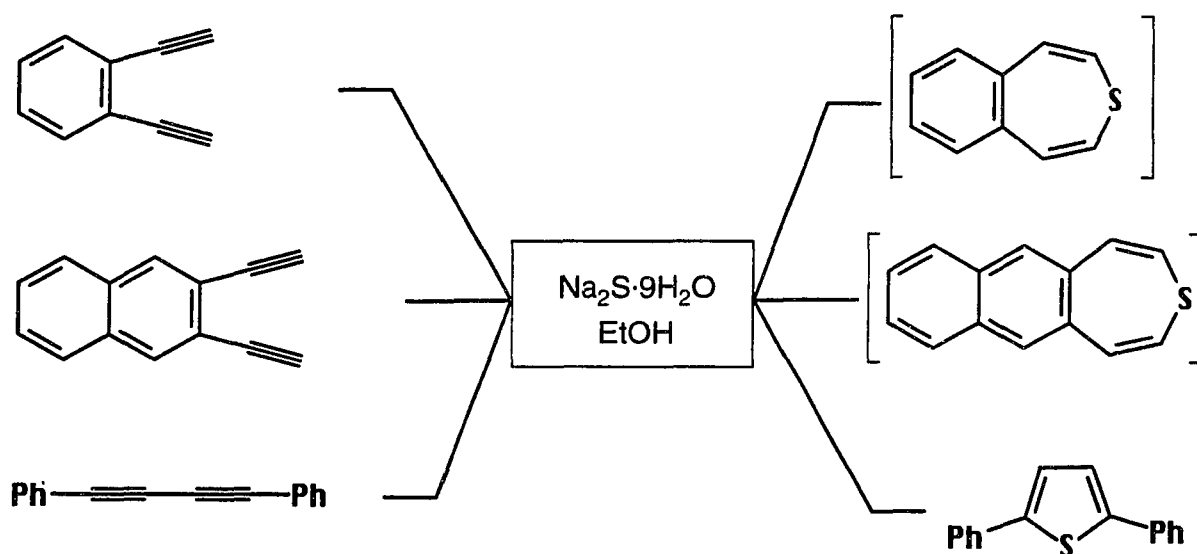
Under our systematic approach towards thiepins and with the strong understanding that benzo annelation together with methano bridging will increase the stability of the resulting thiepin, we set our goal to synthesize **IV**.

Two proposed syntheses of **IV** were investigated. The first, was a Wittig olefination of the dialdehyde, **220**, with the phosphonium salt derived from 1,1'-dichloromethylthioether.

Vogel⁹⁴ utilized this bis-Wittig reaction for the synthesis of 1-thia-4,9-methano[11] annulene, **212**.



The second method towards **IV** utilized sulfide addition to 1,6-diethynyl-3,4-benzocycloheptatriene **221**. This type of addition has been utilized in many cases⁹⁵. Examples are shown below.



The key building block, it seems, in both approaches is the unknown dialdehyde **220** (Figure 22). Vogel in his synthesis of the non-benzoid thia methano [11] annulene, **212**, synthesized cycloheptatriene-1,6-dialdehyde, **211**, in two ways.

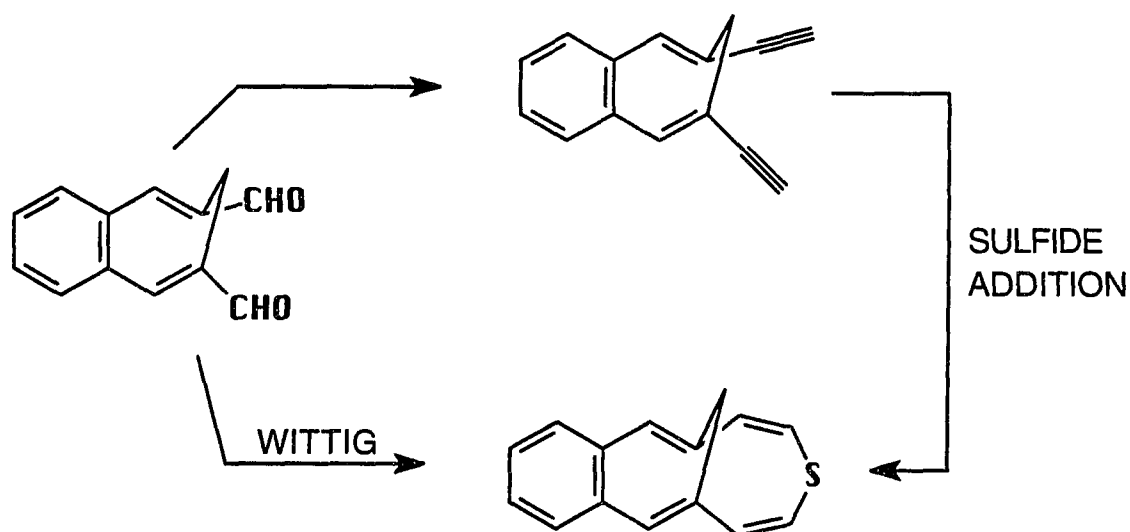
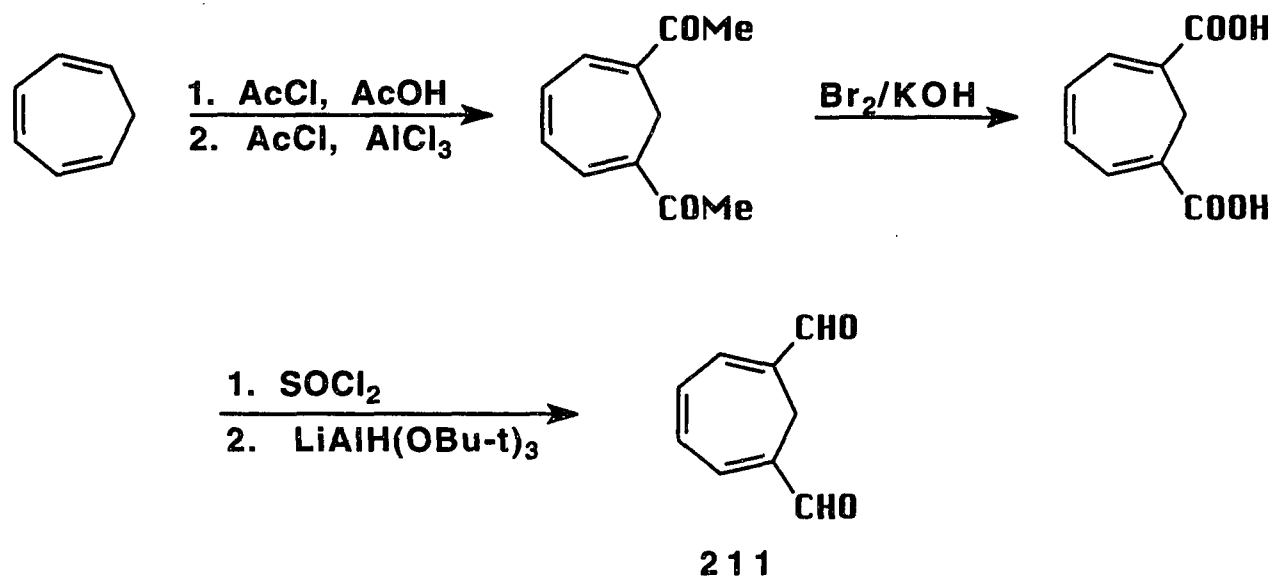
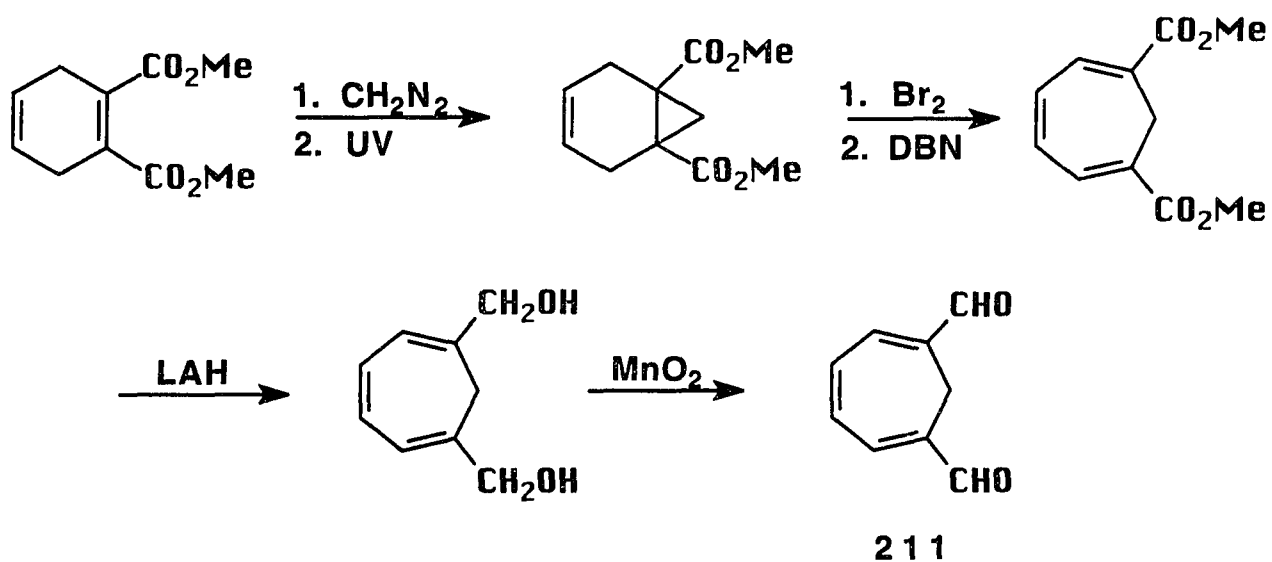


Figure 22: 220 as a building block for the synthesis of thiepin IV.

The first⁹⁶, 7 steps, utilized a Diels-Alder addition of butadiene to dimethyl acetylenedicarboxylate followed by cyclopropanation as the building of the ring skeleton. Further manipulations were required. The second⁹⁷, 5 steps, utilized commercially available cycloheptatriene, as shown in Scheme 35. Capricious functional group transformations were required in each synthesis.

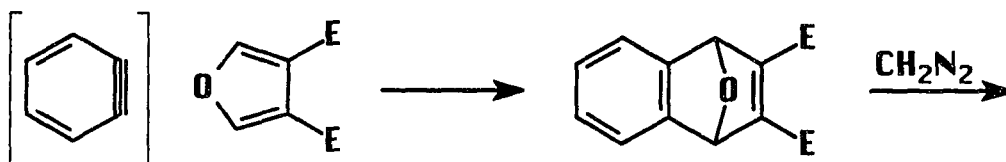


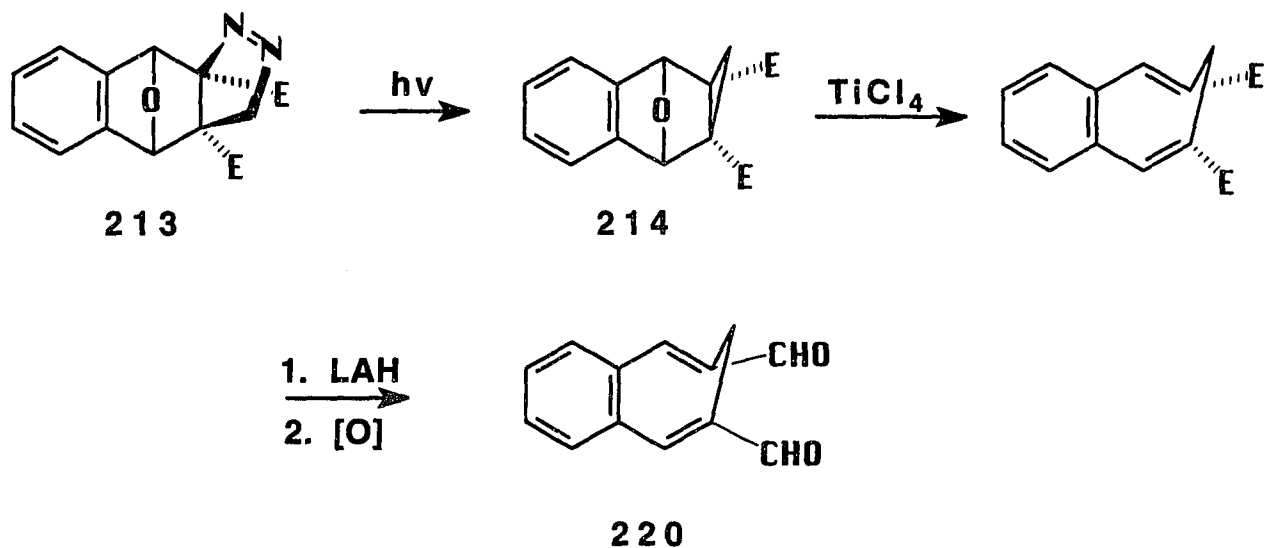
Scheme 35: Two approaches for the synthesis of **211**.

Similar functional group manipulation for the production of **220** would have been even more tedious owing to the unavailability, instabilities and difficulties in the synthesis of benzocycloheptatriene.

2.3.1 SYNTHESIS OF 3,4-BENZOCYCLOHEPTATRIENE-1,6-DICARBOXALDEHYDE, 220.

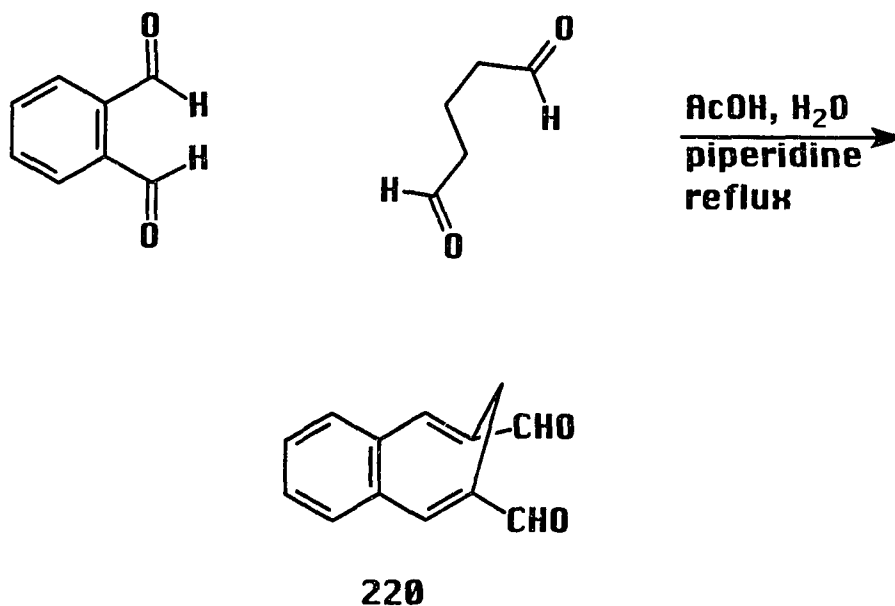
The great importance of **220** as providing an access to the new, yet unknown, class of benzoannulenes, set us searching for a method of synthesis. No previous synthesis of a benzannelated building block such as **220** had been known except for the lengthy synthetic pathway utilized previously in our group⁹⁸ (Scheme 36). This method relied on Vogel's first synthetic approach to **211**. Benzyne addition to dimethyl furandicarboxylate followed by diazomethane addition yielded **213** as a colorless oil in 40.0% (2 steps). Irradiation of **213** yielded **214** in quantitative yield. Titanium chloride deoxygenation and cyclopropyl ring opening yielded the diester which was reduced and re-oxidized to yield **220** in ca. 12% yield overall, from step one.





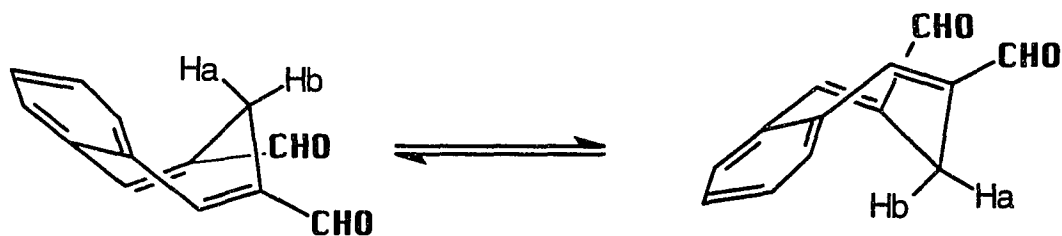
Scheme 36: 6-step synthesis of **220**

With Lepage's convenient one-pot synthesis⁹⁹ of naphthalene-2,3-dialdehyde from o-phthalaldehyde and succinic dialdehyde, we decided to attempt the synthesis of **220** by condensing o-phthalaldehyde with aqueous 1,5-glutaric dialdehyde under identical conditions as described earlier. Thus, addition of phthalaldehyde to glacial acetic acid, piperidine and 4 equivalents of glutaric dialdehyde yields, at the end of a 4.5-hour reflux period, **220** as a yellow solid which sublimes as a white fluffy cotton in 63.8% yield. Alternatively, using 2,2'-trimethylene bis-1,3-dioxolane as a precursor for 1,5-glutaric dialdehyde, under identical conditions, yields **220** in 77.9% yield. This preparation was found easier and cleaner as the amounts of polymerized glutaric dialdehyde are reduced.

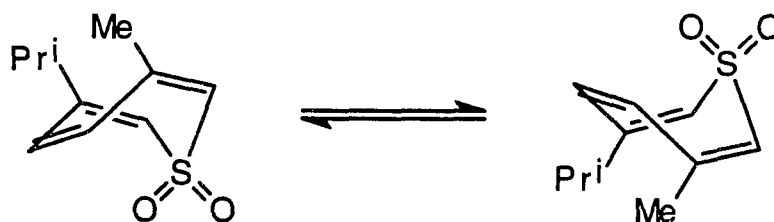


Scheme 37: Synthesis of 3,4-benzocycloheptatriene-1,6-dialdehyde, **220**.

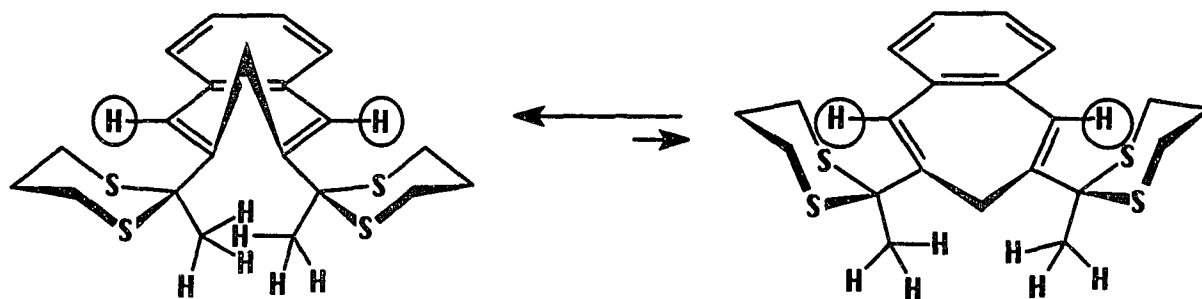
^1H NMR of **220** (Figure 23) indicates the existence of a ring inversion process as shown below.



Such a ring inversion process has been studied in thiepins by low temperature NMR. A barrier of approximately 26.8 KJ/Mole has been determined for 3-methyl-6-isopropylthiepin 1,1-dioxide¹⁰⁰.



In **215**, however, such flipping is diminished due to steric repulsion of the thioketal groups and the hydrogens on the periphery.



215

The rigidity, thus, positions the bridge CH₂ protons in magnetically unequivalent environments. The ¹H NMR of **215**, exhibits the bridge protons as an AA'BB' quartet positioned at 3.20 and 3.91 ppm.

This inversion mechanism in **220**, transforms the bridge H_a and H_b

into a magnetically equivalent resonance at 3.26 ppm.

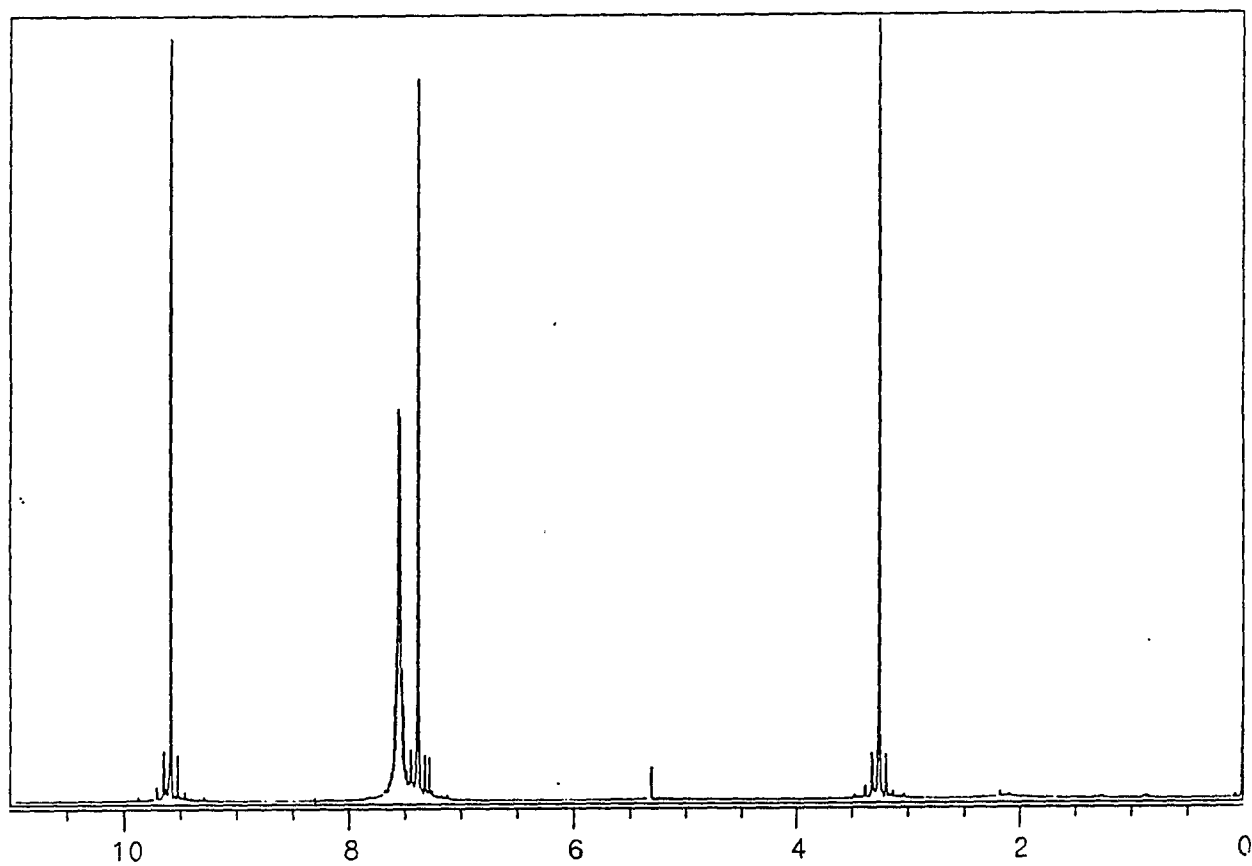
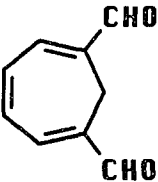
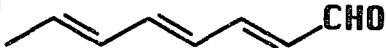


Figure 23: ^1H NMR of 220.

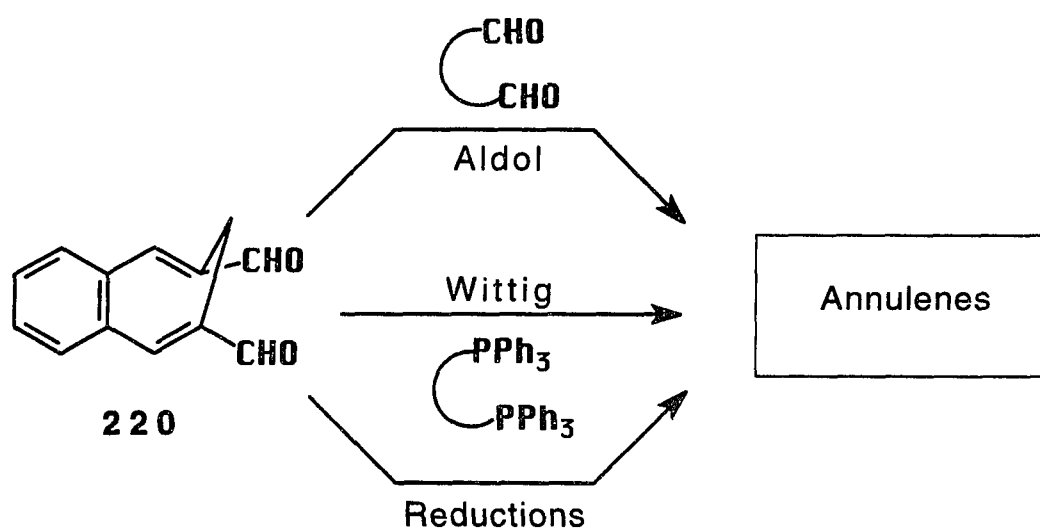
The IR spectrum of dialdehyde **220** shows a prominent band at 1671 cm^{-1} corresponding to the carbonyl stretching and with C-O stretch at 1182 cm^{-1} . The conjugated double bonds appear at 1631 cm^{-1} which is lower than the observed stretches in other double bonds conjugated with a carbonyl group as shown below¹⁰¹.

Aldehyde	Carbonyl stretch
	1670 cm^{-1}
	1677 cm^{-1}
	1674 cm^{-1}

Conjugation of a double bond with a carbonyl group or with other double bonds, generally increases the single bond character through resonance, decreases the force constant K and thus lowers the frequency of vibration.

The UV spectrum of **220** shows an absorption at λ_{max} at 312 ($\log \epsilon$ 3.40).

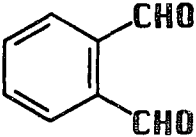
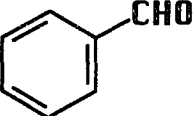
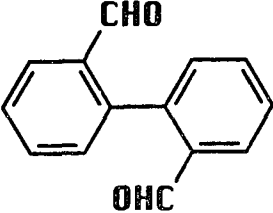
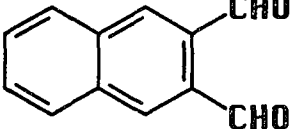
The availability of **220** as a building block for benzoannelated systems avoids the need for tedious functional group transformations.

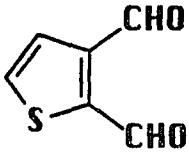
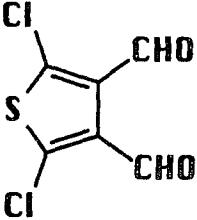
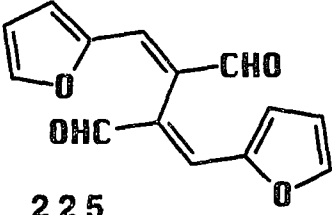
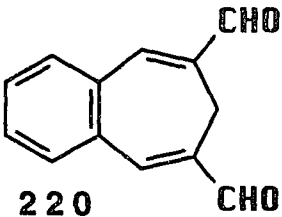


The route for annelation directly from **220** via Wittig reactions and aldol condensations were examined and will be discussed in a later section.

To examine the generality of the method, we attempted the condensation of 1,5-glutaric dialdehydes with various vic-dialdehydes under identical set of conditions (4.5 hrs, 4 equivalents of glutaric dialdehyde), without optimization of yields (Table 9.)

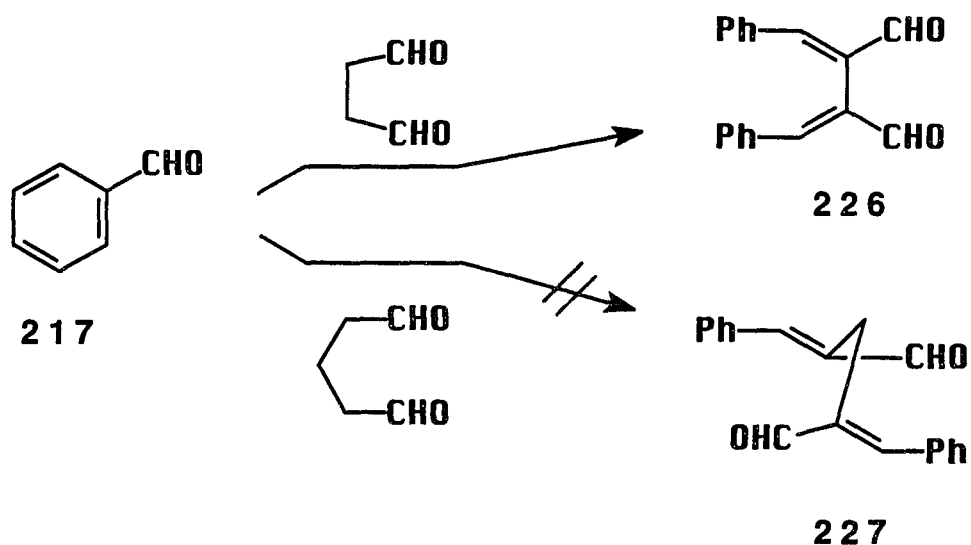
Table 9: Aldol condensations of 1,5-glutaric dialdehyde

Dialdehyde substrate.	mp	% yield	¹ H CH ₂	NMR: =CH	CHO
 216	178- 179°C	63.8%	3.26 (s)	7.31 (s)	9.59 (s)
 217	NO REACTION				
 218	NO REACTION				
 131	204- 205°C	40.0%	3.44 (s)	7.47 (s)	9.59 (s)

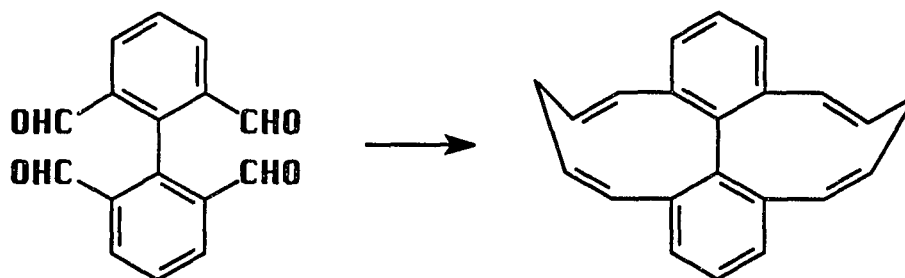
 223	192- 193°C	15.1%	3.29 (s)	7.44 (s) 7.49 (s)	9.56 (s) 9.58 (s)
 224	218- 219°C	9.4%	3.47 (s)	7.28 (s)	9.57 (s)
 225	NO REACTION				
 220	NO REACTION				

Addition of glutaric dialdehyde to substituted or parent thiophene-dialdehydes (**223**, **224**) yielded the corresponding cycloheptatriene dialdehydes in variable yields. Condensations with **217**, **218** and **225** did not proceed even though previous reactions indicated comparability. Benzaldehyde **217**, was condensed by Lepage with succinic dialdehyde¹⁰² in AcOH/Pip to yield the corresponding product **226** in low yield. However, under identical conditions with

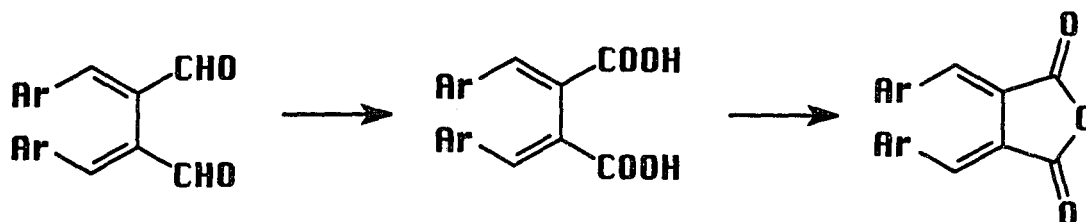
glutaric dialdehyde, none of **227** was observed.



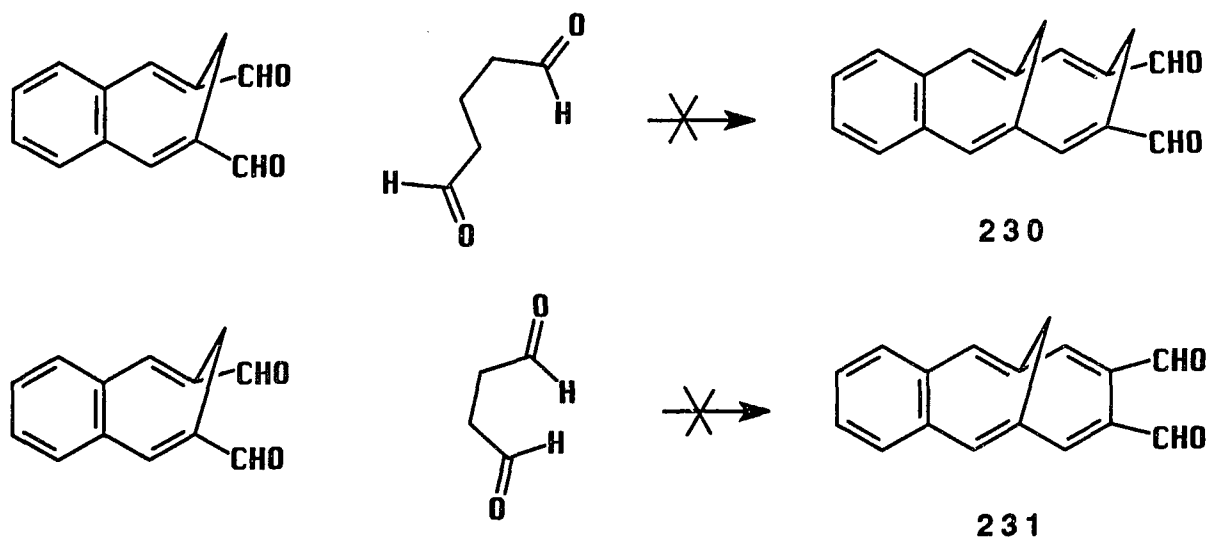
Wittig olefination of biphenyl-2,2'-dicarboxaldehyde, **218**, with various phosphonium salts yielded the corresponding dibenzo-1-thia nona-2,4,6,8-tetraene. Two consecutive bis-Wittig reactions of biphenyl 2,2',6,6'-tetracarboxaldehyde and propane bisylidetriphenylphosphorane were achieved as well¹⁰³.



Compound **225** was synthesized by Lapege's method, refused condensation with glutaric dialdehyde, as well, even though the succinic anhydride had been prepared.



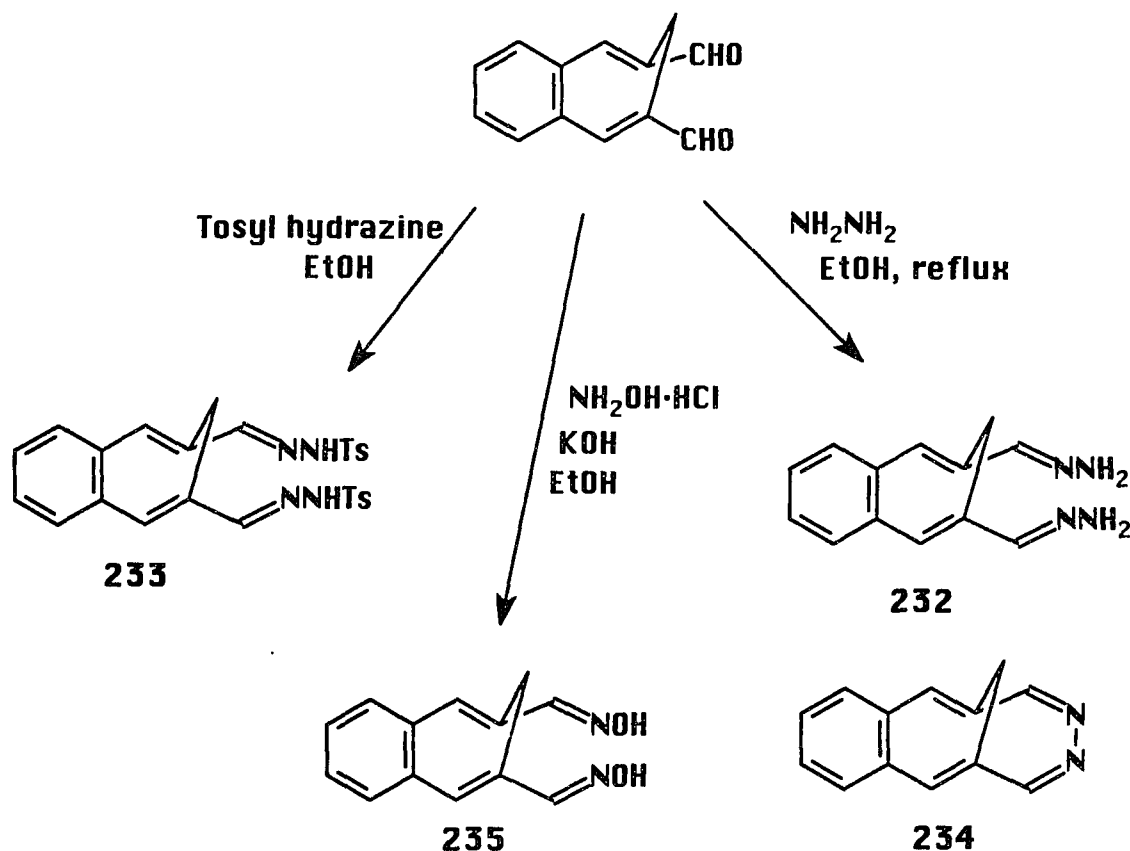
Unlike Lepage's building block approach towards linear polyacenes, addition of glutaric dialdehyde to **220** did not yield the desired bis methano annulene **230**; nor did the condensation of **220** with succinic dialdehyde yield the novel benzo-1,6-methano[10]annulene dialdehyde **231** (Scheme 38).



Scheme 38: Failed condensation of **220** with glutaric- and succinic dialdehydes.

Addition of **220** to an ethanolic solution of AcOH, piperidine and 50% aqueous glutaric dialdehyde failed to yield **230**, as well. Similarly, attempts to generate **231** in a benzene solution under acidic conditions were to no avail.

The chemistry of **220** was examined next. Reactions with hydrazine as well as with p-tosylhydrazine yielded the corresponding bis hydrazones, **232** and **233**, respectively as high melting solids. None of the cyclic azine derivatives, such as **234**, were detected (scheme 39).

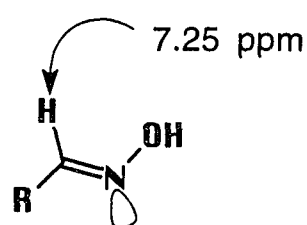
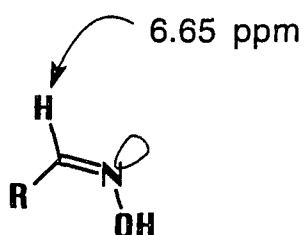


Scheme 39: Reaction of **220** with hydrazines and hydroxylamine.

This observation contributed to the suspicion that the distance between the two aldehydes in **220** is too large in order for cyclization of this type to proceed. Drieding models suggested a larger distance in **220** by 33% when compared with o-phthalaldehyde, **216**. AM1 calculations showed a distance of 4.298Å in **220** as compared with 3.060Å in **216**.

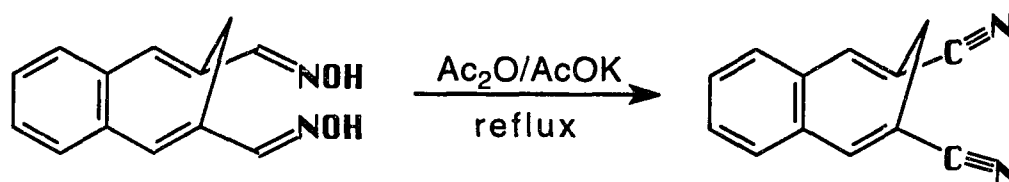
Reaction of **220** with hydroxylamine in ethanolic KOH yielded only one bis oxime **235**, as determined by its ^1H NMR and IR spectroscopy. ^1H NMR of **235** in DMSO- d_6 showed only one OH

resonance at 11.14 δ as a sharp singlet. The chemical shift of $\text{HC}=\text{N}$, however, was 6.87 δ . This position along with the ease of dehydration to the corresponding dinitrile, points out the presence of the anti isomer.



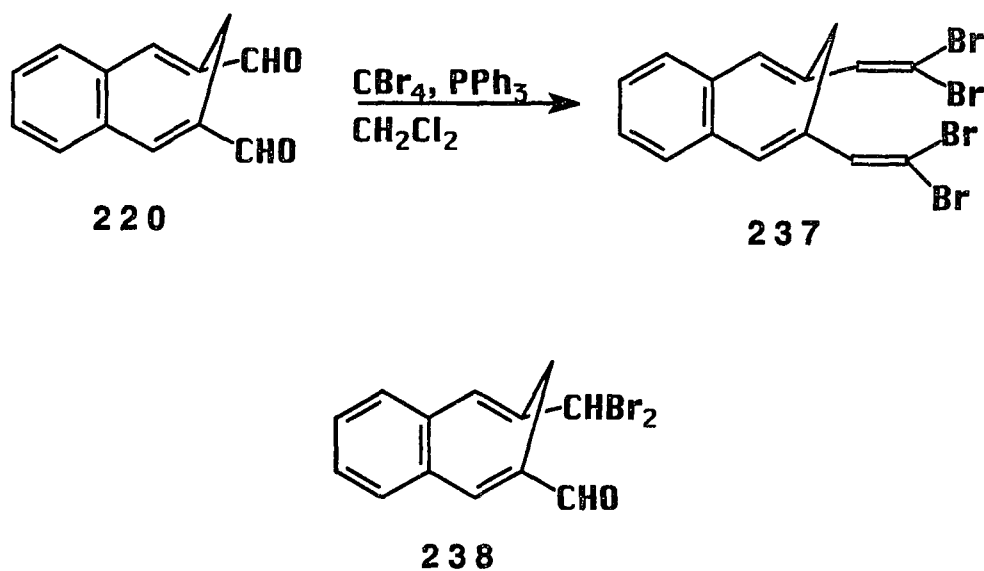
In its IR spectrum, **235** showed a C=N stretch at 1619 and a sharp OH at 3531 cm^{-1} .

235 was dehydrated to the bis nitrile **236** in acetic anhydride/sodium acetate solution in high yield of 79.8%.



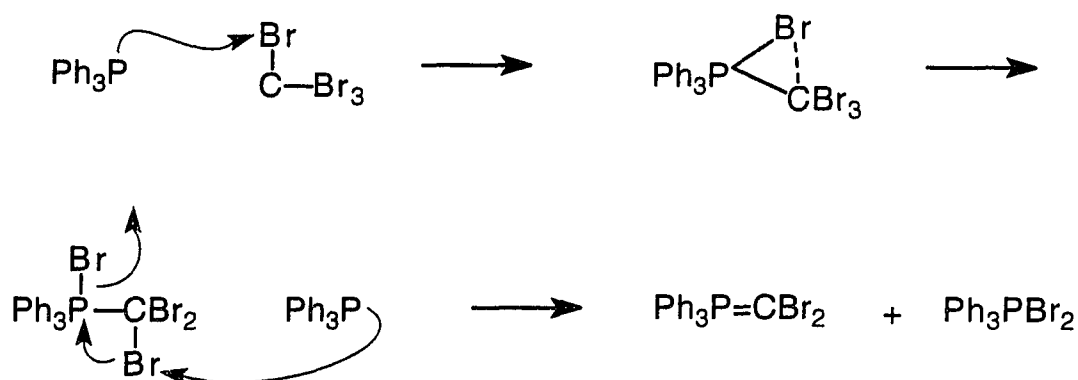
Scheme 40: Dehydration of **235**.

With carbon tetrabromide and triphenylphosphine¹⁰⁴ in CH_2Cl_2 at 0-5°, **220** is converted to the 1,6-bis(β,β -dibromovinyl)-3,4-benzocycloheptatriene, **237**, as a yellow oil which crystallizes slowly into a colorless, cubic crystals in 63.4% yield. A second product, **238**, was observed in some of the runs, in variable yields (Scheme 41).



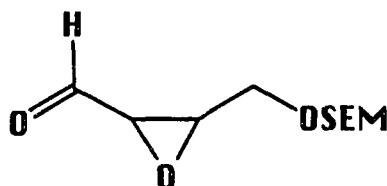
Scheme 41: Synthesis of 1,6-bis(β,β -dibromovinyl)-3,4-benzocycloheptatriene, **237**

The reaction of triphenylphosphine with carbon tetrabromide involves an attack by phosphorus on a bromine atom leading to a pentavalent phosphorus as shown:



Attack of a second Ph_3P on the pentavalent phosphorbromide generates triphenylphosphine dibromomethylene.

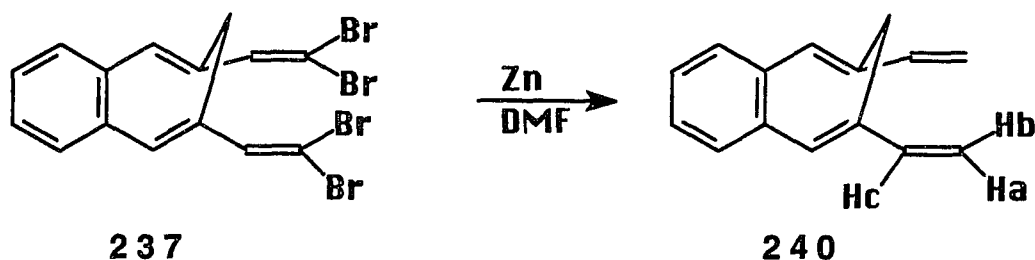
The actual reagent for dibromoolefination is always contaminated, therefore, with dibromotriphenylphosphine generated in situ. This contaminant is known to be a strong electrophile as well as a brominating agent which is the source of side product **238**. In situ reduction of the contaminant was successfully achieved by one of two methods: 1). Zinc dust reduction at room temperature for 24-30 hours; 2). Addition of triethylamine prior to the addition of the CBr_4 - Ph_3P reagent at -60°C . Method 1 was reported to fail with labile systems such as **239** which are sensitive to the presence of zinc bromide.



239

With dialdehyde **220**, no such complications were observed.

Treatment of **237** with excess zinc in refluxing DMF gave the tetrakis dehalogenated divinyl product **240**, in 48.1% yield (Scheme 42.)



Scheme 42: Synthesis of 240

Divinyl **240** Was also prepared by a Wittig olefination of dialdehyde **220** with triphenylphosphonium methyllide.

The ^1H NMR of **240** is consistent with typical vinylic pattern expected of a terminal, mono substituted alkene.

The splitting pattern observed for the vinylic hydrogens is described below. A 3-bond coupling (J^3) between trans- H_b and H_c gives a value of 14 Hertz as compared with the cis- J^3 value of 9 Hertz observed between H_a and H_c . Splitting between the geminal H_a and H_b is very small and is undetected-- $J^2=0$ Hz.

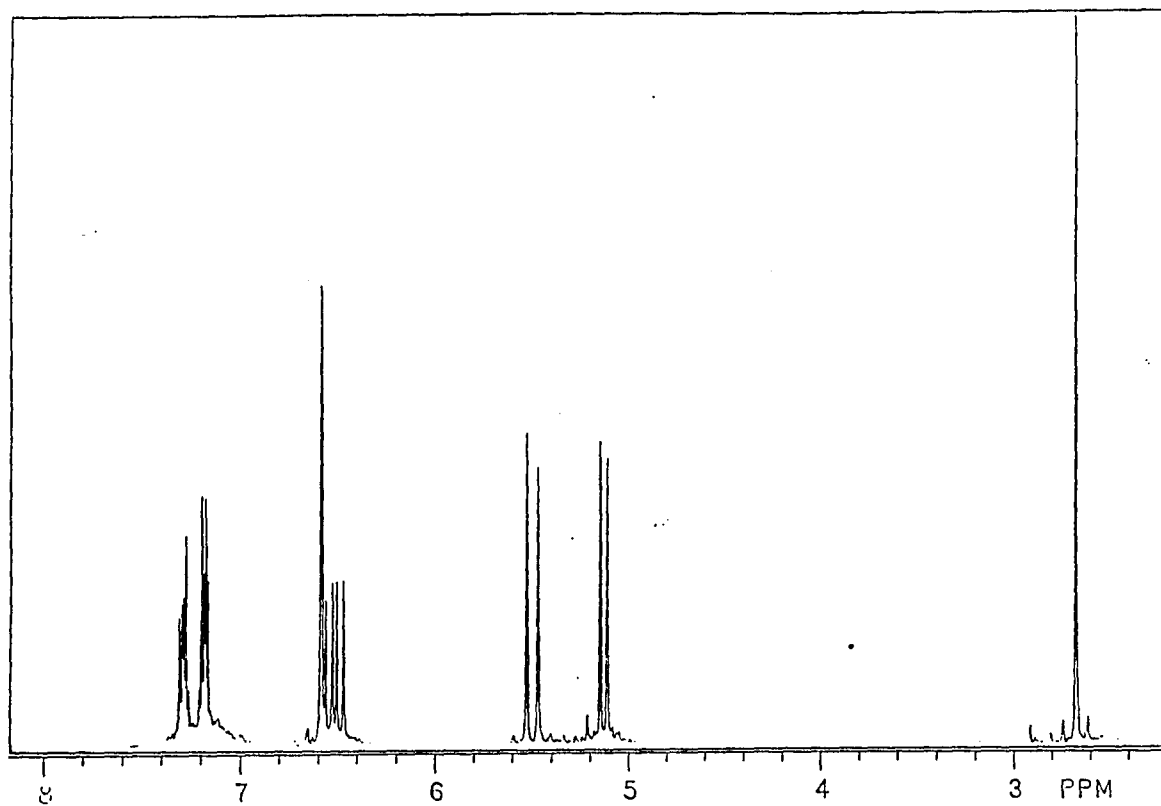


Figure 24: ^1H NMR of 240.

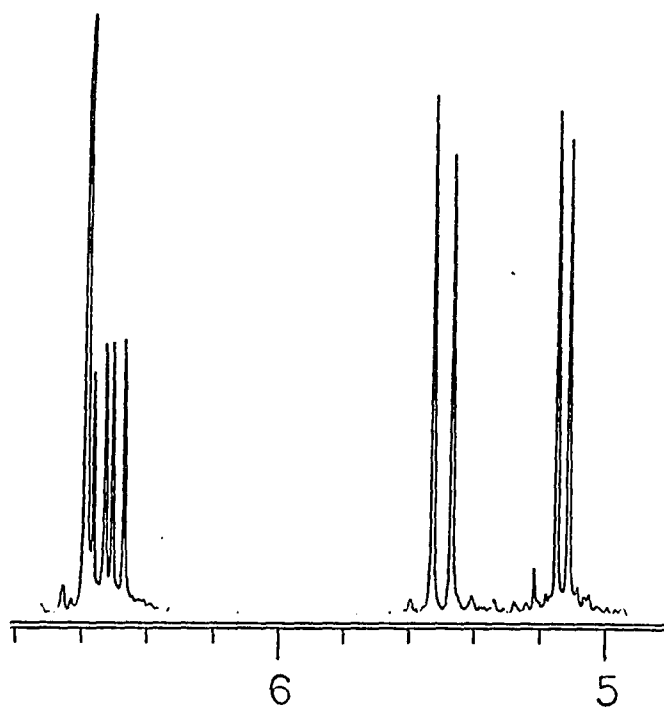
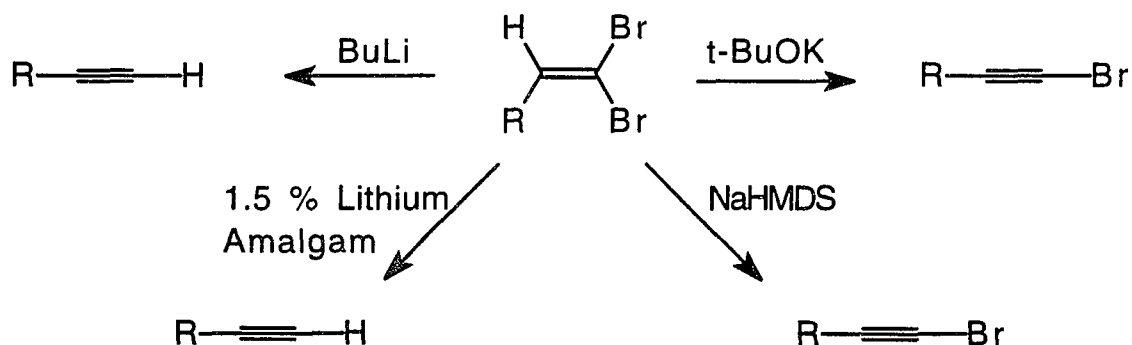


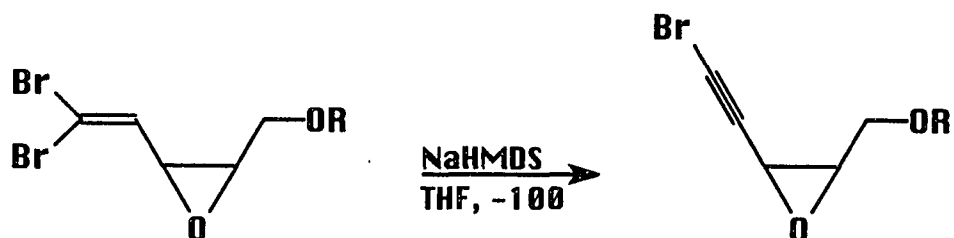
Figure 25: ^1H NMR splitting pattern of the vinylic protons in 240.

Numerous methods are known to affect the transformation of dibromoolefines to acetylenes.



With $t\text{-BuOK}$ or NaHMDS the alkyne formation is known to result from a β -elimination to yield the corresponding bromoacetylene. Eglinton and Galbraith used β -elimination of similar type for the synthesis of *o*-diethynylbenzene¹⁰⁵.

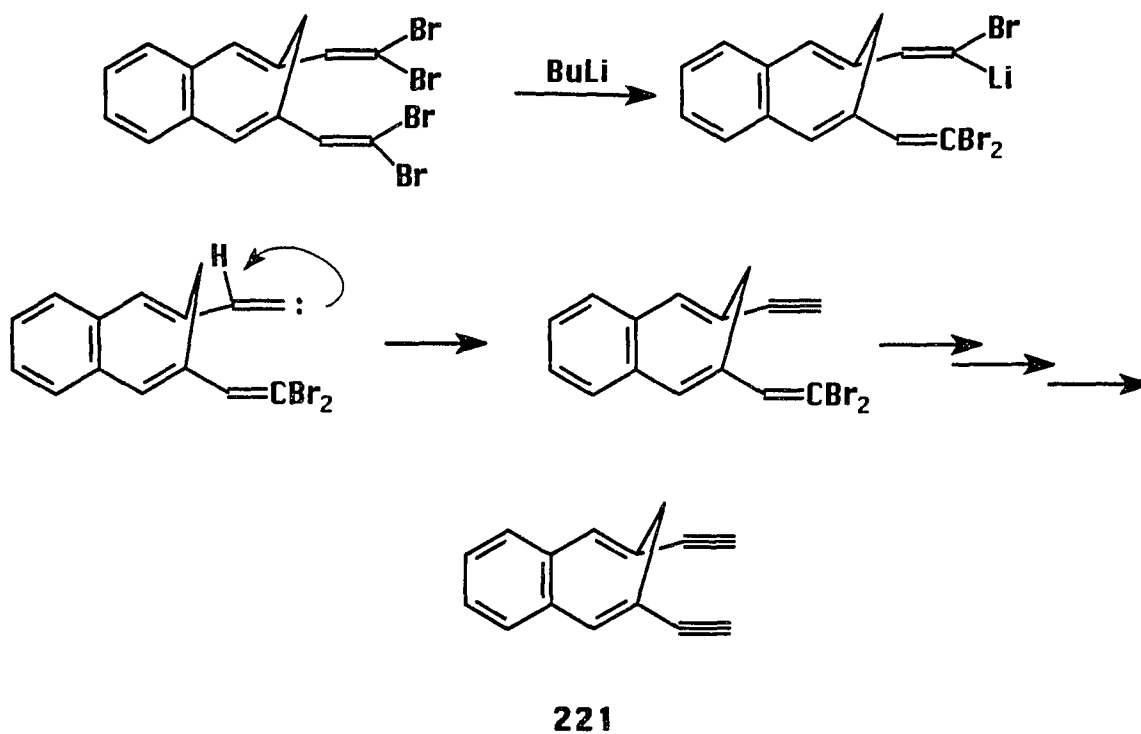
Grandjean and Chuche utilized NaHMDS as a mild base for the conversion of a dibromoolefin to a bromoacetylene:



Metal exchange of the bromoacetylene with 1 equivalent of butyllithium yielded the lithiated acetylene which may be trapped with various electrophiles.

Corey and Fuchs utilized Butyllithium and lithium amalgam as direct methods for the generation of the acetylide, in yields of 80-95% in each case. The transformation of a dibromoolefin to an acetylene in the presence of BuLi proceeds via the Fritsch-Buttenburg-Wiechell rearrangement¹⁰⁶ described earlier.

Treatment of **237** with 4 equivalents of BuLi in THF at -78°C, yields **221** as an oil. Chromatography of the crude **221** yields a white solid which shows a melting point at 102-103°C. In the crude the solid colorizes dark over time. Pure, however, the solid is stable dry in a dark vial without any noticeable decomposition. The easiness of this method makes it possible to convert **220** to **221** on a large scale.



Scheme 43: Fritsch-Buttenburg-Wiechell rearrangement of **237**.

In refluxing ethanolic, etheric or in a DMF solution, **221** is stable as judged by TLC and gas chromatography (Table 10).

Table 10: Stability of **221** under various conditions.

	Conditions tested	Decomposition state after time period indicated.
1	Room temperature, exposure to air	Stable when pure, turns black slowly. No significant decomposition after 2 months
2	At -30° in a tightly capped vial	Stable.
3	Refluxing DMF	Stable after 4 hours.
4	Refluxing Ethanol	Stable after 4 hours.
5	Sublimation at 0.1 mm	~20% sublimes; reminder decomposes
6	Heating above melting point	Decomposes into a black oil. Only small amount soluble in chloroform-d ₁ .

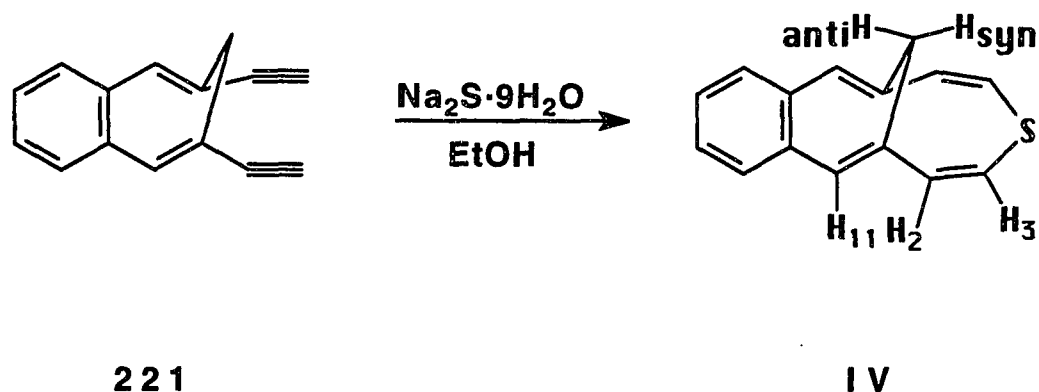
UV absorption of **221** shows λ_{max} (ethanol) at 304 nm. This absorption which represents a bathchromic (red) shift relative to o-diethynylbenzene and a slight hypsochromic (blue) shift relative to diphenylbutadiene ¹⁰⁷, positions **221** midway between the two in terms of conjugation observed between the two triple bonds.

The rather simplistic ¹H NMR of **221** consists of two singlets at 2.99 δ and 2.79 δ . The assignment of the two as the acetylenic protons (2H) and the bridge head CH₂ protons (2H) was achieved by 2D Hetero ¹³C-¹H correlation, deuteration (BuLi/THF, -20°, then D₂O) to yield **221-d₂**. The ¹H NMR spectrum of **221-d₂** showed complete disappearance of the peak at 2.99 δ .

2.4.0 CHEMISTRY OF 1,6-DIETHYNYL-3,4-BENZOCYCLO-HEPTATRIENE, 129.

2.4.1 SYNTHESIS OF THIEPIN IV.

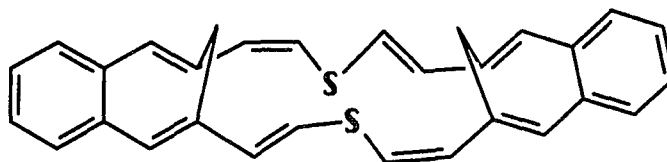
In our attempts to achieve thiepin synthesis by addition of sodium sulfide nonahydrate to diacetylenes, **221** was the most suitable candidate. When **221** was refluxed in an ethanolic solution of $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$ for 12 hours, thiepin **IV** was obtained as the sole product in 34.0% yield, with recovery of no starting material.



Scheme 44: Synthesis of thiepin IV

Thiepin **IV**, a yellow solid, was found stable and without noticeable decomposition at -30° for long periods of time. In distilled solvents, no detectable decomposition was observed as determined by TLC and

GC-MS. However, neat, at temperatures above its melting point and on attempts to sublime it, **IV** decomposes into an insoluble, thiopin free, black solid.



241

In one of the many repeated reactions, however, dimer **241** was obtained in 23% yield. Dimer **241** will be discussed at the end of this section.

Table 11: Stability of Thiepin IV

	Conditions	stability	Method of evaluation
1	Solid at room temperature	Stable in the dark; colorizes to black over time	TLC, GC, Visualization
2	In solution at room temp. (In THF, Ether, DMF, CH ₂ Cl ₂ , EtOH)	Stable	TLC, GC, Visualization
3	Reflux EtOH, 4 hours	Stable	TLC, GC
4	Reflux DMF, 2 hours	Stable	TLC, GC, NMR
5	Sublimation	Decomposes	GC, NMR, solubility
6	Heating above melting	Decomposes	GC, NMR, solubility

The ^1H NMR of **IV** shows an AA'BB' quartet for the disubstituted benzene centered at 7.30δ . A singlet at 6.50δ corresponding to H_{11} overlaps the doublet assigned for H_2 with $J=10.1\text{ Hz}$. H_3 , similarly, shows a doublet of the same intensity and coupling constant at 5.51δ . The bridge protons 12_{syn} and 12_{anti} exhibit an interesting pattern. While 12_{anti} shows only a doublet at 1.98δ arising from coupling with 12_{syn} ($J=11.9\text{ Hz}$), 12_{syn} exhibits a fine splitting of the doublet. Centered at 5.72δ , it shows a J^4 of 0.73 Hz arising from a **W** coupling with H_{11} . Similar coupling of the singlet exhibited for H_1 at 6.50δ is missing. However, in Benzene- d_6 , where the overlap between H_{11} and H_2 is diminished, broadening of the H_{11} singlet is observed. This suggests not only a **W** coupling with $\text{H}_{12\text{syn}}$ but possibly with the benzene ortho protons. The broadening is due to the limited resolution power of the spectrometer. In fact, most **W** splitting give rise to peak broadening for the protons that are coupled rather than a clear splitting.

When thiopin **IV** was treated with $t\text{-BuOK}$ in refluxing $t\text{-BuOD}$, complete deuteration of the α -protons was observed in 3 hours. The ^1H NMR spectrum of thiopin- d_2 , reveals the disappearance of a doublet at 5.51 ppm (H_3 and H_5) and the transformation of a doublet at 6.50 ppm into a broad singlet (H_2 and H_6 .)

Confirmation of the 1D proton NMR assignment, comes from a 2D COSY and NOESY experiments, as well.

The 2D COSY experiment enabled us to establish connectivity in regards to H_2 - H_3 and $H_{12\text{syn}}$ and $H_{12\text{anti}}$, as shown in Figure 28.

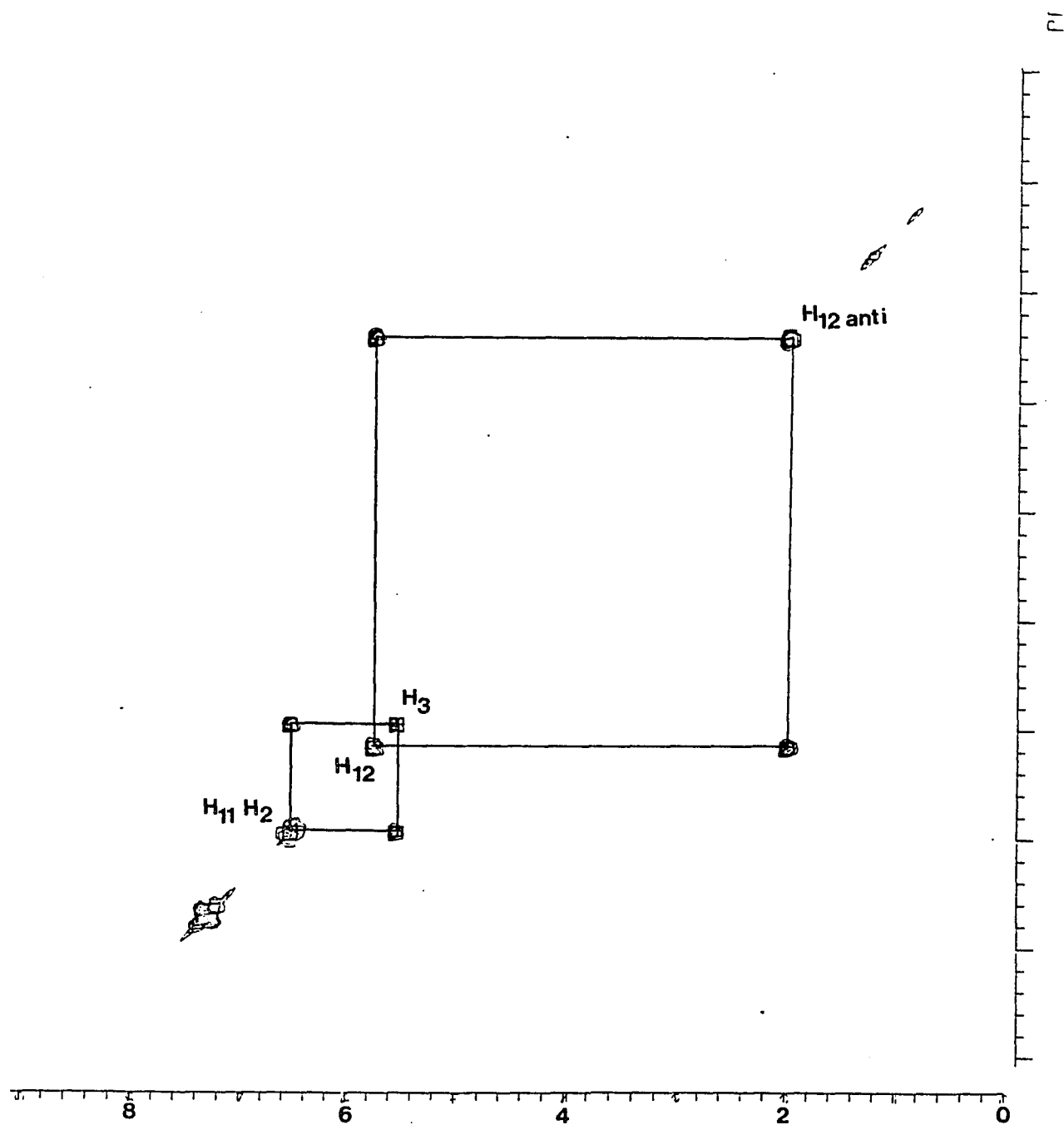
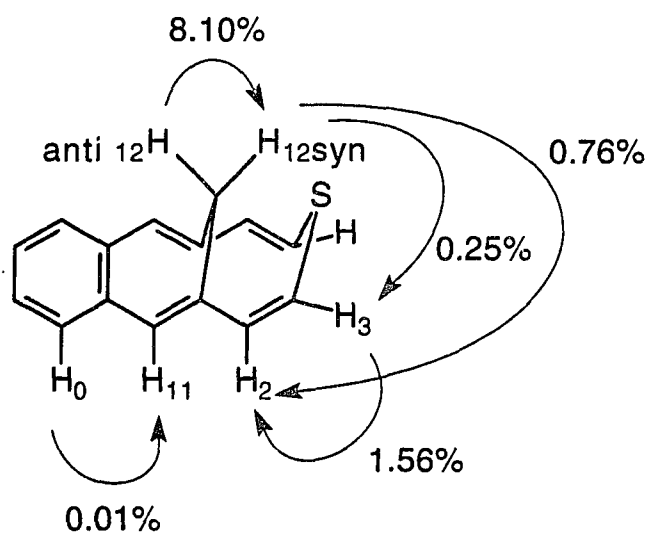


Figure 26: 2D COSY spectrum of IV.

The 2D NOESY experiment established the relative positions of H_{11} , H_2 , H_3 , H_{12syn} , and H_{12anti} relative to each other.



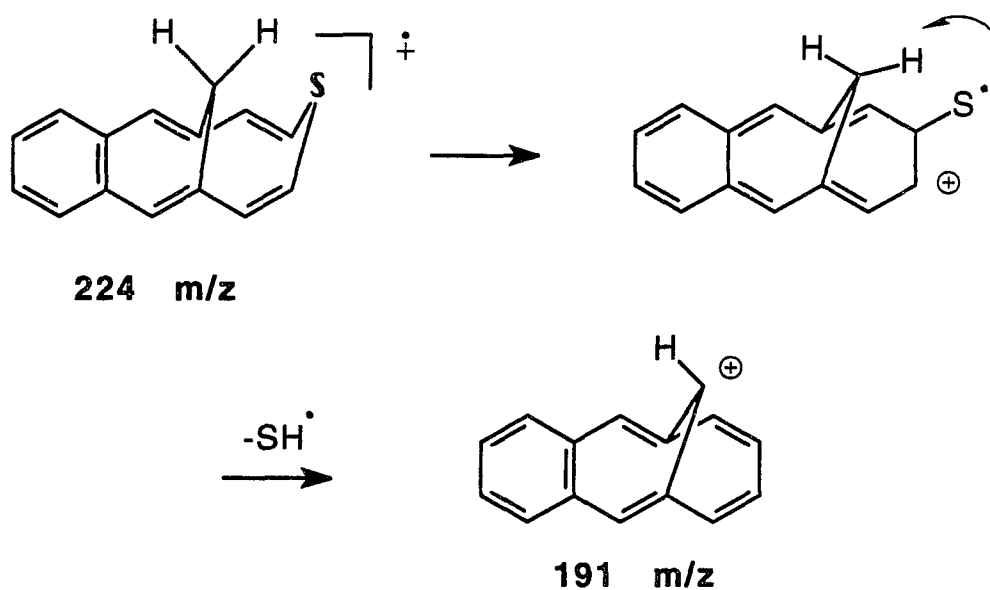
NOE %	H_2	H_{12-syn}	$H_{12-anti}$	H_0
H_3	1.56	0.25		
H_{12-syn}	0.76		8.10	
H_{11}				0.01

Figure 27: NOE values established for thiepin IV.

Difficulties in obtaining NOE values for H_{12anti} - H_{11} and H_{11} - H_2 due to the similar chemical shifts H_{11} and H_2 shown in both $CDCl_3$ or

Benzene. Therefore, the corresponding values are ignored.

The mass spectrum of thiepin **IV** shows a molecular ion of 224 m/z (91%) and a base peak of 191 m/z (100%). The fragmentation is believed to follow a loss of SH radical (33 m/z) via the shown mechanism:



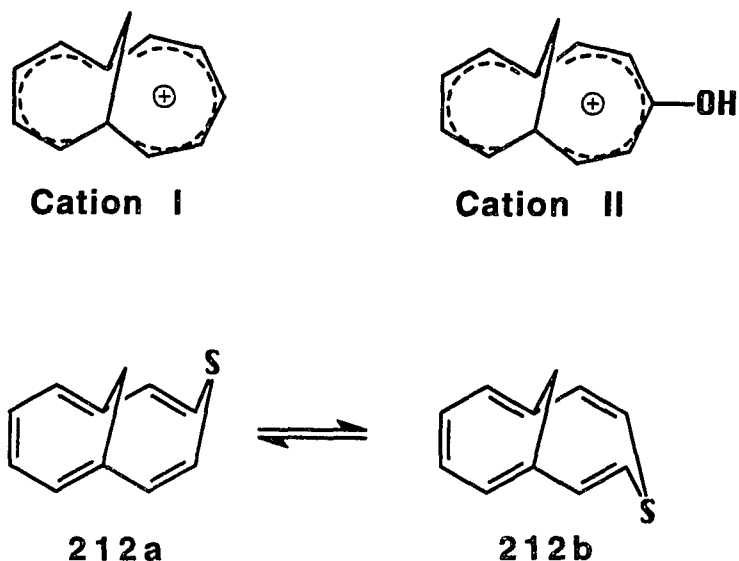
From molecular ion 191 m/z a CH^+ loss yields m/z 178 (43%). The fragmentation now follows that observed in anthracene. The implication of this suggested behavior will be discussed later on.

UV absorption of thiepin **IV** was observed at λ_{max} (ethanol) 296, 348, 420 with tailing into the visible region. Here, too, a bathchromic shift is observed relative to Vogel's thiepin **212**¹⁰⁸ (λ_{max} 233, 284, 395) due to the presence of higher aromatic conjugation.

Some significant ring current changes are observed in **IV** as

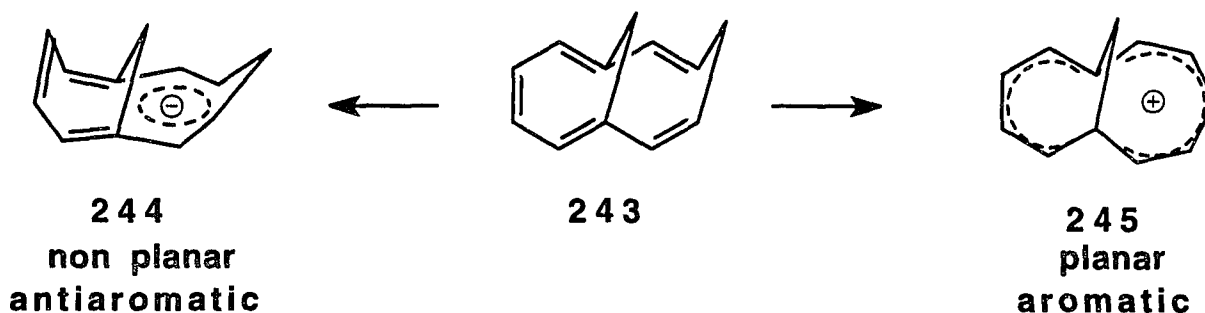
compared with **212**. In this regard, there are two points of great importance: the possibility of homoaromaticity rather than antiaromaticity in this 12π -electron system and conformational considerations. To determine the ring current present in **IV**, one must, however, determine its conformation first.

Two general conformations of bis-methano bridged systems are known to maintain. The first, a planar geometry such as with **cations I**¹⁰⁹ and **II**¹¹⁰, in which the contribution of each π orbital to the ring current is accounted for, and the second, a syn-anti conformation in which the two bridges lie one above and/or one below the relatively nonplanar polyene system as shown for **212a** and **212b**.



In thiepin **212** and **IV** the possibility of a planar conformation is excluded. The inclusion of one of sulfur's lone pair into conjugation results in a high energy, antiaromatic system. This consideration

was nicely demonstrated in the case of bicyclo[5.4.1]dodeca-2,5,7,9,11-pentaene, **243**.



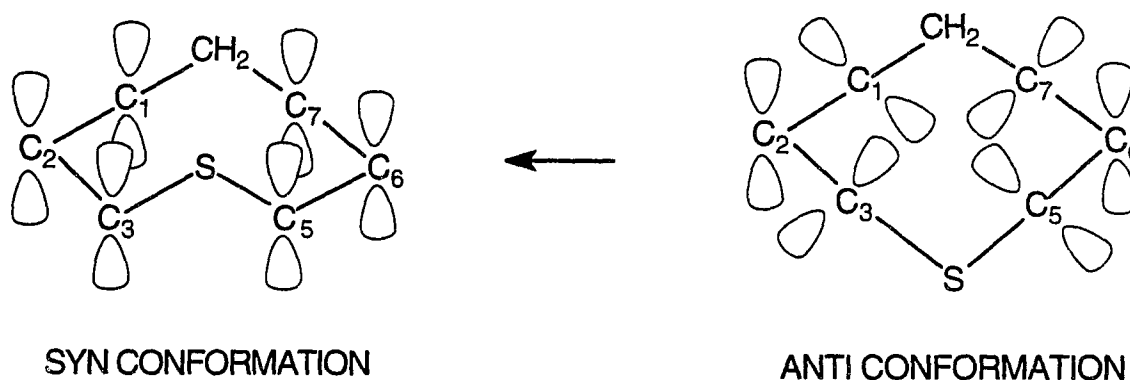
The aromatic 10π electron cation **245** was shown to be a planar molecule while the anion **244**, as a 12π antiaromatic system, was showed to be buckled and non planar¹¹¹.

Of the two possible conformations that **IV** can take, the syn conformation, **IV-a**, is the preferred one. As observed with other bis methano or related systems where the number of bridges is larger than one, geometrical isomerization occurs with the system possibly being in a syn or an anti form (Figure 28).



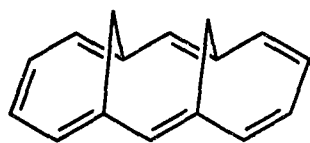
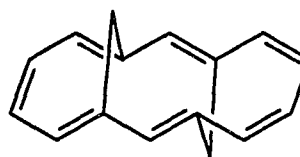
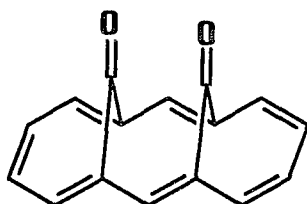
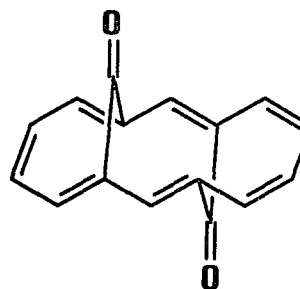
Figure 28: Geometrical isomerization of syn/anti forms

Different models have shown that these molecules have a relatively rigid skeleton and that the relative planarity of the ring skeleton perimeter is larger in the syn form. The $2P_z$ orbitals on C₅, C₆, and C₇ (similarly on C₃, C₂, and C₁) can assume a nearly parallel orientation in the syn form while these orbitals are twisted in relative to each other in the anti form.



Thus, the resonance stabilization should be larger in **IV-a** than in **IV-b**. Unfortunately, attempts to grow X-ray quality crystals of **IV** failed.

Two such systems have been synthesized: Syn/anti-1,6:8,13-bismethano[14]annulene, **247**, and 15,16-dioxo-syn/anti-1,6:8,13-bismethano[14]annulene, **248**¹¹².

**Syn-247****anti-247****Syn-248****anti-248**

In both systems, the syn conformation proved to support diamagnetic ring current as compared with the anti conformation. In fact, the aromaticity of both syn systems manifests itself very beautifully in the ^1H NMR spectra.

Syn-247 exhibits a 1.2 ppm downfield shift for the periphery hydrogens and a 3.1 ppm upfield shift of the bridge protons as compared with the anti isomer. X-ray analysis revealed the structure to be in excellent agreement with calculations. The distance of the inner hydrogen atoms is $1.78\text{\AA}$, one of the shortest distances between nonbonded hydrogens reported. Calculations indicate that

the contact between the inner hydrogens is relieved by increased angle between the two bridges to 26.6° .

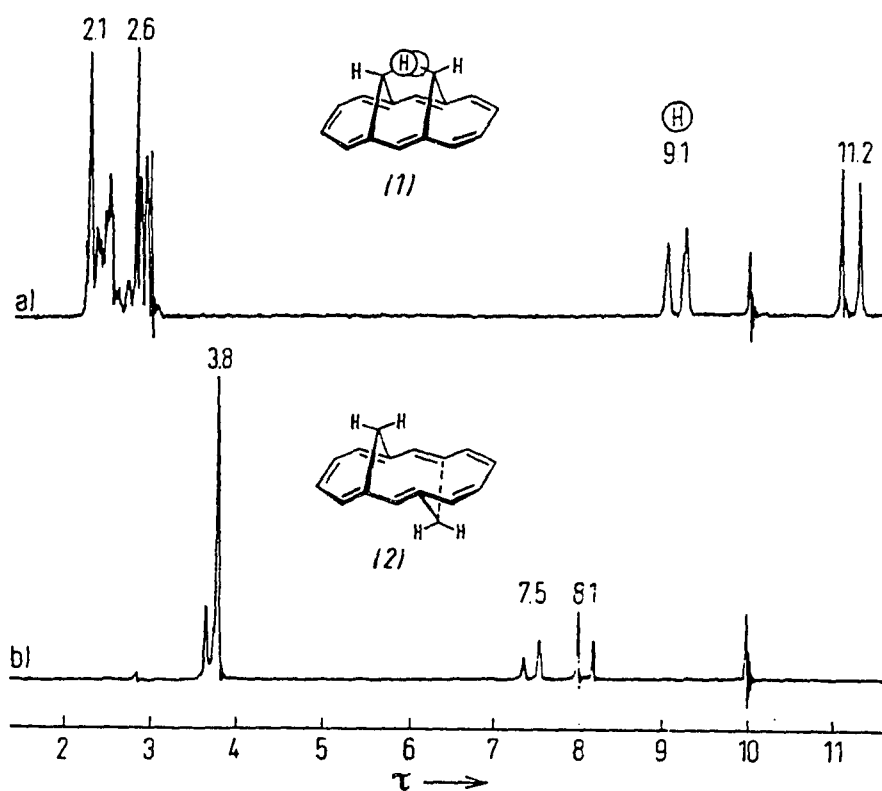


Figure 29: ^1H NMR spectra of **syn-247 (A)** and **anti-247 (B)**

This increase puts the syn isomer 15 Kcal/mole higher in strain than the anti isomer. Yet, it can maintain aromaticity at the expense of steric compression of the inner hydrogen atoms.

In the syn-diketo, **syn-248**, all of the resonances show a downfield shift of about 1 ppm with respect to the anti isomer. These shifts clearly indicate the change that occurs from an olefinic to an aromatic 14π system as one goes from the anti isomer to the syn system.

The homoaromaticity of **IV** may be examined, therefore, as an extended model of cycloheptatriene itself.

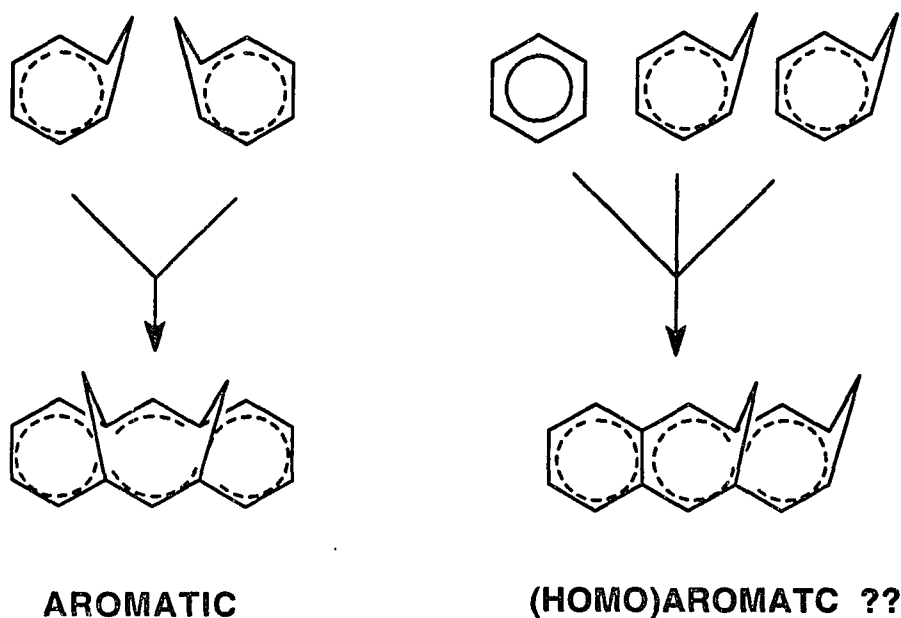
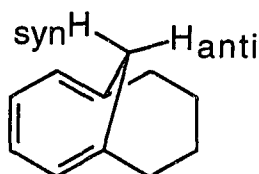
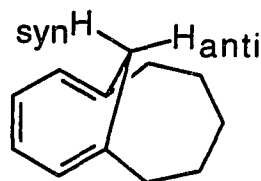
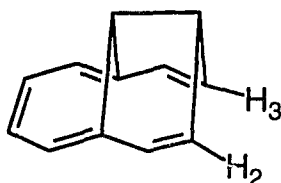


Figure 30: Cycloheptatriene as model of homoaromaticity; or, Is thiepin **IV** Homoaromatic ?

There is evidence¹¹³ that cycloheptatriene can support an induced diamagnetic ring current, as observed from its ^1H NMR and diamagnetic susceptibility data. On the basis of these, chemists have referred to cycloheptatriene as being homobenzene. This is not to say, however, that homoconjugation refers to norcaradiene-like character. Homoconjugation refers strictly to the interaction between π orbitals which are geometrically prohibited to be parallel to each other but may interact only on one surface. In norcaradiene, however, the rehybridized carbons are sigmoid type orbitals as observed in cyclopropanes, with the carbon skeleton displaying substantial alternation.

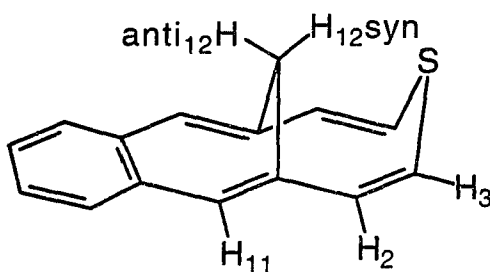
In bridged cycloheptatriene such as **250** and **251**¹¹⁴ the bridge syn proton lies over the π electron cloud and is therefore shielded while the anti proton is deshielded.

**250****251****252**

Both Paquette¹¹⁵ and Vogel¹¹⁶ have prepared elassovalene **252**, and examined the extent of homoaromaticity present. On the basis of spectral information, supported by diamagnetic studies, Paquette has determined that **252** possess some degree of homoaromaticity in the cycloheptatriene segment of the molecule. Vogel and Gunter¹¹⁷, however, who performed a similar investigation determined unequivocally that the system does not possess any degree of homoaromaticity and should be considered as nonaromatic.

A comparison between Vogel's thiepin **212** and **IV** clearly indicates changes that may be attributed to the controversial aspects of homoaromaticity. However, if one ignores such possibility on the basis of the absence of homoaromaticity in thiepin **212**, then these changes may be attributed to altered geometry and reduction in ring current. Vogel based the conclusion as to the non-aromaticity of **212** on superficial comparison of chemical shifts observed in **212** relative to similar compounds. This comparison, in fact, as Table 12 shows, attributed the low field resonance of H_{12syn} to sulfur atom effects rather than to paratropicity. A bridge proton in **212** resonates at abnormally low field of 6.27 ppm while the periphery hydrogen H_3 at relatively high field. Ring puckering clearly reduces the level of paratropicity as compared with pure [12]annulene. In comparison with **212**, **IV** shows a 0.55 ppm upfield shift for the bridge proton syn to the sulfur atom and a 0.7 ppm downfield shift for the anti hydrogen. Substantiated by a 0.74 ppm downfield shift of H_3 in **IV** and (since the distances between H_{syn} and the sulfur atom

and the sulfur atom in both thiepins is assumed similar) by the upfield shift of the H_{syn} , a reduction in paratropicity may be concluded for **IV**, with some conjugation still present. In the absence of a benzene ring, H_{anti} however, is highly shielded by the triene system. With benzannelation, H_{anti} now lies on the rim of the aromatic sextet, in the deshielding cone.



Thiepin IV

Resonance	212	IV	$\Delta\delta$ (212-IV)
H_2	6.60 ppm	6.50 ppm	+0.10
H_3	4.77 ppm	5.51 ppm	-0.74
H_{11}	AA'XX'	6.50 ppm	- -
$H_{12\text{syn}}$	6.27 ppm	5.72 ppm	+0.55
$H_{12\text{anti}}$	1.24 ppm	1.98 ppm	-0.74

Table 12: ^1H NMR data comparison between thiepin **212** and **IV**

The ^{13}C spectrum of thiepin **IV** displays no indication as to the antiaromaticity of the system. ^1H - ^{13}C HETCOR correlation obtained for this thiepin reveals the positioning of α -carbon at a higher field than the β -carbon. This is a remarkable reversal of the observed with simple vinyl thioethers. While in the latest case resonance effects may deshield the α -position with increased electron density on the β -carbon, in $4n$ π -systems such an effect is absent. Inclusion of any contribution from a sulfur lone pair should result in an overall destabilization. In fact, the strong shielding observed for the α -position in thiepin **IV** is indicative of this behavior. The position of the α -carbon and α -proton at higher field relative to the β -carbon reflects the polarizability of the double bond α to the sulfur.

On benzannelation these effects remain unchanged. It is probable that the chemical shift differences may vary upon annelation, but inversion of polarization has never been observed in these cases.

Sulfur extrusion from **IV** to the yet unknown 3,4-benzo-1,6-methano[10]annulene **VI** was expected to be found in the reaction mixture from which **IV** was obtained. However, none of **VI** was detected. Unlike Vogel's thiepin **212**, where sulfur extrusion and formation of the methano[10]annulene was observed at temperatures above 50°, and unlike other masked thiepins listed in Table 13 below, Thiepin **IV** did not extrude sulfur at 78° (refluxing reaction solvent-ethanol).

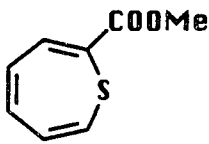
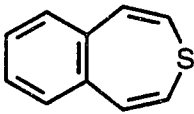
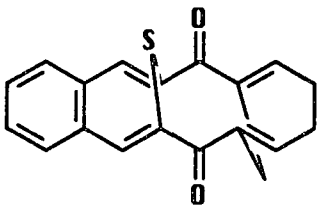
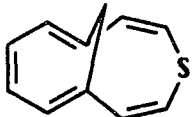
#	Thiepin	Sulfur Extrusion
3 2		Detected only in an argon matrix at 10K
2 8		Detected below -10°
4 1		Solid; extrudes in refluxing benzene or at 60° ($t_{1/2}$ =39.6 min)
3 4		Solid; extrudes above 50° or in refluxing benzene, hexane

Table 13: Sulfur extrusion in various thiepins

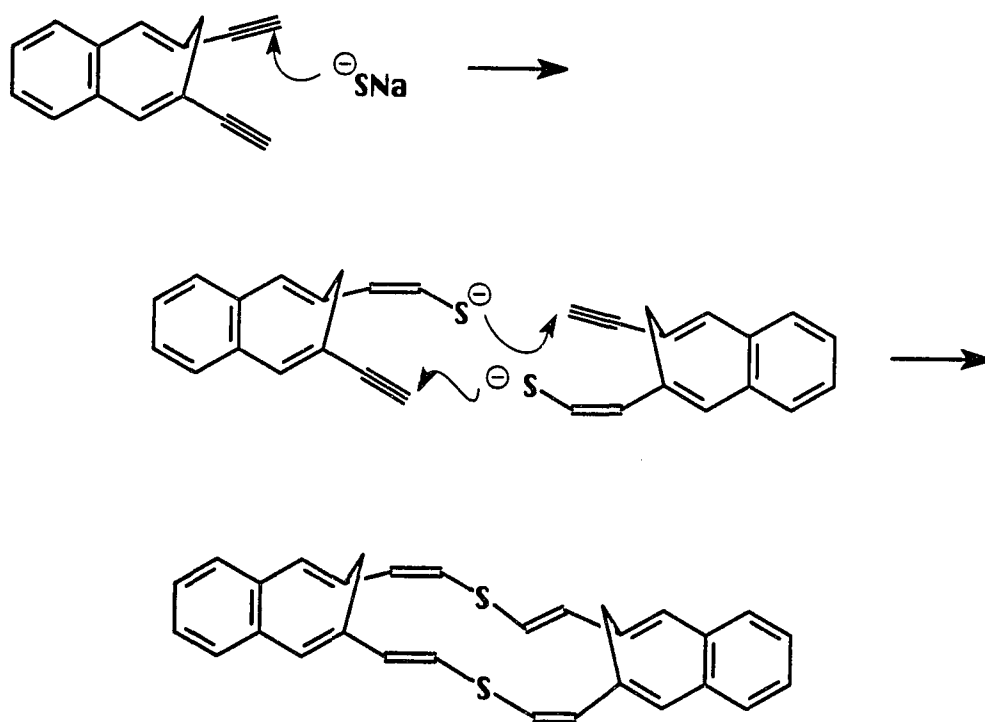
We carried out several attempts to achieve sulfur extrusion from **IV** as shown below. All attempts failed.

#	Conditions	Results
1	Refluxing EtOH, 78°	No change. Sample recovered pure.
2	Benzene, 120°, 99 hrs, sealed tube,	As above
3	Benzene, PPh ₃ , 150°, 72 hours	As above
4	Refluxing EtOH, PhSNa, 72 hours	As above
5	Neat, 250°, 2 hours	Decomposes to an insoluble black solid
6	Neat, PPh ₃ , 6 hours	Recovered thiopin, inseparable benzmethano[10]annulene, and Ph ₃ P=S
7	Copper bronze	No change. Sample recovered pure.

Table 14: Sulfur extrusion attempts from **IV**

The reduced susceptibility of **IV** to extrude sulfur is of great significance. Increase in thermal stability due to benzo annelation of Vogel's thiepin **212** reflects increase in the energy involved with the o-quinoid formation in **IV** which is absent in Vogel's **212**. Moreover, the earlier observation that naphthothiepin **I**, extrudes sulfur in refluxing ethanol, supports the conclusion that the ortho quinoid intermediate of **IV** is a much higher energy intermediate than that of **I**. The decomposition observed with **IV** on heating to high temperatures suggests the possibility of a different mechanism via which sulfur extrusion proceeds. The mass spectrum of **IV** as described earlier does not indicate the presence of an $M^+ 32$ fragment. It, however, indicates the loss of an SH fragment. A free radical mechanism involving radical sulfide species may explain the polymerization observed upon heating of **IV** but not on heating of the corresponding oxides (described next).

The presence of side product **241** in the reaction mixture along with thiepin **IV** may be explained by an intermolecular sulfide addition. The addition of vinylsulfide to acetylene and the unique formation of a trans-alkene was discussed earlier. The formation of **241** proceeds in a rather concentrated ethanolic solution of **221** via initial addition of sulfide to terminal acetylene to form a cis-alkene, followed by intermolecular addition of the newly formed vinylsulfide to a second acetylene to yield the trans double bond. Addition of a second mole of sodium sulfide follows the same path, as shown below.



241

Scheme 45: Synthesis of 241

2.4.2 THE OXIDES OF THIEPIN IV: THIEPIN-1-OXIDE, 260
and THIEPIN-1,1-DIOXIDE, 261.

It has been reported quite extensively in the literature that the task of thiepin oxidation may not be a simple one. Even under mild conditions many thiepins resist oxidation and decompose by sulfur extrusion into aromatic hydrocarbons or into unidentified mixtures. Vogel reported unsuccessful attempts to oxidize **212**¹¹⁸. In other cases, however, the oxidation of a thiepin system was the only mode of isolation of a labile parent thiepin.

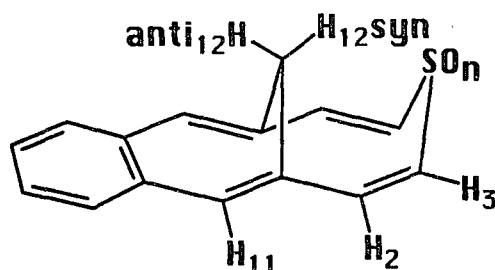
Treatment of thiepin **IV** with one equivalent of mCPBA in CH_2Cl_2 at 0° or with excess aqueous NaIO_4 in THF at room temperature yielded thiepin-1-oxide, **260**, in 42.0% and 47.0% yield, respectively. Slight over oxidation was observed in both cases. However, addition of **IV** to two equivalents of mCPBA yields the sulfone **261** directly in 46.8% yield as the sole product. The two oxides may be easily separated by chromatography (elution with EtOAc.) The two showed melting points above 300° and greater stability as compared with the parent thiepin **IV** (Table 15.) On sublimation, both **260** and **261** sublime easily with out any observable decomposition and without any sulfur extrusion. Sulfone **261** was allowed to heat and sublime at 350° , under normal pressure, and in a 1:1 mixture with basic alumina under identical conditions. The majority of the sample decomposed with only small

amounts subliming without any observable extrusion of sulfur dioxide.

Table 15: Stability comparison of thiepin **IV**, its oxide **260** and dioxide, **261**

	Thiepin IV	1-Oxide, 260	1,1-dioxide, 261
Solid at r.t./ air	Stable in dark, decolorizes	stable	stable
In solution at r.t	stable	stable	stable
EtOH / reflux	stable	stable	stable
DMF / reflux	stable	N/A	stable
sublimation	decomposes	stable	stable
Above mp	decomposes	Darkens at 250°	Darkens at 200°

The ^1H NMR differences observed between thiepin **IV** and its oxides, **260** and **261** are summarized below in Table 16.



IV; n=0
260; n=1
261; n=2

Thiepin	Chemical Shifts, δ : J in Hz					
	H ₁₂ anti	H ₁₂ syn	H ₃	H ₂	H ₁₁	AA'BB'
IV	1.98 J=11.9	5.72 J=11.9, 0.73	5.51 J=10.1	6.50 J=10.1	6.50	7.30
260	1.36 J=14.0	3.06 J=14.0, 1.03	5.66 J=10.4	6.73 J=10.4	6.92	7.50
261	0.98 J=13.7	4.06 J=13.7	6.28 J=11.4	7.14 J=11.4	7.20	7.70
Δ ppm= IV-261	1.0	1.66	-0.77	-0.64	-0.70	-0.40

Table 16: ^1H NMR data for thiepin **IV** and its oxides **260** and **261**.

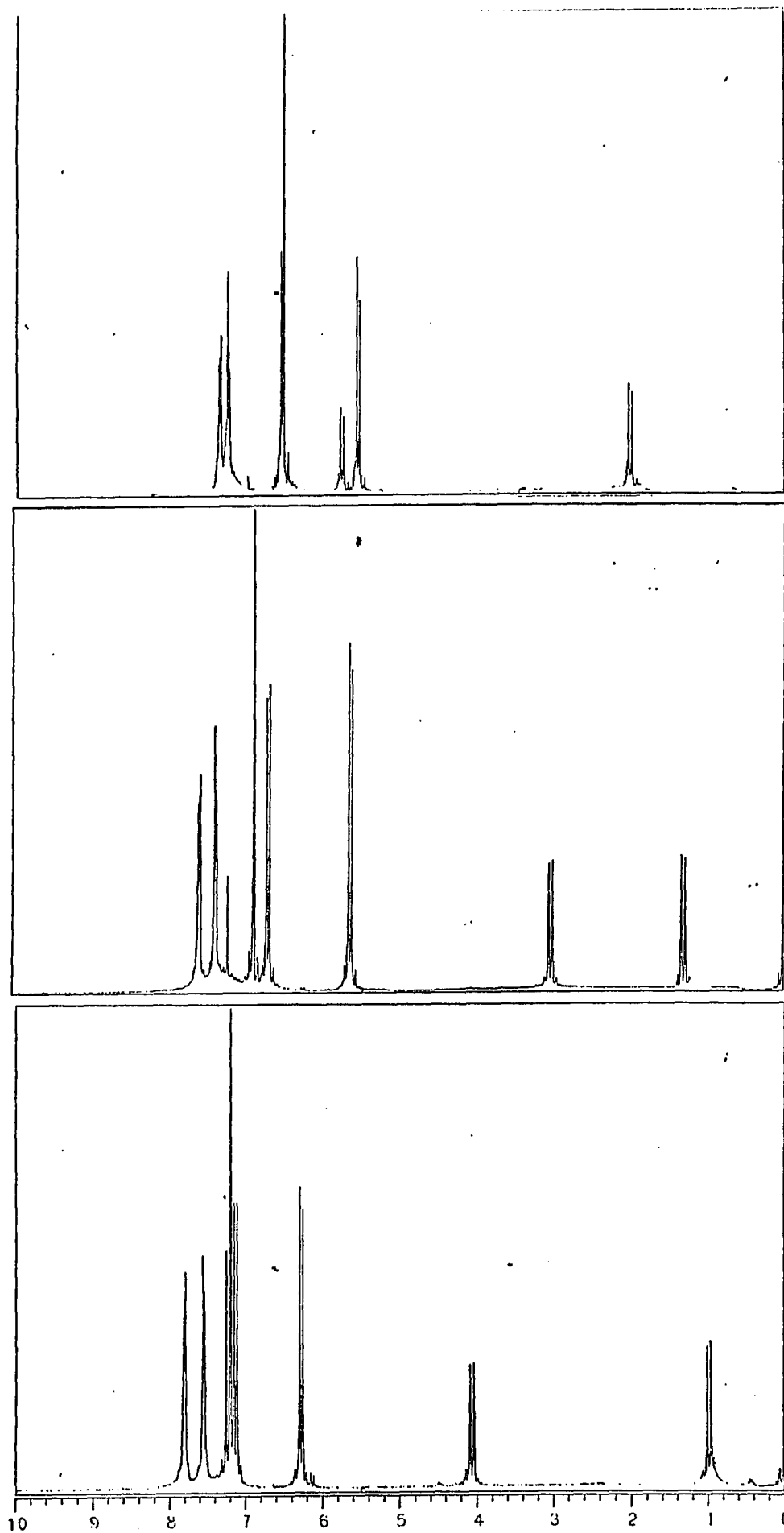
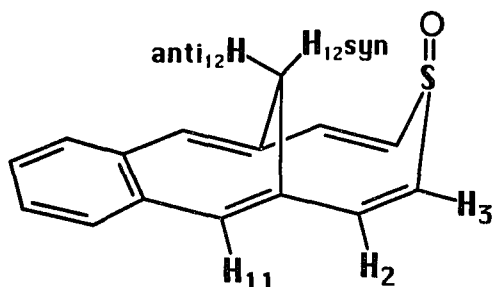
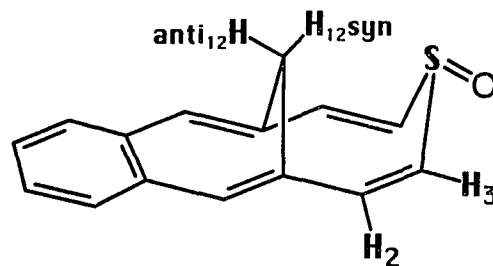


Figure 31: ^1H NMR of thiepin IV (top), Oxide 260 (middle) and dioxide 261 (bottom).

Clearly, changes in coupling constants and in the chemical shift difference observed in each of the systems indicate several geometrical changes in the ring skeleton as well as reduction in paratropicity. Whatever level of paratropicity which exists in thiepin **212** is clearly reduced in **IV**. Moreover, the continuous upfield shift observed for H_{syn} as one goes to oxide **260** is in support. With oxide **260** the contribution of sulfur's lone pair to the conjugated system is reduced and so is the observed paramagnetic ring current. In sulfone **262**, however, compression between H_{syn} and the oxide bond determine the relative resonance of the bridge protons. Note that the relative position of the hydrogens anti to the sulfur atoms in **IV**, **260**, and **261** is relatively unchanged.

Infra red spectroscopy exhibits the characteristic sulfoxide bond for **260** at 1038 cm^{-1} and that of sulfone **261** at 1107 and 1276 cm^{-1} .

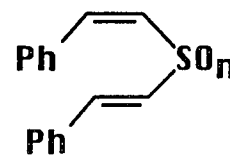
Sulfoxide **260** was obtained as a single isomer. On the basis of ^1H NMR experiment using $\text{Eu}(\text{FOD})_3$ [tris(6,6,7,7,8,8,8-heptafluoro-2,2-dimethyl-3,5-octanedionato)europium(III)], syn-geometry was determined. Addition of this reagent caused the $H_{12\text{syn}}$ signal to move down field faster than either ring proton H_3 or H_2 , as would be expected of the anti-sulfoxide.

**Syn-****Anti-**

To study the UV absorptions of oxides **260** and **261**, we examined the behavior of E,Z-distyrylsulfide, **106**, its sulfoxide, **262** and sulfone **263**. The synthesis of the sulfide was described earlier. The oxides **262** and **263** were prepared by mCPBA oxidation of **106** by the usual method¹¹⁹.

UV absorption spectra of **106**, **262**, **263** are shown in Figure 32 below.

106	302, 308, 314, 318, 328 nm
262	304
263	302



106; $n=0$

262; $n=1$

263; $n=2$

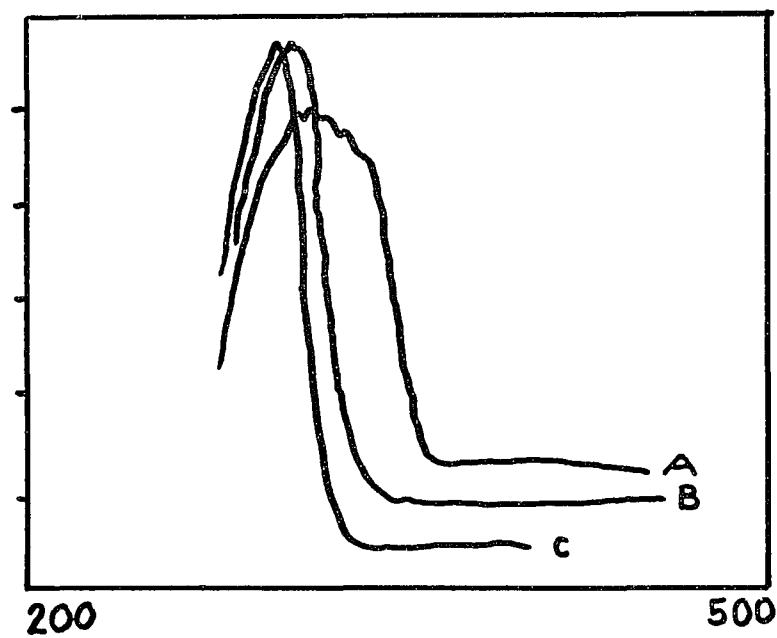


Figure 32: UV absorptions of E,Z-distyrylsulfide, **106** (A), sulfoxide, **262** (B), and sulfone, **263** (C)

The pattern observed is a hypsochromic shift of the oxides from the well defined pattern of **106**. This shift is due primarily to inductive effect of the oxygen. Identical shift is observed in thiepin **IV** (Figure 33).

IV	296, 348, 420
260	290, 320
261	286, 312, 316, 320

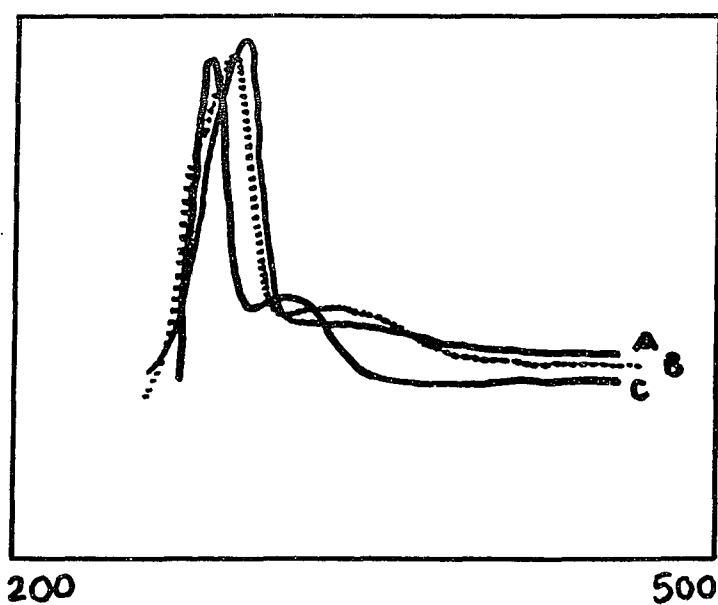


Figure 33: UV spectra of **IV** (A), **260** (B) and **261** (C)

Mass spectrum of the sulfoxide **260** was impossible to obtain. However, the sulfone **261** showed a fragmentation pattern consistent with the sulfur extrusion mechanism suggested earlier. The sole extrusion of sulfur dioxide from **261**, $[M+]-64$, suggests that a chelotropic ring contraction may be the mechanism by which sulfur dioxide is extruded. In **IV**, however, such mechanism is probably invalid. Experimental support for this comes from the behavior of thiepins **IV** and its sulfone, **261**, upon sublimation.

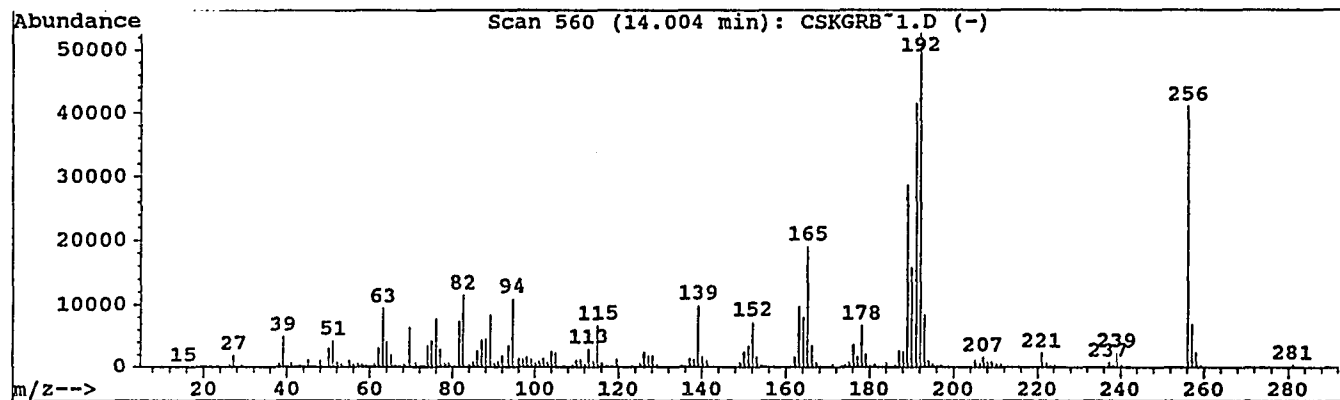
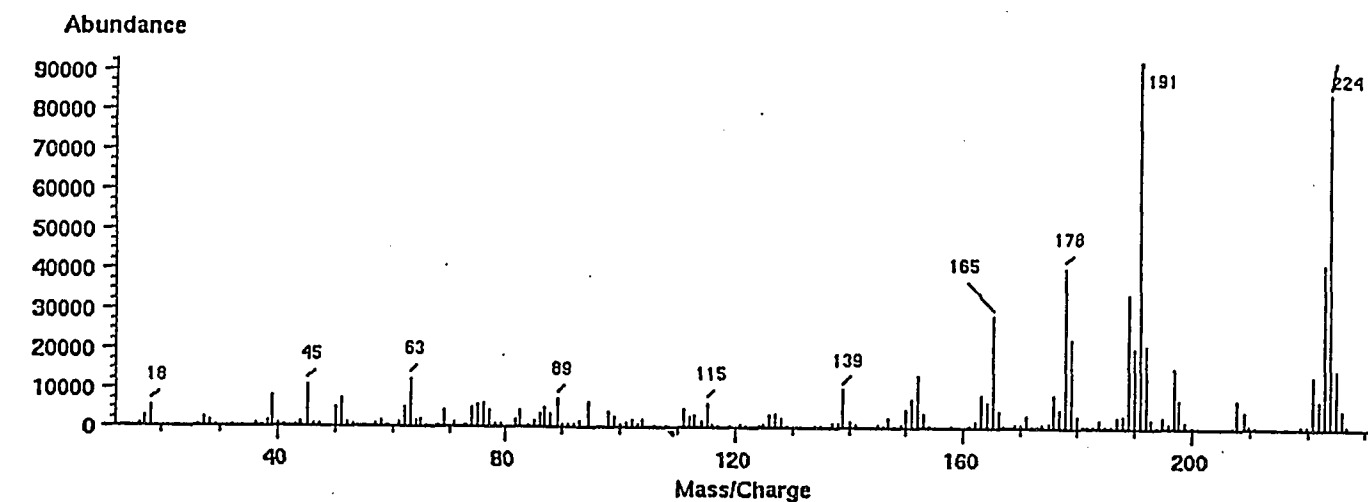


Figure 34: Mass Spectra of thiepin IV (above), and sulfone 261 (below)

X-Ray structure of sulfone **261** was acquired. Its ORTEP structure confirmed the syn-conformation of the two bridges. The distances between the syn oxide and the bridge syn-hydrogen was measured to be 2.204Å, while the C₁₂-sulfur atom distance was longer at 3.219Å. Models indicated no extra steric repulsion or electronic attraction between the syn-hydrogen and the oxide. The skeleton perimeter is observed to be non planar with alternating single and double bonds.

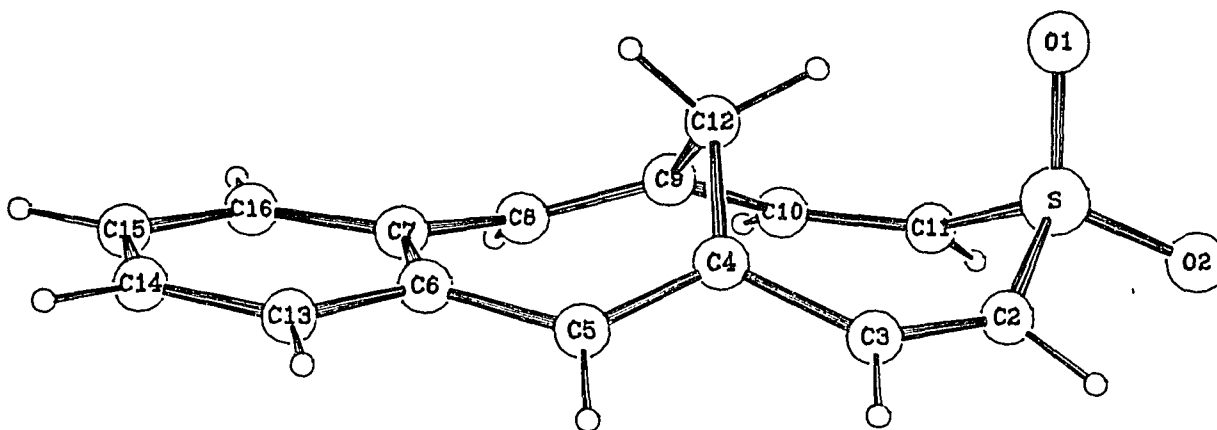
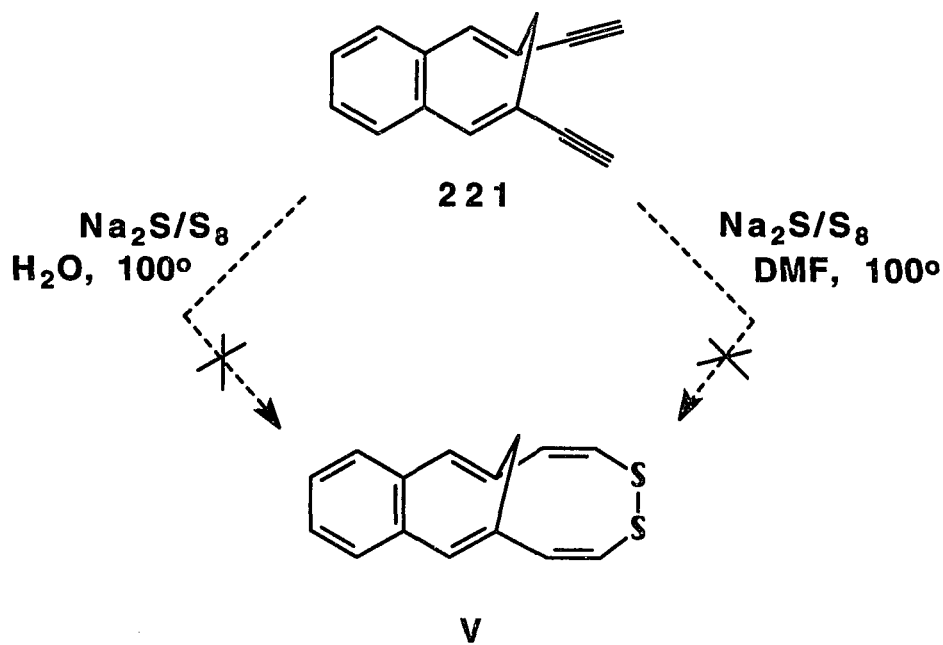


Figure 35: ORTEP drawing of sulfone **261**.

2.4.3 INVESTIGATIONS OF 5,9-METHANO-7,8-BENZO-1,2-DITHIADODECA-3,5,7,9,11-PENTAENE, V

Similarly to the approach utilized in the attempted synthesis of naphtho-1,2-dithiocin **II**, we executed the synthesis of **V**. On the basis of the increased stability observed with thiopin **IV** as compared with naphthothiopin we predicted increased stability in **V** as compared to **II** resulting from methano bridging and aromatic stabilization.

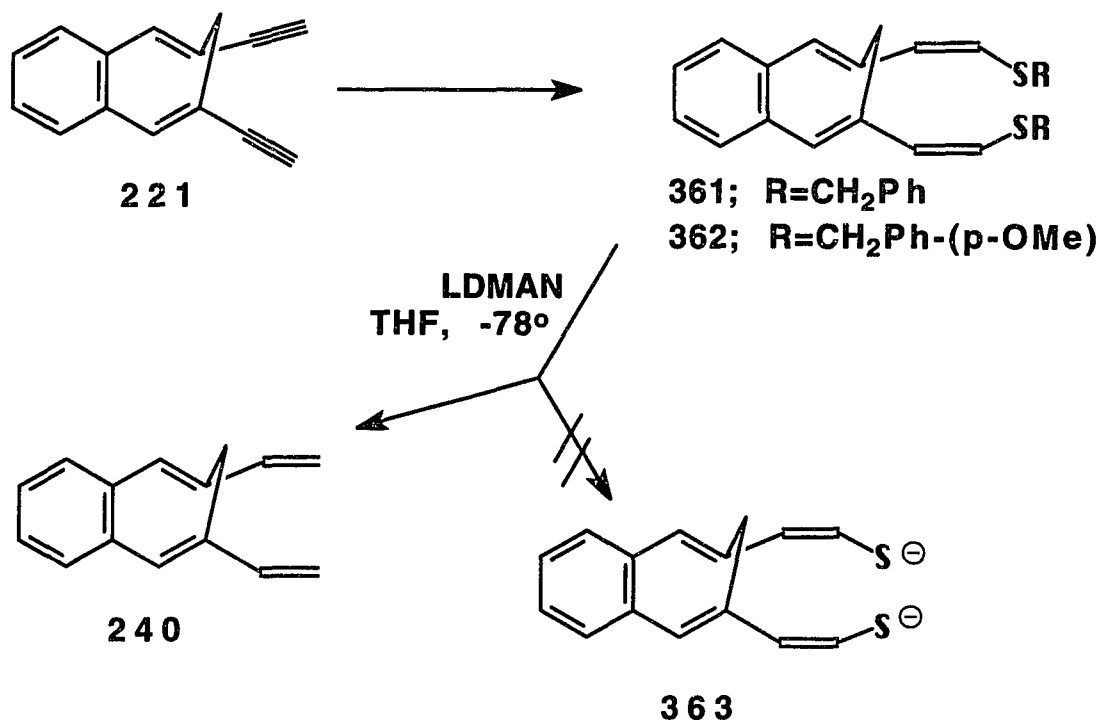
Initial attempts to synthesize **V** via sodium disulfide addition to diacetylene **221**, in DMF, failed. Within 15 minutes after the addition of **221** to the solution containing the disulfide, TLC indicated decomposition of the sample. No starting material was



Scheme 46: Attempted synthesis of 1,2-dithiocin, **V**.

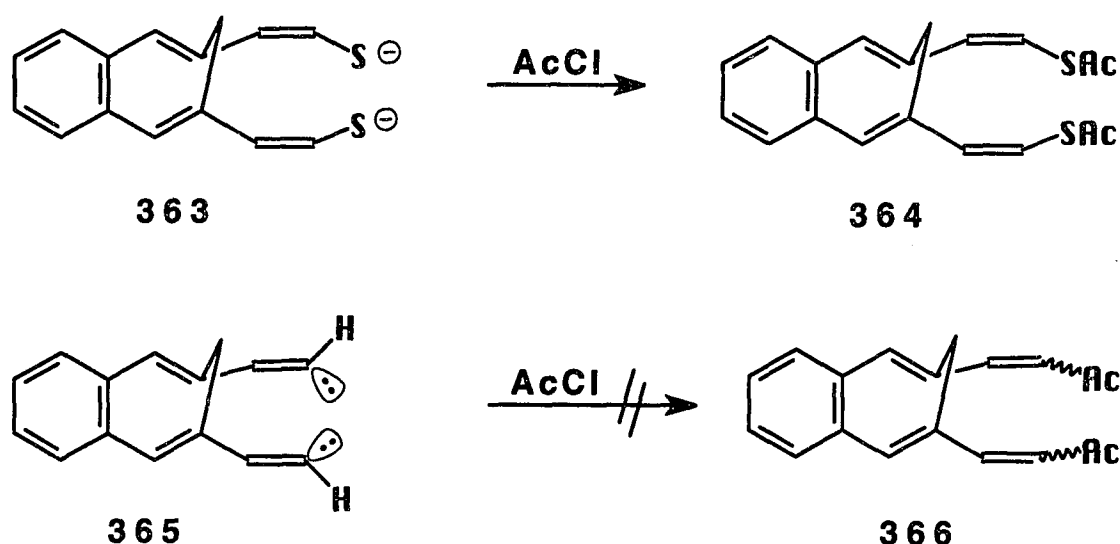
recovered and no sulfur extrusion to the benz-1,6-methano [10]annulene was detected.

Bis-benzylmercaptovinyl compound **361** was formed as a yellow oil in 79.6% yield by addition of benzylmercaptan to diacetylene **221** in ethanolic sodium ethoxide. Reductive lithiation of **360** in THF at -78° did not yield the desired dithiolate **363** as shown below. Instead divinyl **240** was collected in 79.1% yield. Identical results were recorded when bis(p-methoxybenzyl)mercaptovinyl was used. Divinyl **240** had been previously obtained by dehalogenation of tetrabromo **237** and by Wittig olefination of dialdehyde **220**. All spectral data were compared and found identical.

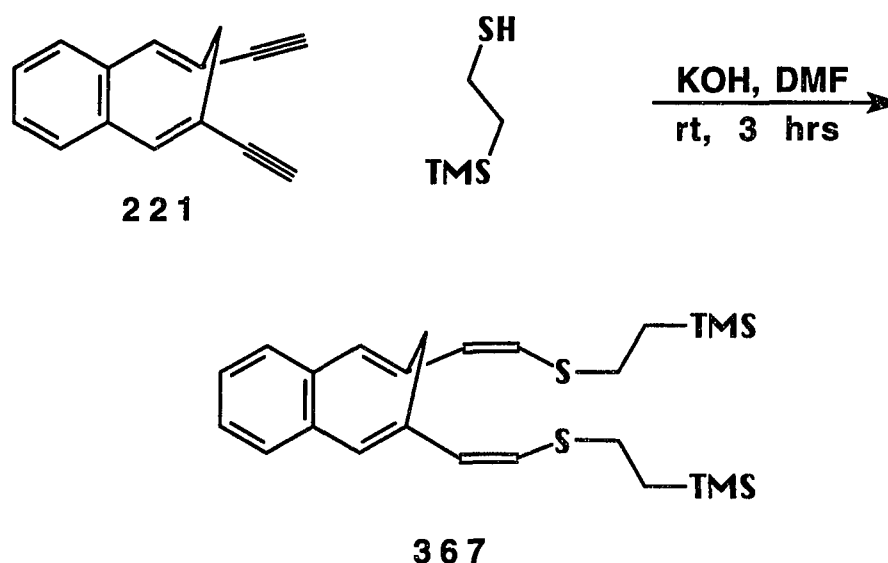


Scheme 47: Attempted debenzylation of **361** and **362**.

Prior attempts to reductively debenzylate a similar precursor to naphtho[2,3-d] 1,2-dithiocin, **II**, under identical conditions, yielded similar difficulties. It seems therefore, that with the homonaphthalene backbone present in **361**, acting as an electron sink, the initial electron transfer from the LDMAN reagent proceeds to the electron rich segment rather than to the S-C bond. This preference results in the formation of a vinyl anion, **365**, which resisted trapping with acetyl chloride due to competing protonation.



The use of 2-(trimethylsilyl)ethanethiol as an excellent sulfur delivering agent, was nicely demonstrated by the ease by which it may be detached from the sulfur atom without the use of dissolving metals. Addition of the reagent to diacetylene, **221**, proceeded according to Koreeda's method at room temperature (Scheme 48.)



Scheme 48: Synthesis of precursor **367**.

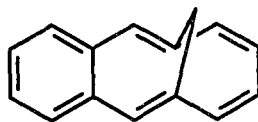
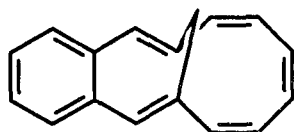
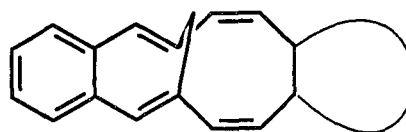
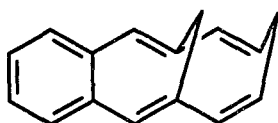
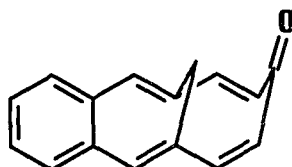
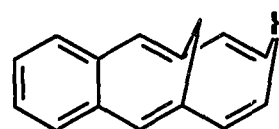
Deprotection of **367** under mild conditions with tributylammonium fluoride in THF follows initial attack of a fluoride ion on the silyl group, elimination of ethylene and formation of a thiolate anion, **363**.

Thus, treatment of a THF solution of **367** with TBAF and molecular sieves, followed by oxidation with iodine, did not result in any detectable oxidation product of **363**; Nor was benzmethano [10]annulene, **VI**, or starting material present in the crude mixture.

Further attempts to synthesize **V** were discontinued.

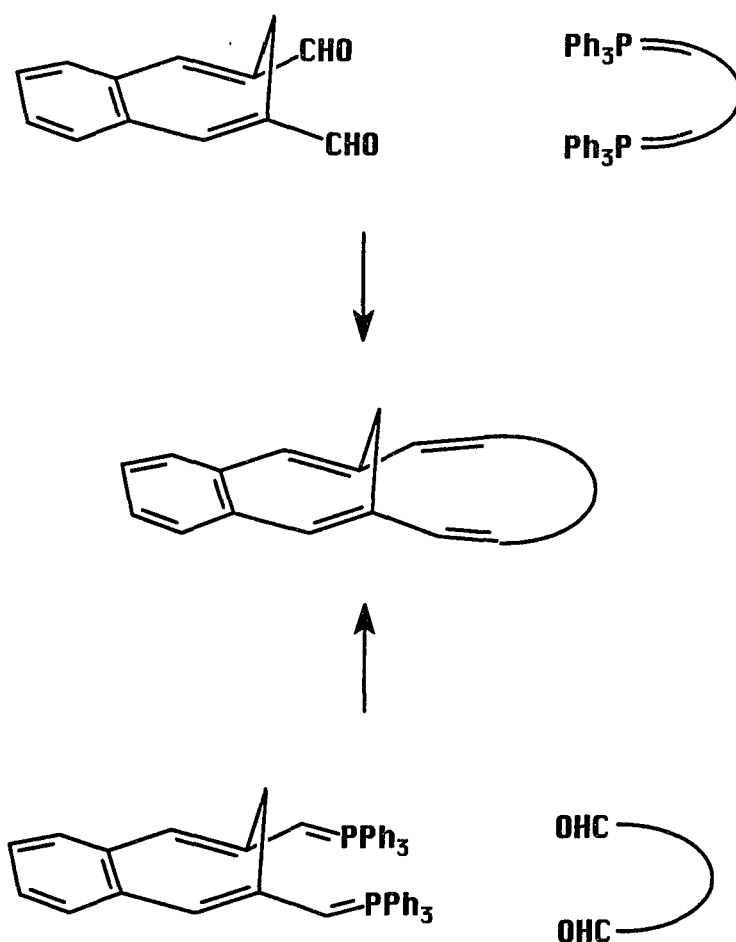
2.5.0 ANNELATIONS VIA 3,4-BENZCYCLOHEPTATRIENE-1,6-DICARBOXALDEHYDE, 220

The routes to annelated systems such as **VI**, **270-274** may be easily achieved by utilizing **220** as a key starting material.

**VI****272****271****270****273****274**

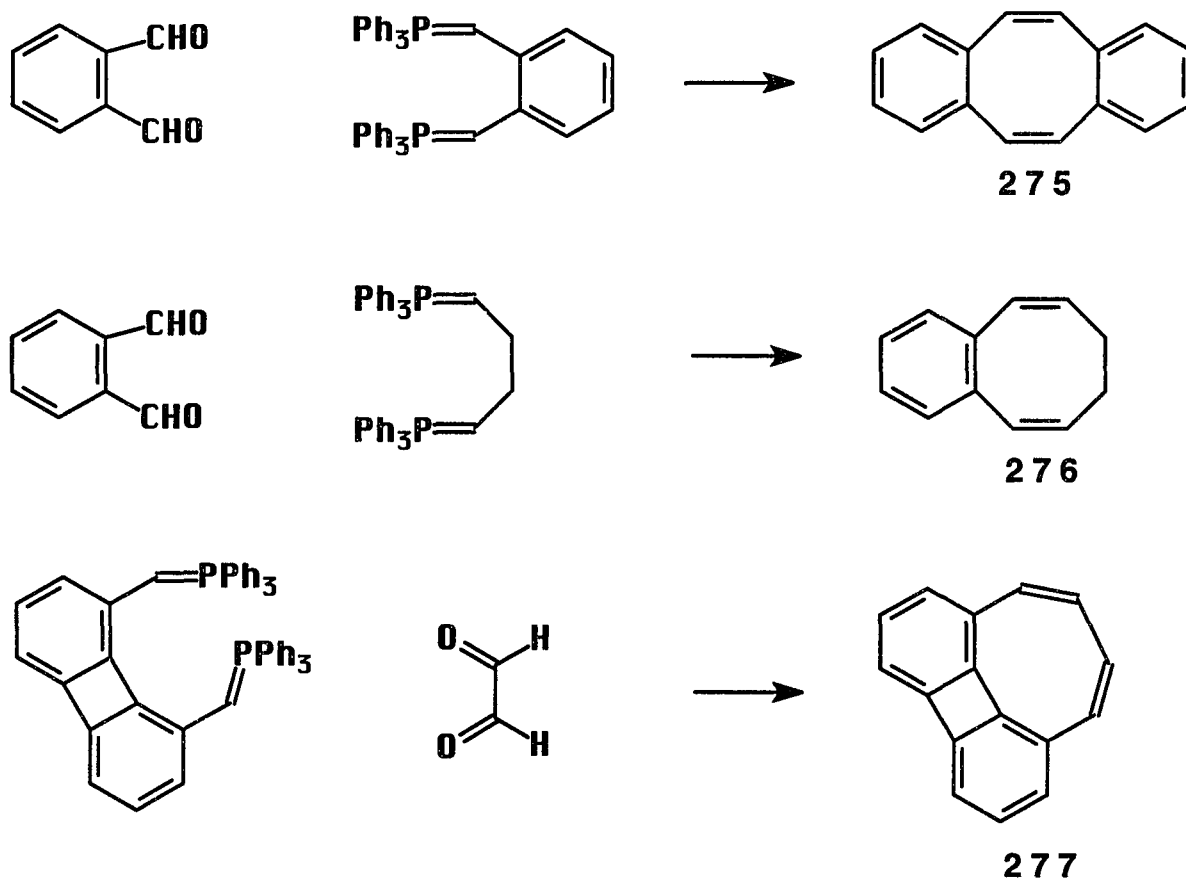
The study of these systems will give not only some insight into aromaticity/antiaromaticity aspects and conformational flexibility, but will support us with indications as to the affects of benzannelation as studied in thiepin **IV**.

The Wittig approach towards annulenes such as **270**, **271** and **272** was found to be a powerful method. A double Wittig reaction of **220** with bisalkylidenephosphoranes may proceed to cyclization via one of two ways:



Reactions of both types are well documented in the literature¹²⁰; most specifically in two reviews by Vollhardt¹²¹ and Becker¹²².

Systems such as **275**¹²³, **276**¹²⁴, and **277**¹²⁵ were synthesized by bis-Wittig reactions.



Although yields are moderate to low, the reactions with dicarbonyls proceed in most cases without much difficulties.

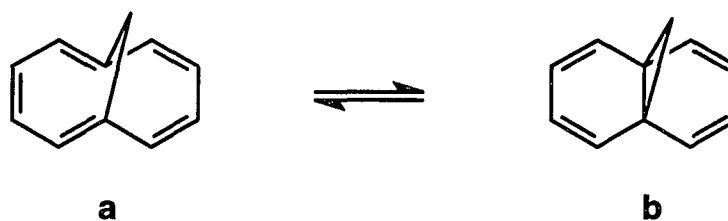
Several Wittig olefinations were successfully performed on **220**. The reactions leading to benzoannulenes are described next.

2.5.1 SYNTHESIS AND INVESTIGATION OF 3,4-BENZO-1,6-METHANO[10]ANNULENE, VI

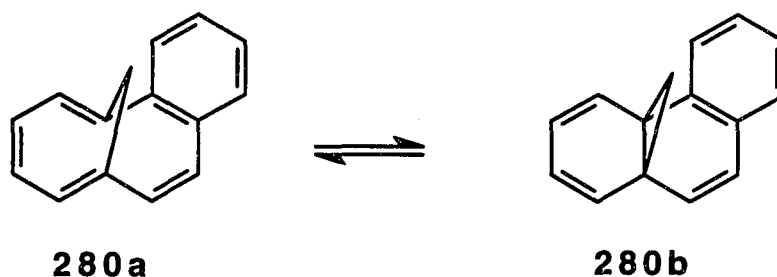
The prediction as to the aromaticity of **VI** stems from the observed diamagnetic ring current in 1,6-methano[10]annulene itself¹²⁶. If one assumes naphthalene, anthracene, etc to be benzannelated systems of benzene and moreover to be bridged systems [4.4.0], then the affects of benzannelations do not include reduction in ring current.

The spectacular advance in the mid 1950's to 1960's in the confirmation of Hückel's rules of aromaticity, led to the idea that [10] annulenes should be aromatic. With the difficulties observed in the synthesis of all cis- or di-trans isomers of [10] annulenes, Vogel suggested that substitution of two H's by a methylene bridge would stabilize the system. Spectroscopic measurements clearly indicated that 1,6-methano[10]annulene had a diamagnetic ring current (AA'BB' system at 7.0 ppm with shielded bridge protons at -0.5 ppm.) The aromatic type chemical behavior of the annulene is quite a strong indication of that. Thus, on benzannelation, reduction in ring current is not expected and similar aromatic behavior is predicted. Mitchell¹²⁷ who investigated the 14π -dimethyldihydropyrene series determined that the effect of benzannelation depended greatly on the relative positions of the annelating benzene rings. Similar dependence is clearly possible with methano[10]annulene. Valence tautomerization of Vogel's 1,6-methano[10]annulene (a) results in the formation of the nonaromatic bisnorcaradienic form (b) and may

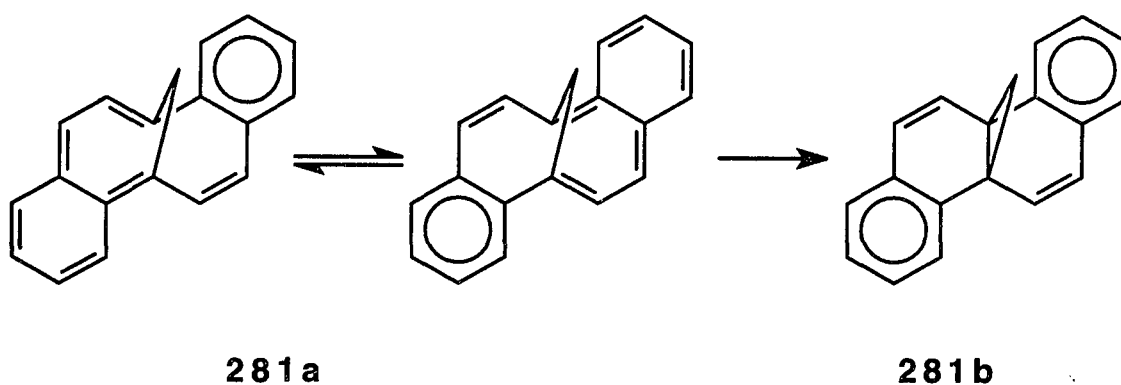
be effected by benzannulation.



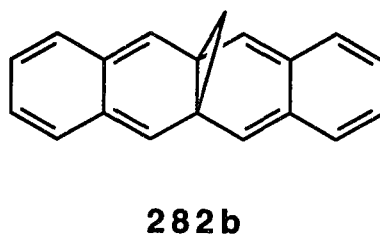
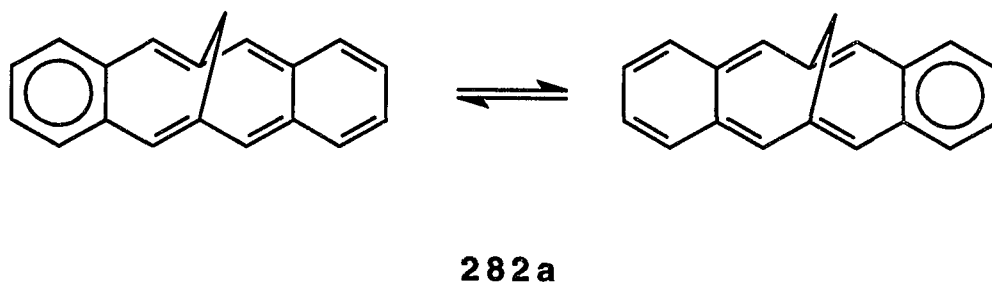
2,3-Monobenz[10]annulene, **280**, was prepared by Vogel¹²⁸ et al and was found to exist as the aromatic **280a** with reduced diamagnetic ring current, however, as determined by its ¹H NMR.



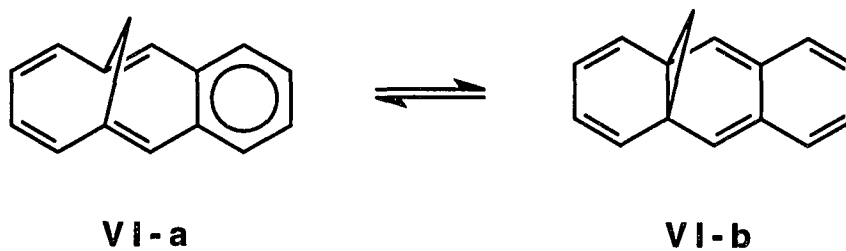
Bisannulation of methano[10]annulene yields two possible structures: phenanthro-fused and anthra-fused. Hill¹²⁹ synthesized the phenanthro fused 2,3,7,8-dibenz-1,6-methano[10]annulene, **281**, which was determined to be non-aromatic, favoring the norcaradienic form **281b**. This form maintains two fully aromatic rings as compared with the reduced aromatic stabilization in **281a**.



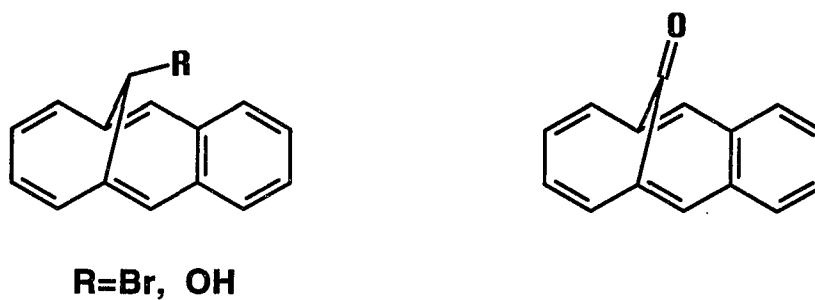
The anthra-fused, 3,4,8,9-bidienz-1,6-methano[10]annulene, **282**, is still unknown. It is expected to exist in two equivalent Kekulé structures without undergoing valence tautomerization to the bis-o-quinoid structure.



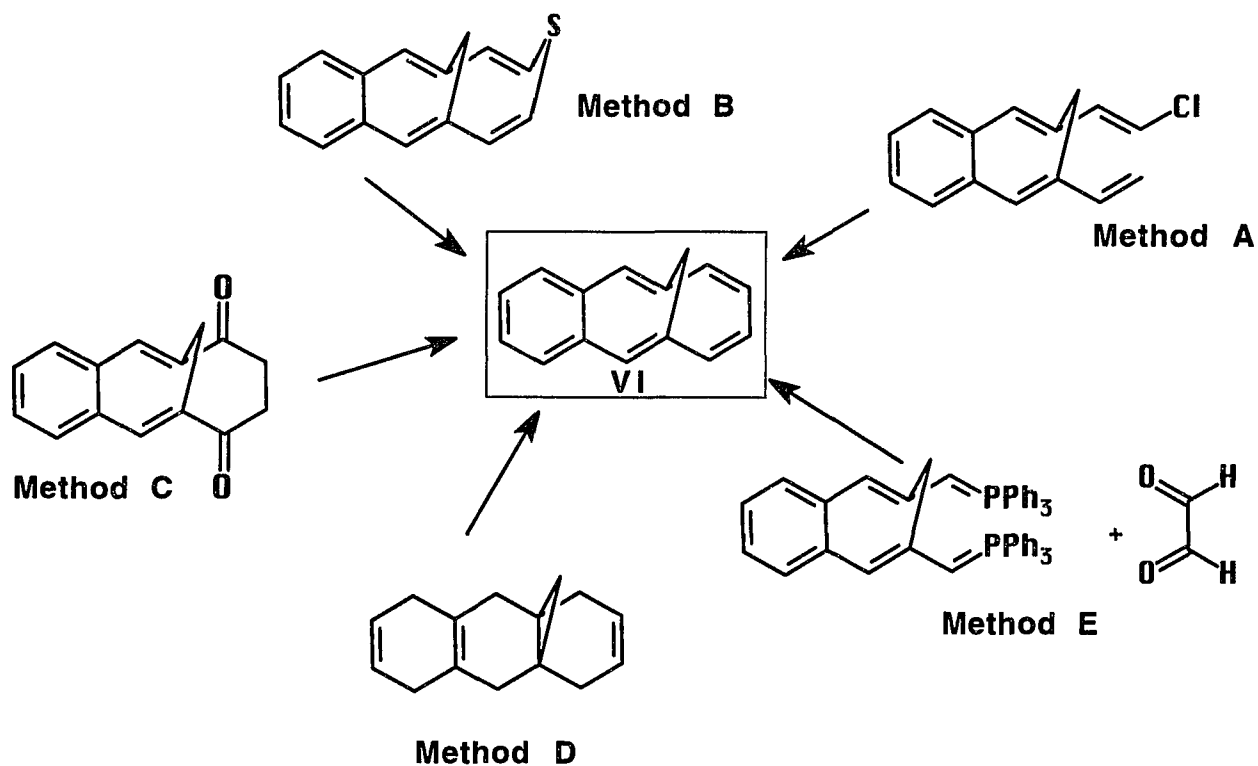
Similarly, 3,4-monobenze[10]annulene, **VI**, is expected to favor the aromatic, non-norcaradienic form **VI-a**.



No synthesis of parent **VI** has been reported in the literature. Only monosubstituted-bridge derivatives of **VI** are known¹³⁰.



Several methods for the synthesis of **VI** were developed.

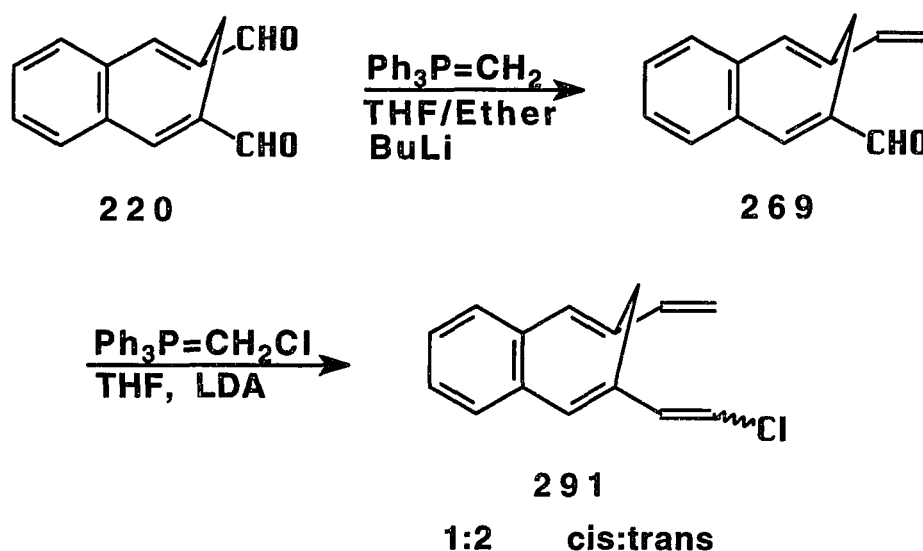


Scheme 49: Synthetic methods towards benzo-1,6-methano[10]annulene, **VI**

Methods A-D are described next. Currently, the approach towards **VI** via method E is being examined in our lab.

METHOD A

Successive Wittig olefination of **220** with 1 equivalent of methylchlorotriphenyl phosphonium chloride and 1 equivalent of methyltriphenyl phosphonium bromide yielded the cis / trans mixture of chlorovinyl-vinyl cycloheptatriene, **291**, in 11.1% yield, overall from **220**. The isomeric mixture of **291** was determined from GC-MS and ^1H NMR to be 1:2 cis:trans.

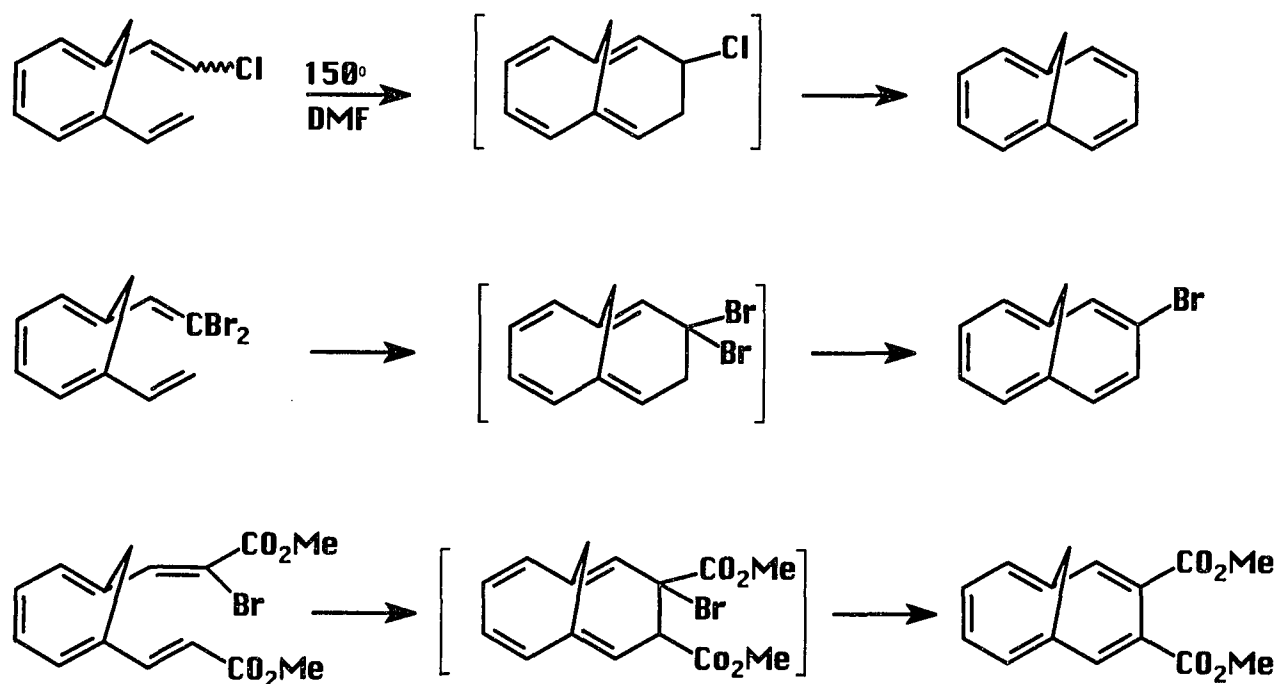


Scheme 50: Synthesis of 291

The oily mixture of **291** was treated without separation in refluxing DMF for 12 hours. No detectable dehydrochlorination product was present. Starting material was completely recovered. Treatment of

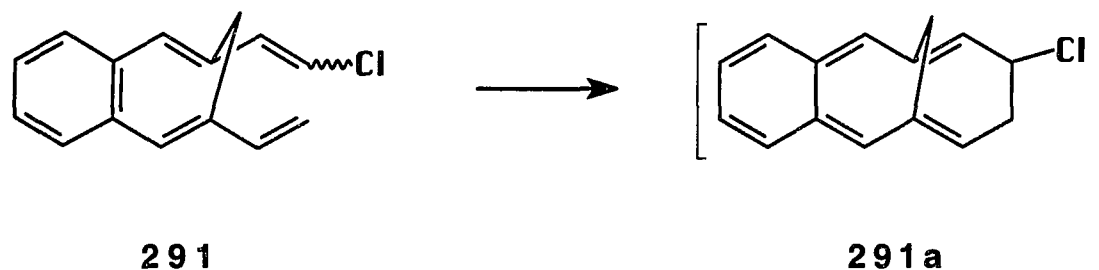
145 in N,N-dimethylaniline at 194°C for 12 hours failed to afford any **VI**.

These results, not surprisingly, are in complete agreement with our expectations, but not in agreement with Vogel's reports¹³¹. Vogel was successfully able to achieve dehydrohalogenation in the non-benzo compounds and yield the corresponding methano [10]annulene (Scheme 51.)



Scheme 51: Thermal dehydrohalogenation cyclizations

Benzannulation in **291** increases the barrier for the formation of o-quinoid methine of type **291a** which lies at a much higher energy state than the corresponding o-quinoid of the non-annelated one.



METHOD B

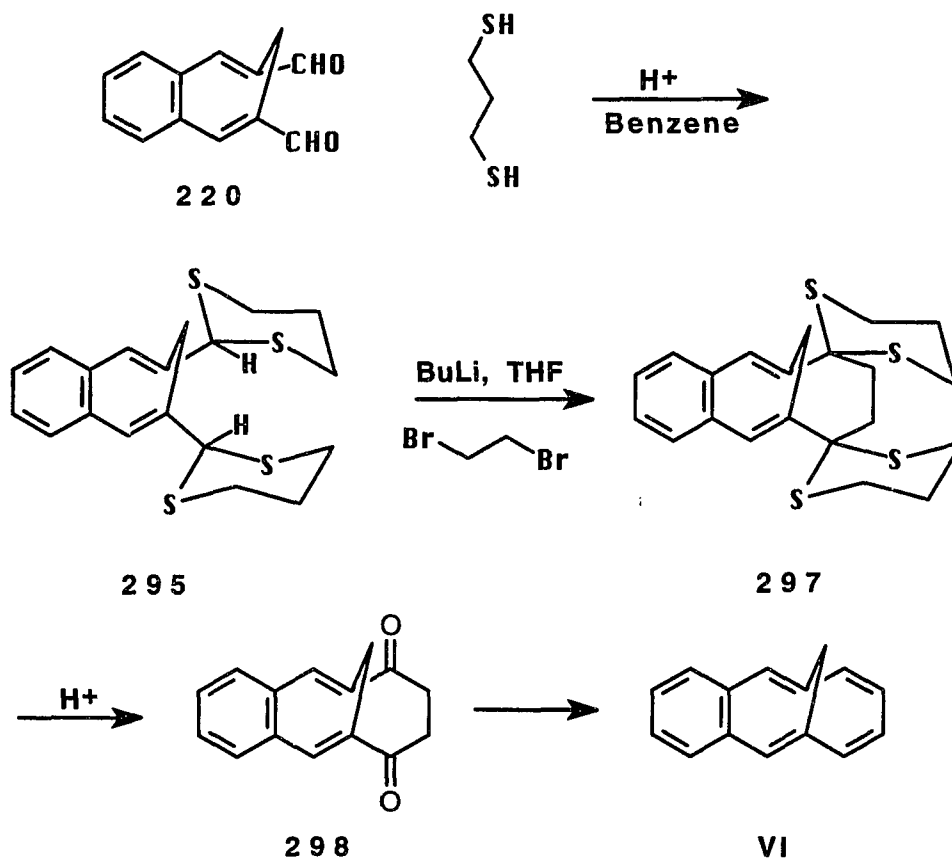
Attempts to generate **VI** via thiopin **IV** were discussed earlier. It had seemed that with Thiopin **IV** available the conversion would be a matter of no great deal. As it turned out, however, the high stability of **IV** made it cumbersome.

When thiopin **IV** was mixed with 2 equivalents of triphenylphosphine and heated neat at 250° for 6 hours, sulfur extrusion was achieved only partially as observed by the formation of triphenylphosphine sulfide and 3,4-benz-1,6-methano [10]annulene, **VI**, by GC-MS.

Attempts to separate **VI** failed.

METHOD C

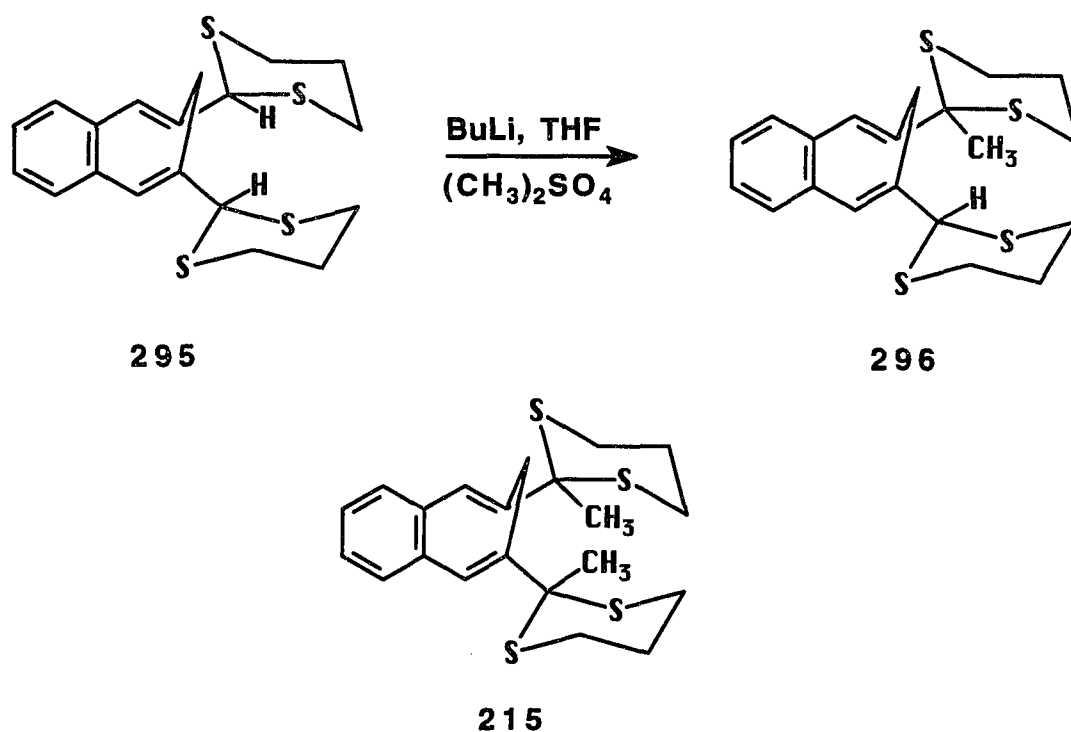
Our third approach towards **VI** involved the conversion of aldehyde **220** to the bis-dithiane **295**, followed by double alkylation with dibromoethane to the cyclic **297**.



Scheme 52: 1,3-dithiane approach towards **VI**.

1,3-Dithiane, **295**, was prepared in high yield from dialdehyde **220** and 1,3-propanedithiol in benzene. To investigate the reactivity of this new bis-dithiane system and with a possible competing elimination process, we attempted methylation with dimethylsulfate

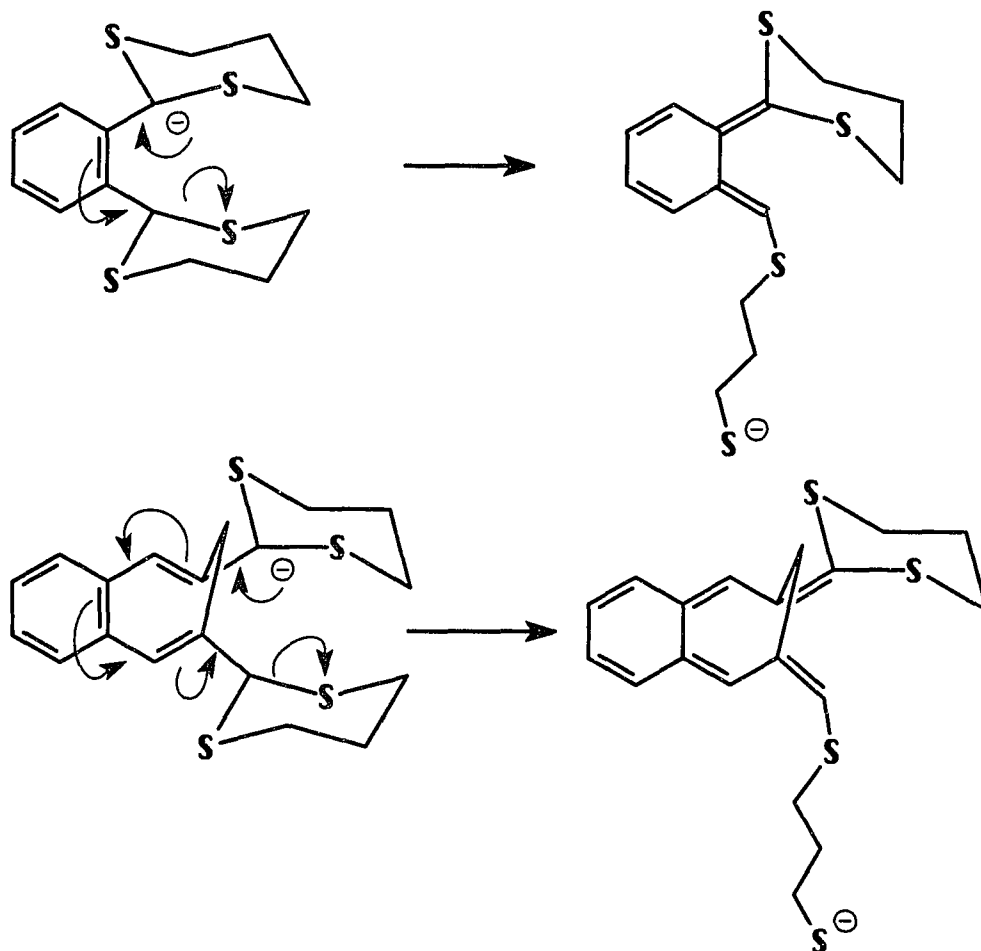
in the presence of excess BuLi. Thus, treatment of dithiane **295** with butyllithium in THF, followed by addition of excess methylating agent, yielded the mono- and bis-methylated thioacetals **296** and **215** in 26.5 and 37.5 % yields, respectively, as shown in Scheme 53 below.



Scheme 53: Methylation of bis-dithiane **295**

The successful methylation is of some importance. When the dithiane derived from o-phthalaldehyde is treated under similar conditions, methylation does not occur due to competing elimination via o-quinoid formation as shown below. Similar process in the dithiane derived from m-phthalaldehyde is not observed and methylation is

possible. In **295**, it seems, such elimination process is diminished and the localization of the charges is achieved.

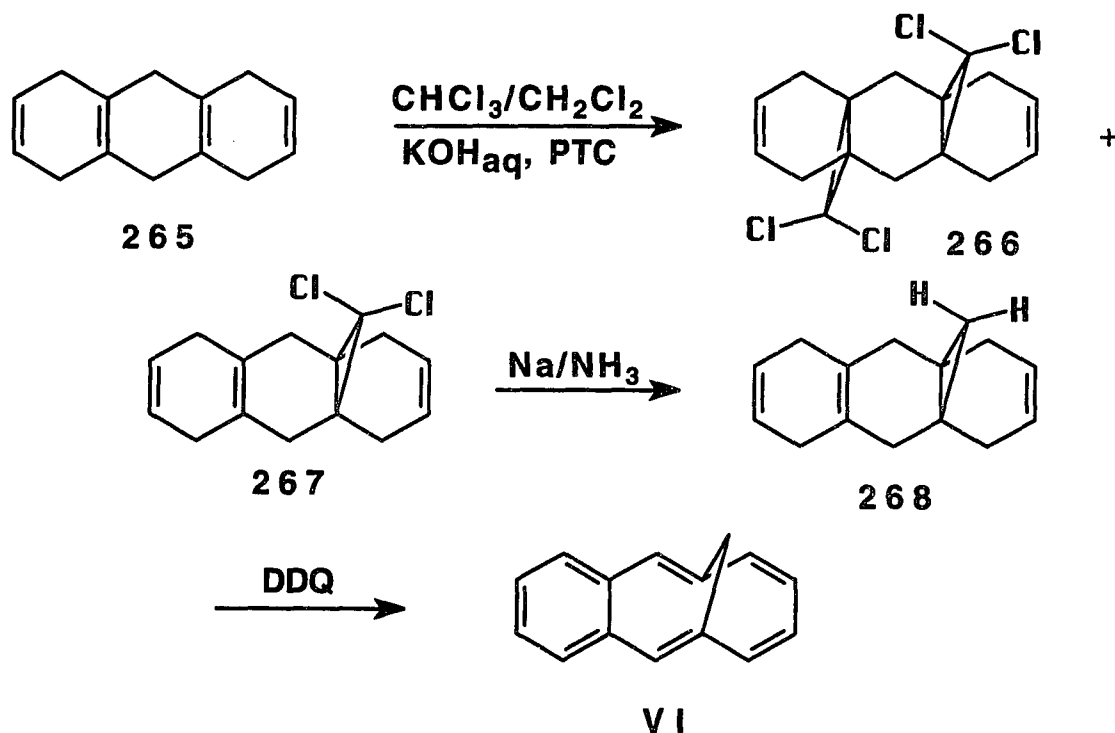


The ^1H NMR of mono-methyl **296** indicates “flipping” -type inversion of the bridge CH_2 group through the cavity created by the two 1,3-dithiane ring structures. In **215**, however, such inversion is not possible due to increased crowding peripheral and increased repulsion of the dithiane moieties with the peripheral protons. This fixation results in the splitting patterns observed for the bridge protons of **215** (see earlier discussion about **215** in section 2.3.1).

With these successful results in hand we proceeded to react **295** with 1,2-dibromoethane under basic conditions. Identical repetition of the successful procedure, however, did not result in the formation of cyclic **297**. With 1,2-dibromoethane, the system is prone to oxidation and polymerization. Products of oxidation or dimerizations were not detected in the reaction mixture.

METHOD D

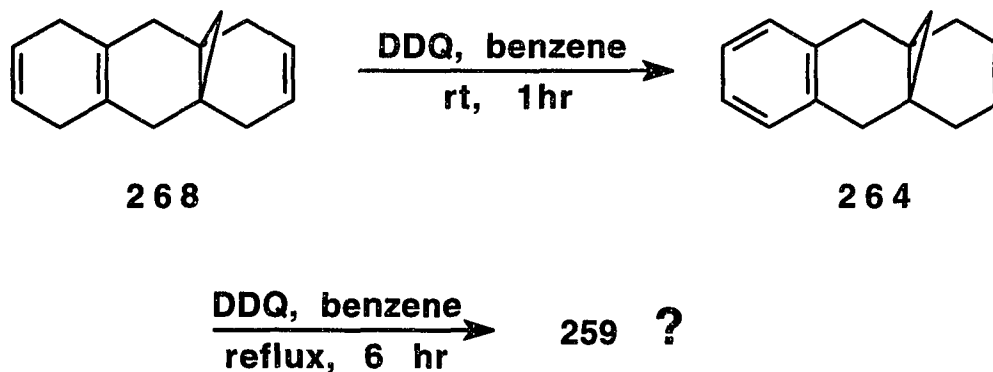
This method utilizes Vogel's approach towards bismethano [14]annulene. Treatment of hexahydroanthracene, **265**, under phase transfer conditions with chloroform, results in the formation of products **266** and **267** in variable yields depending on the relative amounts used. The two solids are obtained as an inseparable mixture. Best results are obtained when 1.2 equivalents of chloroform are used and when the reaction is stirred over night. The resulting solid, a 1:2 mixture of **266:267** is treated with sodium in liquid ammonia or with metallic lithium in a THF/t-BuOH solution resulting in the separation of **268** as the major component.



Scheme 54: Fourth approach towards **VI**

The mixture containing mostly **268** was treated with excess DDQ in benzene at room temperature. TLC indicated the disappearance of starting material within the first hour and so workup and chromatography yielded the benz-tetrahydro **264** as a colorless oil in quantitative yield. When **264** was heated in benzene, in the presence of DDQ for 6 hours, a colorless oil was obtained in low yield. The oil whose structure was not determined, exhibits a very unique ^1H NMR spectrum which consists of a pair of doublet of

triplets at -0.03 and -0.75 ppm. These very high field resonances of ^1H each are not clear and the structure is not determined.



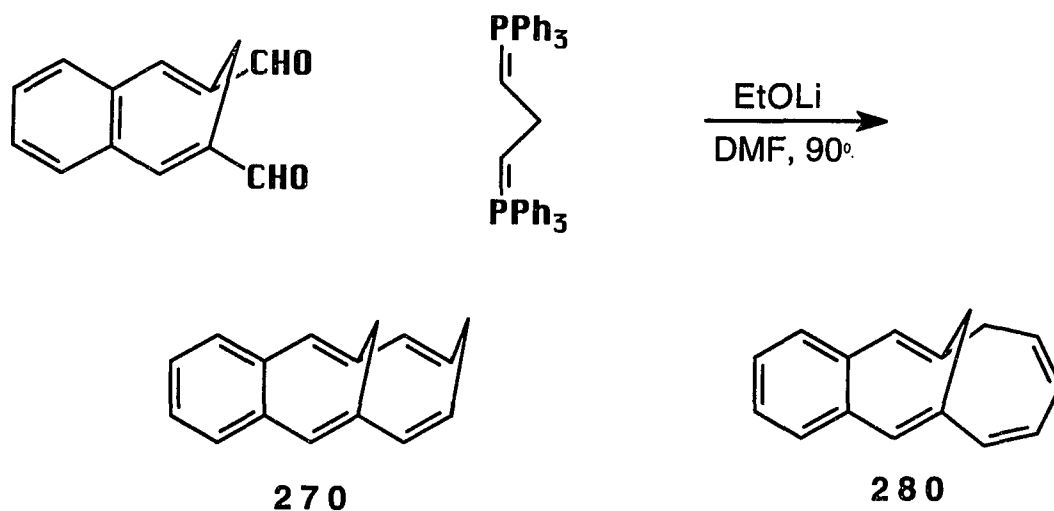
Scheme 55: DDQ oxidation of 268.

Benzmethano[10]annulene **VI** was present in the oxidation mixture in only very minute amounts. Its presence was confirmed by GC-MS. With the unexpected difficulties arising from the synthesis of **VI** we terminated further attempts for the moment. Other methods of synthesis are being investigated by other members of our group.

2.5.2 SYNTHESIS AND INVESTIGATIONS OF 9-BENZBICYCLO[5.4.1] DODECA-2,5,7,9,11-PENTAENE, 270

The structural similarities between **270** and thiepin **IV** are great. Yet, the extent of ring current in hydrocarbon **270** is expected to be smaller. With the methylene group being unable to support conjugation, paramagnetic ring current, as observed in **IV** is not expected.

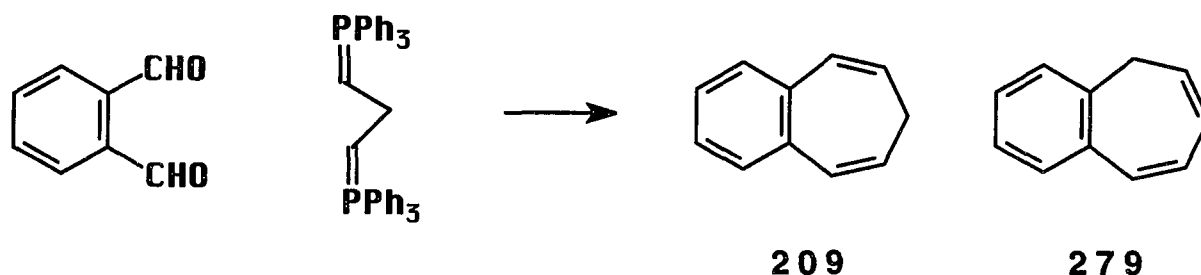
The Wittig addition of trimethylene-1,3-(triphenyl phosphonium) bromide¹³² to dialdehyde **220** in DMF (EtOLi, 90°) yielded two products which were identified as **270** and its isomer 9-benzbicyclo [5.4.1]dodeca-3,5,7,9,11-pentaene, **280** in a 1.2:1 ratio, respectively.



Scheme 56: Synthesis of bis-methano **270** and **280**.

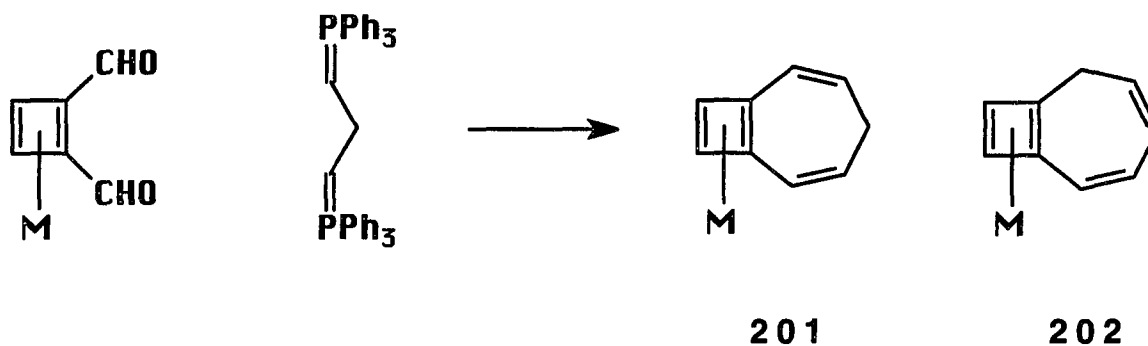
When the addition was carried out at 50° and under the same conditions as before, **270** was separated as the sole product in 24.9% yield.

The isomerization of such systems is reported only twice in the literature. Both 2,3- and 4,5-benzcycloheptatrienes were obtained¹³³ in an undetermined ratio from the condensation of o-phthalaldehyde and the identical phosphonium salt. Wittig's work indicated that the cross conjugated triene, **209**, is less stable relative to **279** because of reduced conjugation.

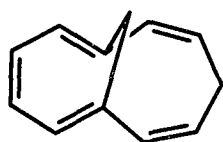
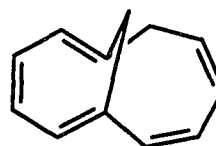


Scheme 57: Synthesis of Wittig's benzcycloheptatrienes

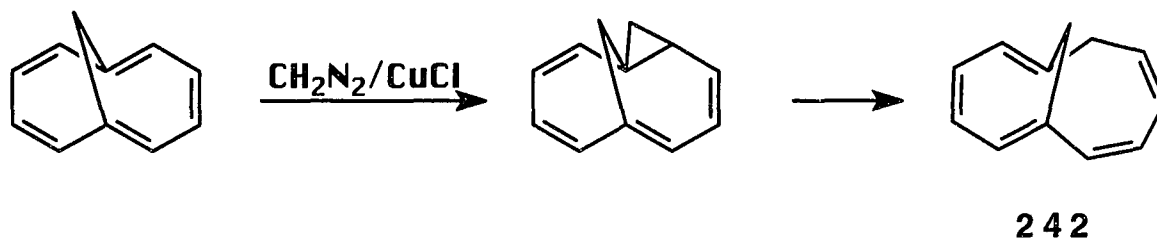
The second report by Wege¹³⁴ describes the addition of the same phosphonium salt to a butadiene dialdehyde-metal complex to yield variable mixtures of the two isomers **201**, **202** in 23% yield combined.



In the synthesis of **243** no isomerization product, **242**, was reported in the "mixture of products." It is quite reasonable to assume that such product was indeed present in the crude mixture, yet was removed by crystallization (**243** is a solid, **242** is an oil.)

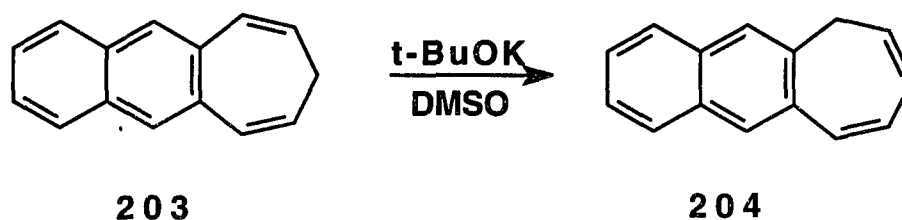
**243****242**

Isomer **242**, however, was synthesized directly from methano [10]annulene via the reaction of diazomethane¹³⁵:

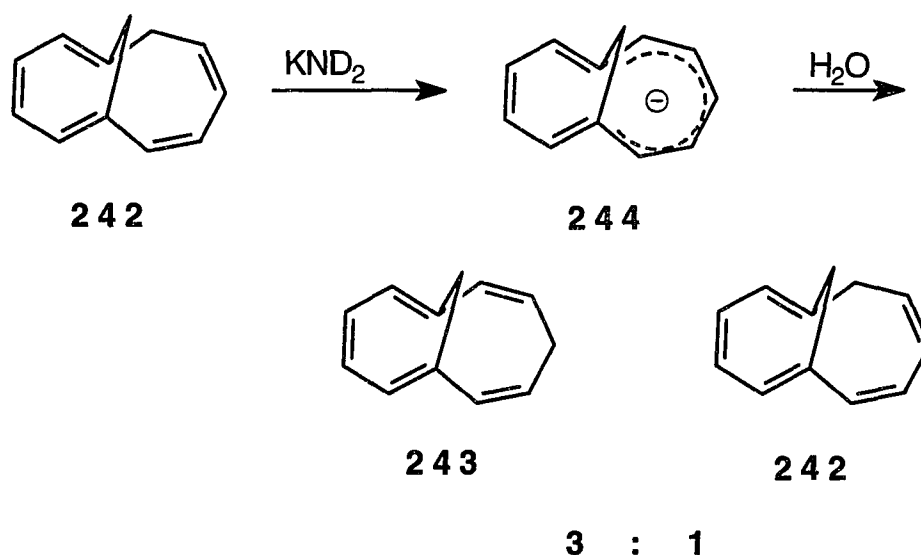


The isomerization path responsible for the formation of **243** in the product mixture is not clear. Nevertheless, it is thermally dependent. Wittig reported that double bond isomerization could be suppressed when the bis ylide is prepared with sodium amide in liquid ammonia and the addition is achieved in ether or THF. We, as was earlier stated, were able to diminish the isomerization by means of temperature control.

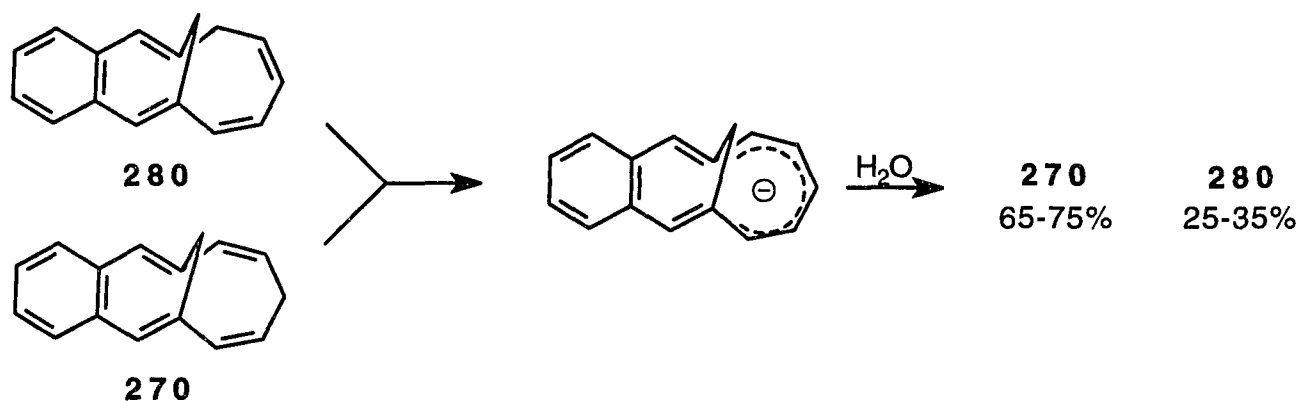
Based on prior reports, we believed that **243**, where larger conjugation exists, should be the thermodynamically favored isomer. Such was the case with **204** and **203** and with **283** and **279** as described earlier. When naphthocycloheptatriene¹³⁶, **203**, was treated with *t*-BuOK in DMSO isomer **204** was obtained as the end product.



However, when the bicyclo [5.4.1]dodecapentaenyl anion¹³⁷, **244**, obtained by KND_2 treatment of **242**, was quenched with water a 3:1 mixture of **243** and **242** was obtained, respectively.



Similarly, treating of the oil **280** with $t\text{-BuOK}$ in $t\text{-BuOH}$ for 3 hours, yielded an equilibrium mixture of **280/270** of 35%/65% in favor of **270**. Purification of the mixture and repeating of the process yielded the same composition mixture without a large observable change as judged by GC (Scheme 58.) Moreover, treating of **270** under identical conditions yielded a mixture of 75% **270** and 25% **280**.



Scheme 58: Isomerization of **270** and **280**.

^1H NMR spectra of **270** and **280** are quite different. Compound **270** exhibits well defined resonances as a symmetrical system. The H_{syn} and H_{anti} bridge protons resonate at 3.88 (dd, $J=12.1$ and 0.5 Hz) and 1.20 (d, $J=12.1$ Hz), respectively. In addition, two resonances at 6.42 (dd, $J=11.5$ and 2.6 Hz) and 6.64 (s) are easily assigned as H_2 and H_{11} respectively. The remainder of the spectrum was not easily assigned by 1D NMR alone. 2D COSY and NOESY experiments allowed complete assignment of the complex patterns.

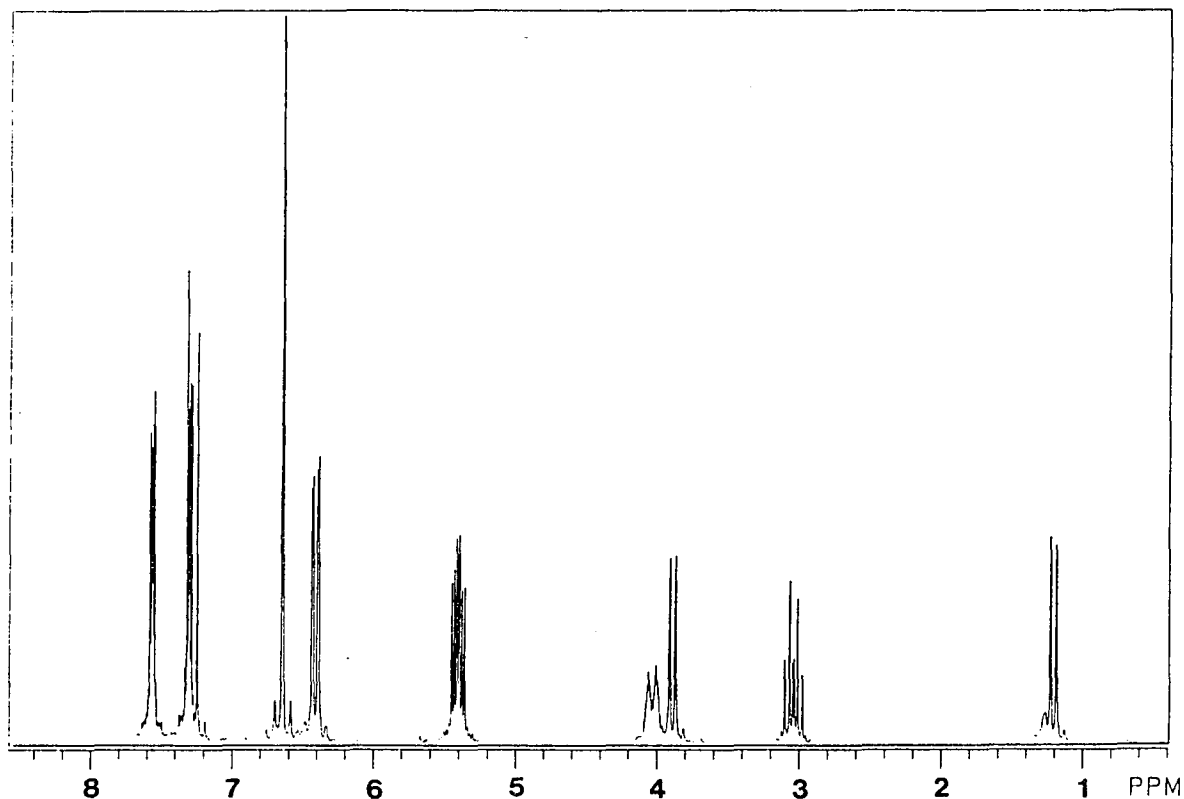


Figure 36: ^1H NMR of **270**

COSY showed connectivity between the multiplets at 3.05 and broad pattern at 4.05 ppm. Further connectivity was observed between 3.05 and 5.39 ppm. The resonance at 5.39 ppm in turn, exhibited connectivity with H_2 at 6.42 ppm. That allowed the assignment of the pattern at 5.39 ppm as H_3 and the broad doublet at 4.05 ppm along with the doublet of triplets at 3.05 ppm as the H_{4a} and H_{4b} , respectively.

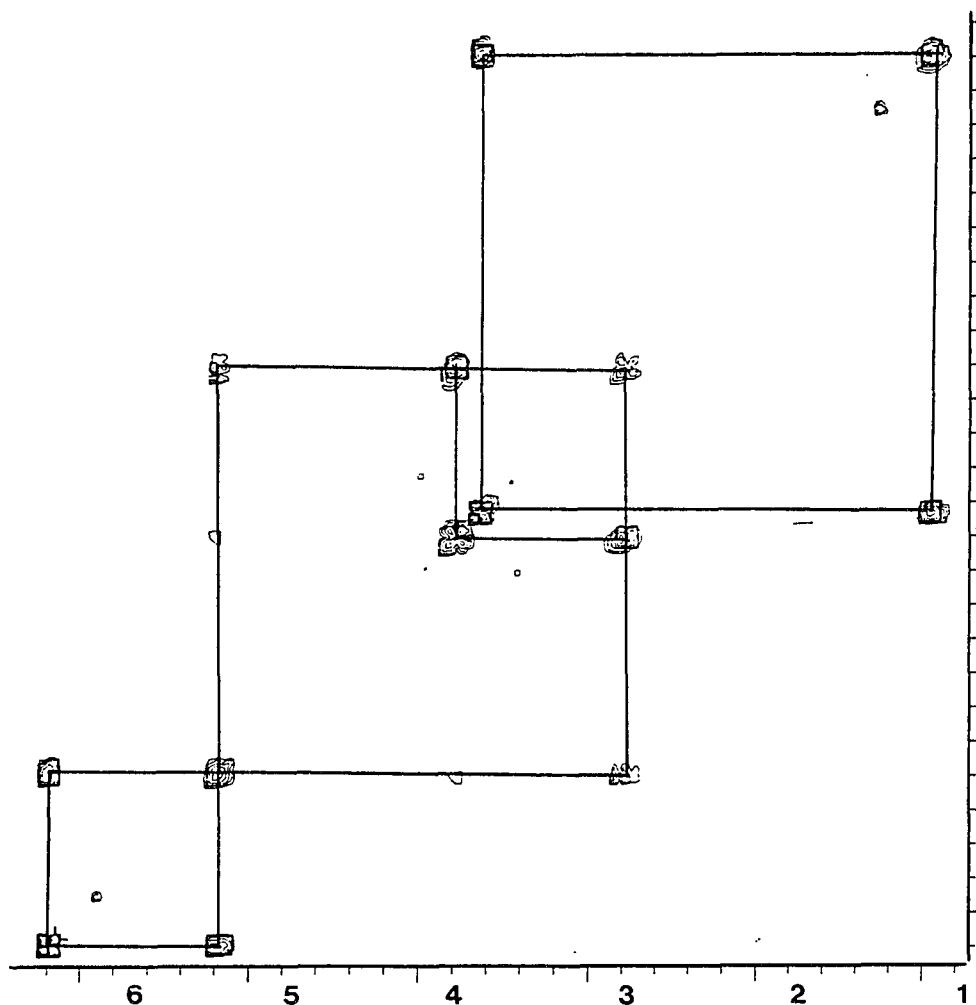


Figure 37: 2D-COSY spectrum of **270**

NOE experiment showed a 5% NOE between H_{syn} at 3.88 and the broad resonance at 4.05 ppm, assigned as H_{4a}, and no NOE with 3.05 ppm, H_{4b}. Thus, the assignment is complete and confirmed as shown below.

NOE	Hanti	H4a	H4b	H3
Hsyn	7%	5%		
H4a			10%	
H4b				0.2%

proton	ppm, splitting
H ₂	6.42, dd
H ₃	5.39, dt
H _{4a}	4.05, broad d
H _{4b}	3.05, dt
H ₁₁	6.64, s
H _{syn}	3.88, dd
H _{anti}	1.20, d
H _{o/m}	7.45, AA'BB'

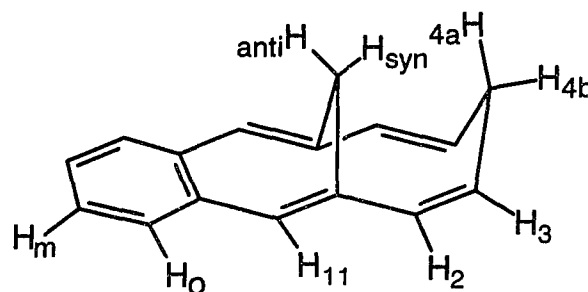


Figure 38: NOE values and final spectral assignment of **270**

The splitting patterns observed for H_{4a}, H_{4b} and H₃ are quite spectacular. H_{4b} exhibits a geminal coupling constant of 16.5 Hz with H_{4a} and a three bond coupling of 10 Hz with the cis oriented H₃. This puts the dihedral angle between the two at 0-5°. No *W* coupling with H₂ are observed.

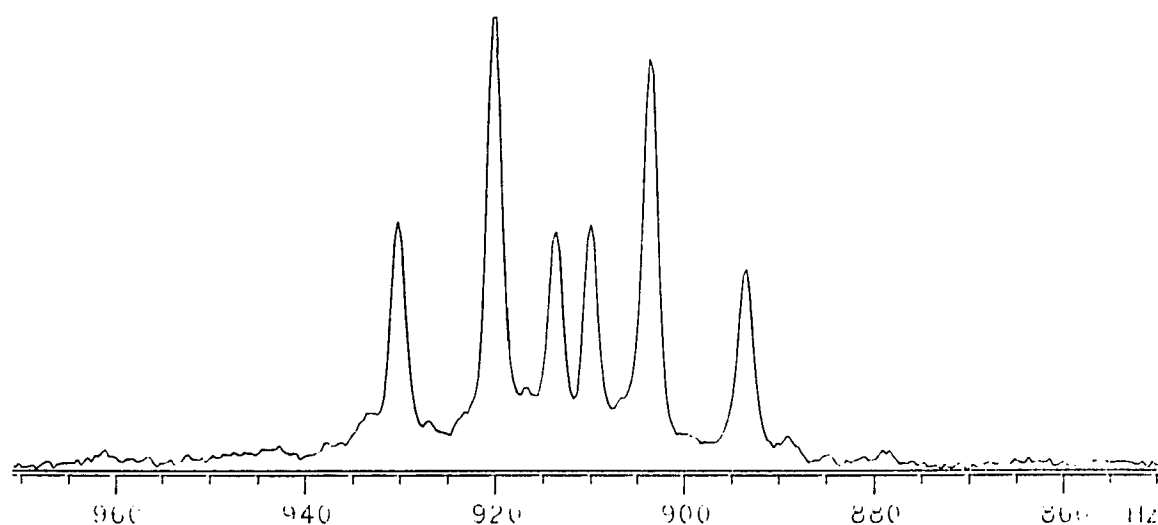


Figure 39: Splitting pattern and coupling constants for proton H_{4b}

The splitting in H_{4a} are not well resolved with the exception of a J² geminal measured at 16.5 Hz. Coupling with H₃ is expected to be smaller than that measured with H_{4b}. Such small spacings may be less than the resolving power of the NMR instrument and thus appears as an unresolved, broad multiplet. Variable temperature NMR experiment did not resolve the pattern. No changes in the spectrum

were observed as the temperature was lowered to -95° or increased to $+65^{\circ}$.

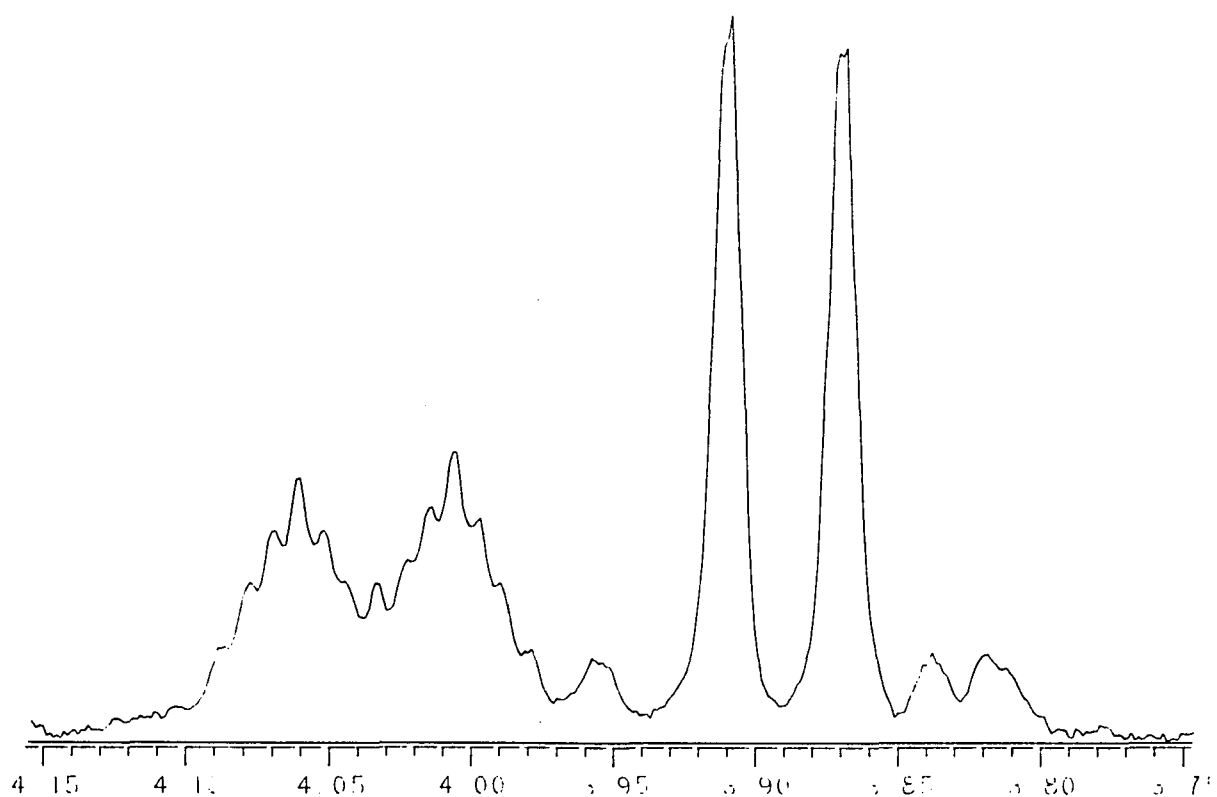


Figure 40: Splitting pattern and coupling constants for proton H_{4a}

H_3 shows too a complex with a well defined splitting pattern. Three types of splittings are observed:

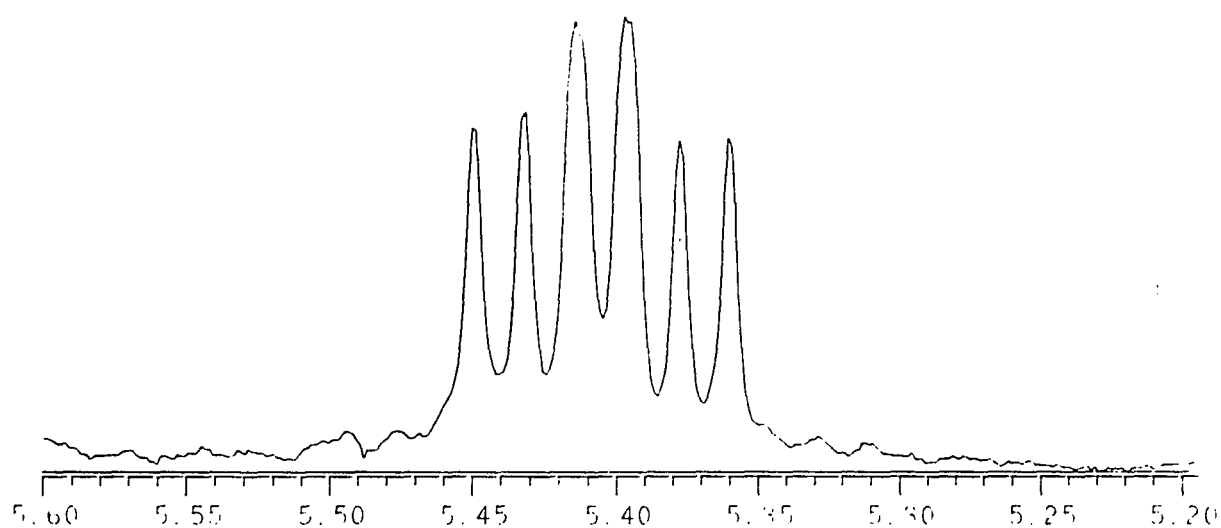


Figure 41: Splitting pattern and coupling constants for proton H₃

Vicinal coupling with H₂ and cis coupling with H_{4b} showed similar size constants of ~11.0 Hz. Trans coupling as expected was smaller.

¹H NMR of the asymmetric isomer **280** was even more complex. The interpretation of the spectrum was assisted by the use of COSY data.

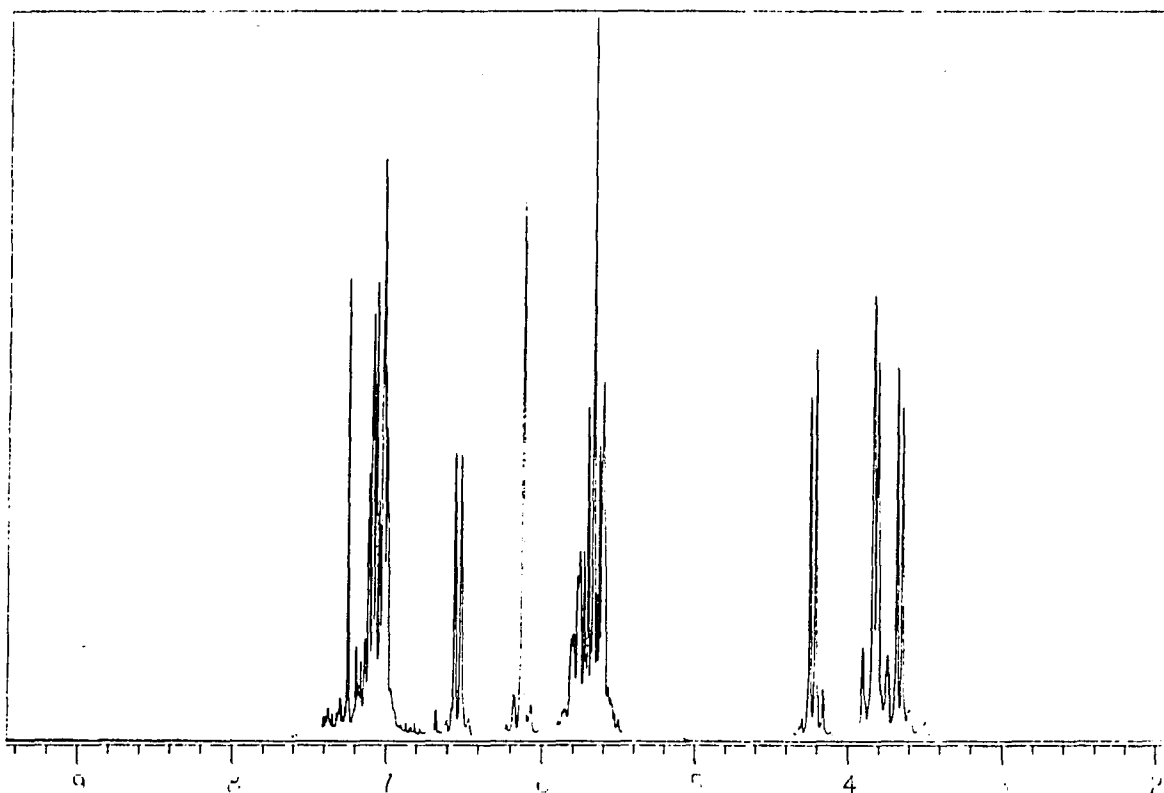


Figure 42: ^1H NMR spectrum of **280**

One obvious start point is the 1H doublet at 6.53 ppm which can be assigned to H_6 ($J^3=11.7$ Hz). Following the COSY pathway, one cross peak is observed from 5.66 ppm to 3.83 ppm, assigns the 2H doublet at 3.83 ppm as both H_α and H_β at carbon 2. H_{anti} at 3.66 ppm shows a coupling constant of $J^2=10.2$ Hz with H_{syn} at 4.22 ppm in addition to a long range coupling with both H_8 at 5.66 ppm and H_{11} at 6.11 ppm.

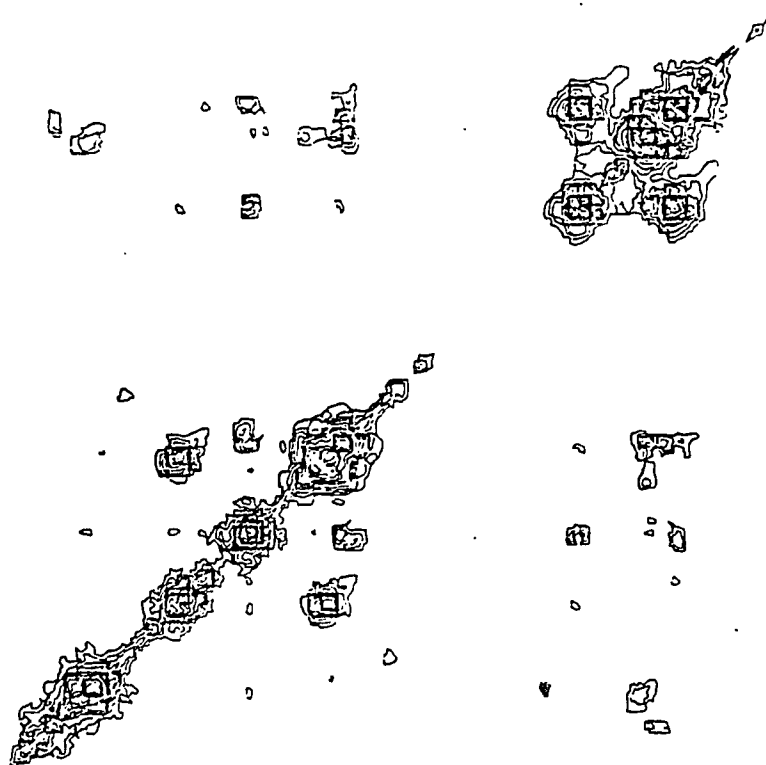


Figure 43: 2D-COSY spectrum of **280**

The assignment is summarized below and is supported by comparison with other similar systems.

proton	ppm	COSY cross peak
H2α	3.82	5.66 (m)
H2β	3.82	5.66 (m)
H3	5.66	3.82 (d)
H4	5.66	-----
H5	5.66	6.53 (d)
H6	6.53	5.66 (m)
H8	6.11	-----
H11	5.66	-----
H_{anti}	3.66	4.22 (d)
H_{syn}	4.22	3.66 (d)

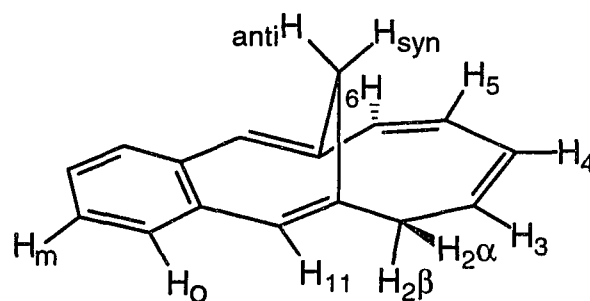


Table 17: ^1H NMR assignment of **280**

Obvious differences are present in the spectrum of **280** as compared with that of **270**, i.e. Symmetry, splitting etc. One other important difference is the chemical shift difference between H_{syn} and H_{anti} . In **270**, $\Delta\delta$ is measured at 2.68 ppm; in **280** the difference is only 0.56 ppm. This large difference between both $\Delta\delta$'s is in agreement with steric compression between the two methano bridges that exists in **270** but not in **280**.

Winstein has reported¹³⁸, based on several observations made in connection with several cage-molecules, that through-space interaction between closely spaced hydrogens was responsible for large chemical shifts observed between geminal pairs of protons. On this basis, the shielding effect on H_{anti} in **270** parallels the deshielding effect on H_{syn} . A possible explanation is the shifting of the bonding electrons of H_{syn} towards H_{anti} due to proximity of H_{syn} to the bonding pair of H_{4a} . While the effect on H_{anti} is large, there is no observable effect on H_{4b} .

Large $\Delta\delta$ s were also observed in Thiepin **IV** (3.74 ppm), its oxides, **260** (1.70 ppm) and **261** (3.08 ppm) and in syn-bismethano [14]annulene, **syn-247** (2.10 ppm). In thiepin **IV** the large $\Delta\delta$ is evidently due to the sulfur field and paratropicity as well.

It is interesting to note that all $\Delta\delta$ s are found to be greater than 1 ppm which agrees with Winstein's observations. While the chemical shift differences are influenced by several effects, the coupling constants in the systems mentioned above remain at around 12 Hz or at about 14 Hz for thiepin oxides **260-261**.

Infra red spectrum of **270** exhibits two C=C bands at 1580 and 1610 cm^{-1} . Two strong methylene absorptions are at 1465 and 1484 cm^{-1} . In **280**, three C=C bands are present at 1607, 1623, and 1639 cm^{-1} . The methylene absorptions are weaker and are found at 1453 and 1480 cm^{-1} .

X-ray analysis of **270** showed the molecule to exist in a syn conformation as expected and was indicated by NMR studies. The distance between the two methano bridges was measured at 3.004Å (C₁₂-C₄). This short distance clearly supports the compression observed between the bridge hydrogens. This, in turn, is supported by the observation that the CH₂ group (C₁₂) leans away from the benzene ring and towards the proximal rim CH₂ (C₄). The distance between H_{anti} and the center of the bond between C₉ and C₁₀ is measured at 2.540Å and at 2.782Å between the same bond and C₁₂. The bridghead carbons H₁ and H₇ are measured to be 2.340Å away from each other, while the distance between the bridghead rim carbons, H₃ and H₅, is measured at 2.560Å. These distances are clearly too large to support any level of homoconjugation. Similar to thiepin dioxide **261**, the system is determined non planar with well defined alternating single and double bonds.

The rigidity of the structure observed in the solid form is maintained in solution as observed from VT experiments. Between 65° and -95° no dependance of the geometry was observed. Splitting patterns remained identical to both directions of the ambient run.

Figure 44: ORTEP drawing of 270

2.5.3 PREPARATION OF BENZBICYCLO [5.4.1] DODECAPENTAENYLUM CATION, 290 -- AN AROMATIC BRIDGED 10π CATION

The tropylium cation, **205**, is one of the most studied diamagnetic, seven membered ring systems. Similarly, the bicyclo [5.4.1] dodecapentaenylum cation, **245**¹³⁹, and its higher homologue **206**¹⁴⁰ show a 10π and a 14π induced diamagnetic ring currents as compared with their neutral precursors.

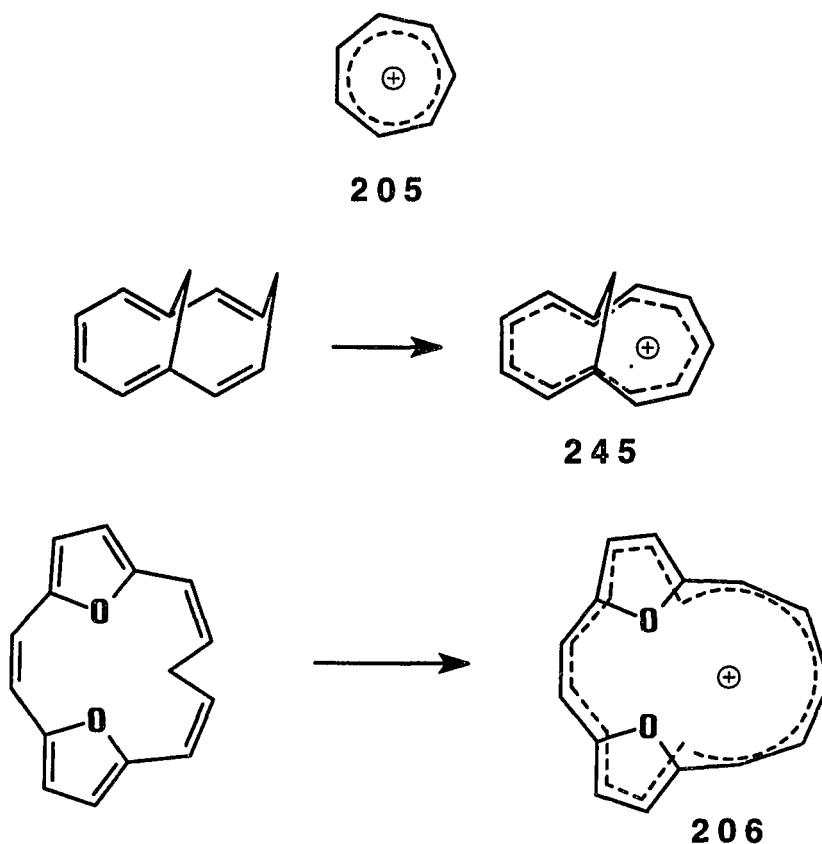
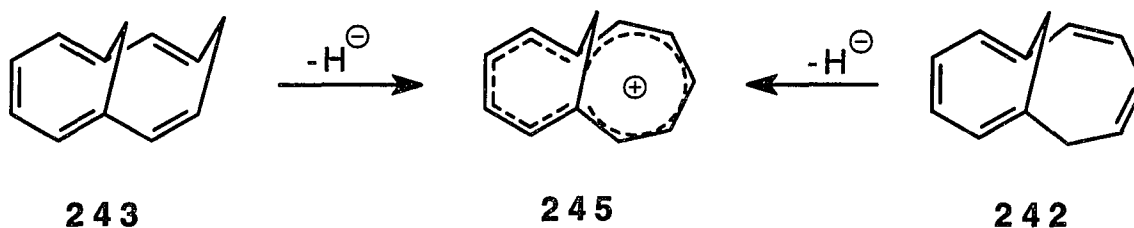
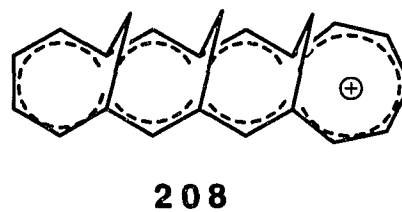
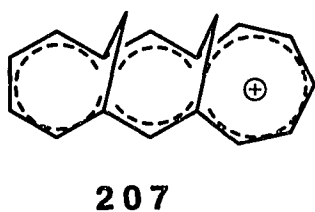


Figure 45: Aromatic 6π , 10π and 14π charged annulenes

Bicyclo [5.4.1] dodecapentaenylium cation **245** was prepared by Vogel¹⁴¹ from the two isomers of bicyclo [5.4.1] dodecapetaene, **243** and **242**.



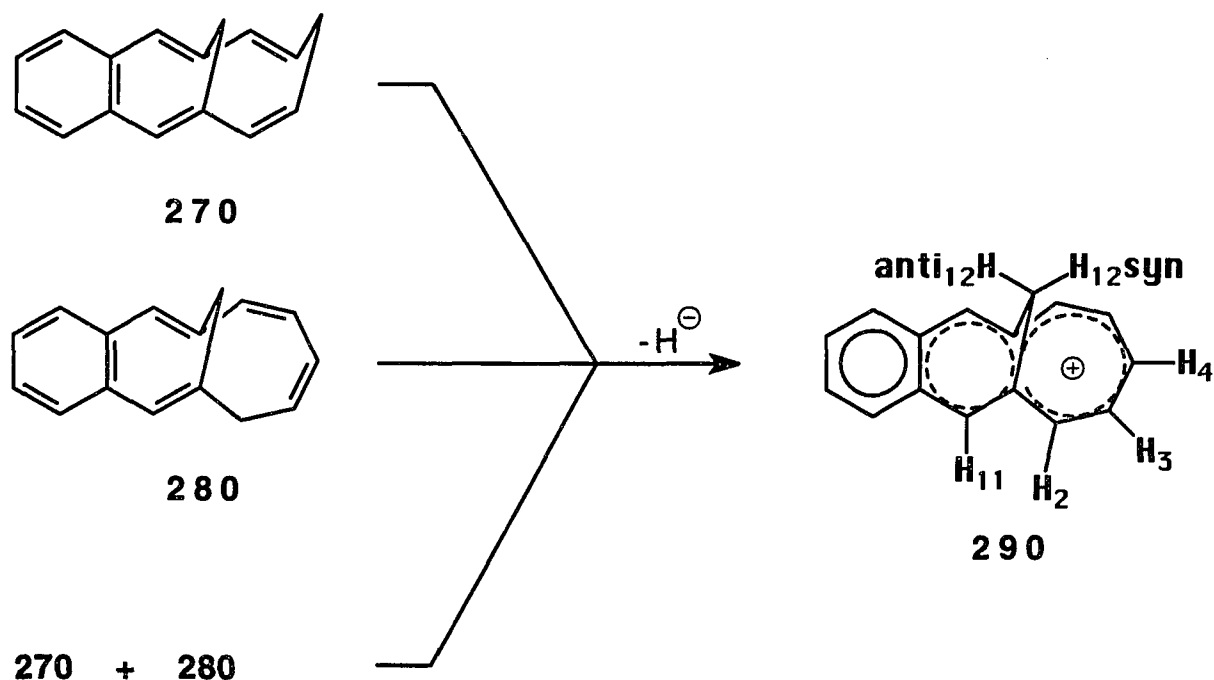
Cation **245** exhibited a definite diamagnetic ring current, and was considered as a perturbed [11]annulanium cation. X-ray analysis of **245** as its hexafluorophosphate salt indicated bond lengths at the 6-carbon segment to be equal to that in the neutral methano [10]annulenes. Other methano bridged systems such as the tetracyclic 18π annulene, **207**, and the pentacyclic **208**¹⁴², were obtained analogously to **245** through a hydride abstraction from the corresponding cyclopolyolefin. The aromatic characters have, as before, been inferred from the ^1H NMR spectra.



4:7,10:13-dioxido-cyclopentadecaheptaenylum salt, **206**, was synthesized by Ogawa by hydride abstraction. The NMR of **206** was surprisingly simple. Downfield shifts of all the periphery hydrogens to 9.5-10.0 ppm (a 6.5 ppm downfield shift relative to the neutral hydrocarbons) confirmed the existence of an induced diamagnetic ring current in the cation.

The formation of the aromatic cations was achieved on treatment of the hydrocarbon precursor with agents such as triphenylmethyl tetrafluoroborate or triphenylmethyl hexafluorophosphate, in solvents such as dichloromethane, acetic anhydride or acetonitrile.

Thus, treatment of 9-benzobicyclo [5.4.1] dodeca-2,5,7,9,11-pentaene, **270**, with equimolar tritylfluoroborate in methylene chloride was attempted. The tetrafluoroborate salt **290**, was isolated in 22.2% as a green-blue solid which melts above 250°. Similarly, hydride abstraction from 9-benzobicyclo [5.4.1] dodeca-3,5,7,9,11-pentaene, **280**, or from the mixture of **270** and **280**, under identical conditions yielded **290** as well. Attempts to generate the salt in acetic anhydride failed.



Scheme 59: Synthesis of **290** via hydride abstraction from **270/280**

^1H NMR of **290** convincingly indicate the presence of a diamagnetic ring current. All ring protons show a downfield shift of 1.80 to 5.87 ppm with the bridge protons showing a 2.40 and 5.08 ppm upfield shift. The chemical shifts for **290** and its precursor **270** are summarized next in Table 18. Note the coincidental overlap of the bridge protons resonating as a singlet of 2H intensity at -1.20 ppm.

	270	290	Δppm
H2	6.42 ppm	9.60 ppm	-3.18 ppm
H3	5.39	8.54	-3.15
H4	4.05, 3.05	8.92	-4.87, -5.87
H11	6.64	9.38	-2.74
H12	3.88, 1.20	-1.20	+5.08, +2.40
Ar	7.31, 7.58	8.94, 9.38	-2.07, -1.80

Table 18: ^1H NMR resonances for **290** as compared with **270**
($\Delta\text{ppm}<0$ indicate downfield shifts)

The ring protons resonate between 8-10 ppm and show a well defined and resolved pattern (Scheme 57). H_4 , formerly part of the rim CH_2 group, resonates as a triplet at 8.92 ppm ($J=11.4\text{Hz}$) and shows the largest chemical shift difference. H_2 and H_3 with similar chemical shift differences resonate as a doublet at 9.60 ppm ($J=9.9\text{Hz}$) and as a triplet at 8.54 ppm ($J=10.8\text{Hz}$), respectively. H_{11} at 9.38 along with the benzene ring protons show the smallest chemical shift differences.

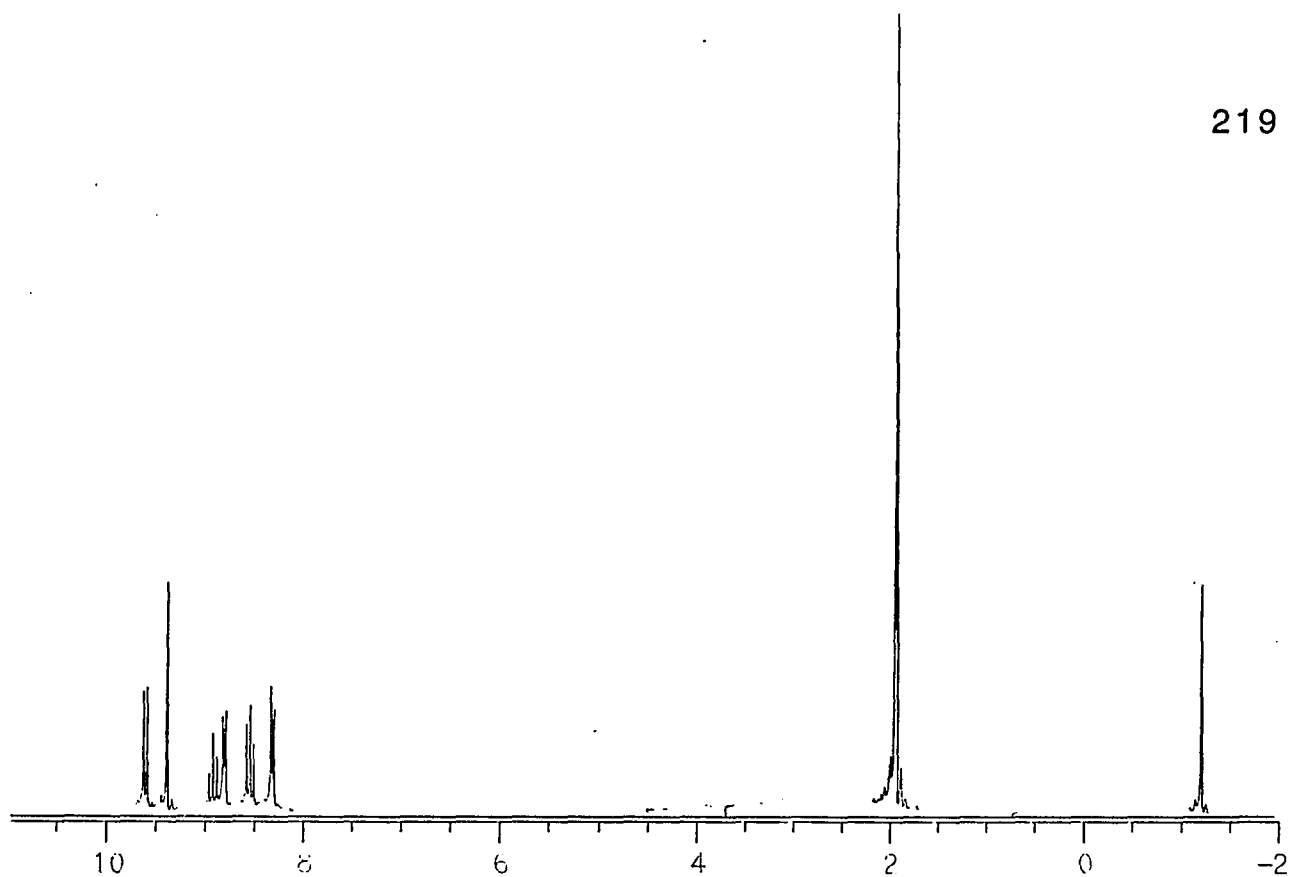


Figure 46: ^1H NMR of 290 in CD_3CN

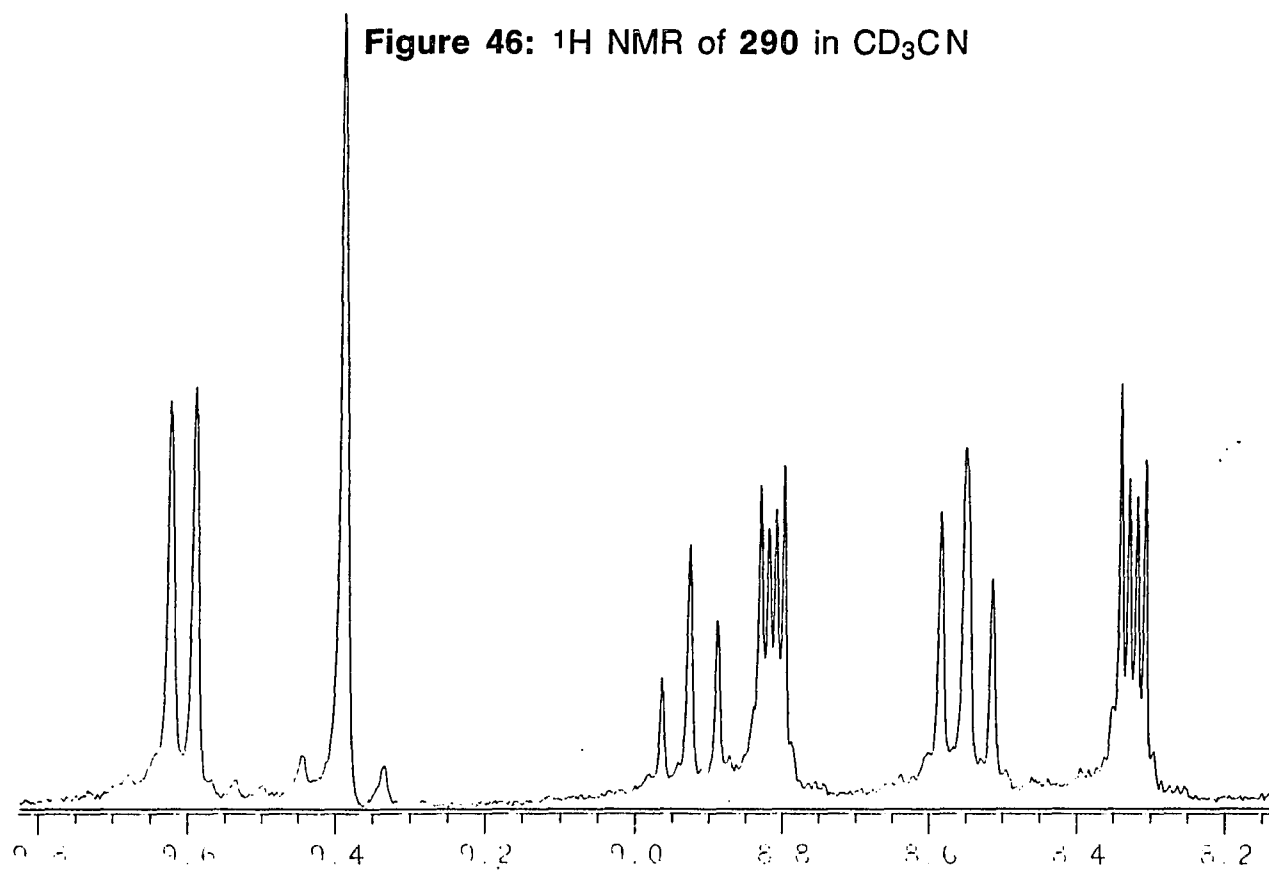


Figure 47: Expansion of aromatic region in the ^1H NMR of 290

Comparison with Vogel's bridged 10π annulene, **245**, reveals that benzannelation does not alter the ring current present. Similar chemical shift differences for all ring protons are observed in **245**. The bridge protons, however, resonate as an AB system centered at -1.0 ppm with $H_{12\text{anti}}$ at -0.3 ppm. This observation is of some importance.

Earlier observations in thiepin **IV** and **270**, indicated a small downfield shift of $H_{12\text{anti}}$, lying over the aromatic benzene ring, as compared with the nonbenzannelated systems **212** and **243**. This shift was attributed to a possible positioning of the examined proton above the deshielding field of the benzene ring. Compound **290** indeed confirms prediction on the basis of the observed upfield shift of $H_{12\text{anti}}$ from -0.3 ppm in the non benzannelated system, **245**, to -1.2 ppm in our benz-cation **290**.

In addition and more importantly, these observed shifts in the aromatic **290** clearly classify thiepin **IV**, pentaenes **270** and **280** as non aromatic. This is not to say, however, that ring current of different intensities are not present in such systems. Some ring current probably does exist, to the extent that it is difficult to estimate.

Moreover, it is clear from the chemical shifts of the aromatic cation, **290**, that ring geometry and bridge proton compression is responsible for large chemical shifts observed in the systems described earlier. In **290**, predicted planar, such compressions are

removed and the resonance differences are minimized (as was observed in **215**).

^{13}C NMR of the aromatic cation, **290**, does not reveal any overwhelming chemical shift differences. The carbon signal previously at 27.4ppm, corresponding to the rim CH_2 group from which a hydride was abstracted, has shifted down field. The aromatic resonances all lie between 130.5 and 167.0 ppm.

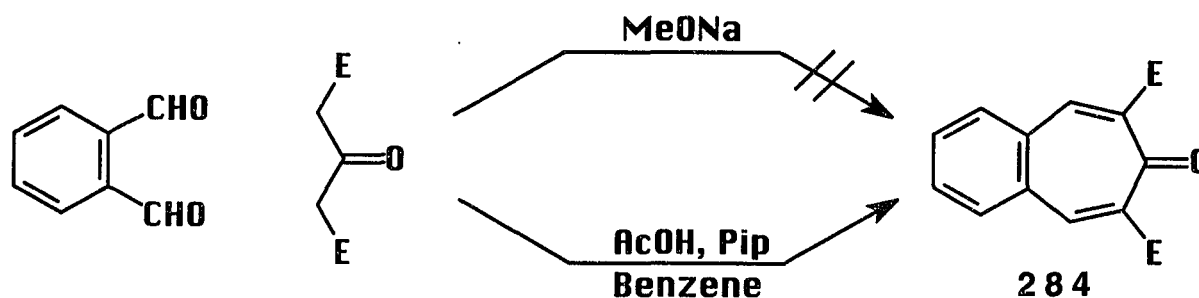
Many studies have shown that ^{13}C resonances are influenced by conformation, ring size, strain, conjugation, but to a lower extent by ring currents. A distinct 1 ppm shift in ^1H NMR which results from altered ring current, can be attributed in the corresponding ^{13}C NMR to one of many other effects, or may be ignored as unindicative.

2.5.4 SYNTHESIS AND INVESTIGATION OF HOMOTROPONES 273 AND 283.

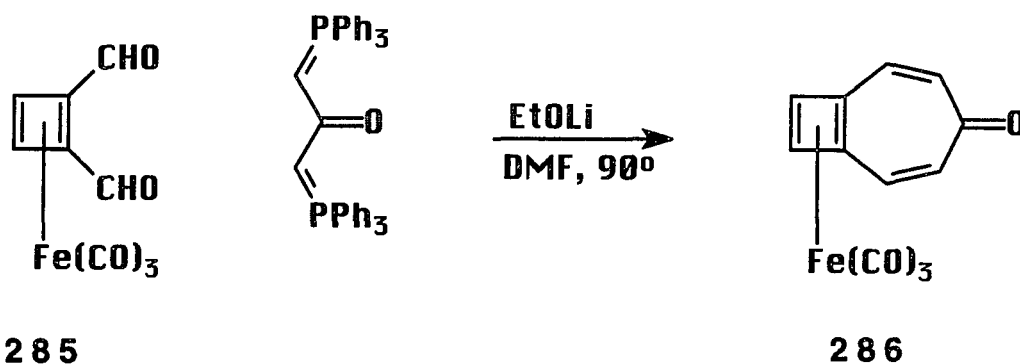
Various methods of tropone synthesis have been reported. Direct methods utilized acetone derivatives in Wittig or aldol type reactions. Cook and Forbes¹⁴³ were able to condense 3,4-furan dicarboxaldehyde with acetone in aqueous KOH solution to yield {4,5-c} furotropone in 38% yield.



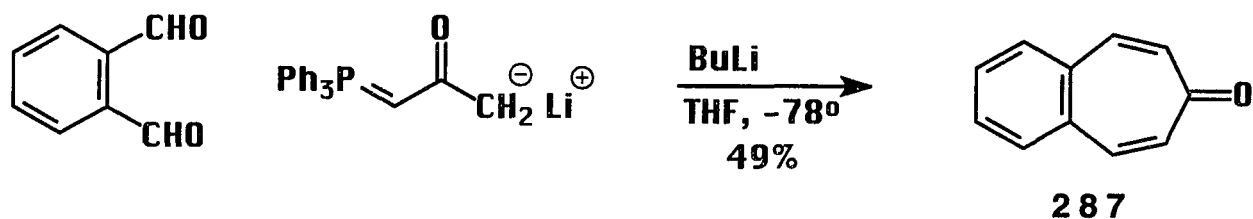
Similar condensation of o-phthalaldehyde with dimethyl acetonedicarboxylate in a basic medium failed to yield the desired keto-diester. However, use of an acetic acid-piperidine mixture in benzene yielded the condensation product 2,7-dicarbethoxy-4,5-benzotropone, **284**, in 65% yield.



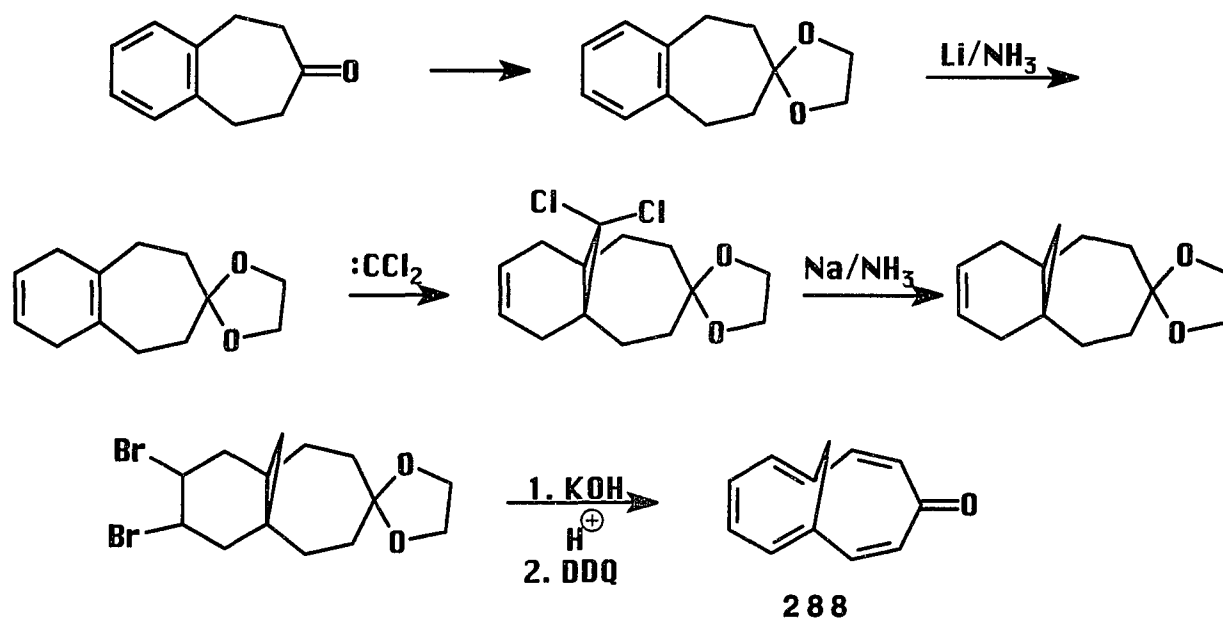
Wege and Stringer¹⁴⁴ utilized the Wittig approach towards the synthesis of a cyclobuta[d]tropone derivative, **286**. Condensation of the dialdehyde **285**, with the bis phosphonium salt generated from 1,3-dichloroacetone in the presence of lithium ethoxide in DMF at 90°, yielded the desired tropone in a low yield of 8%.



Benzcycloheptatrieneone (4,5-benzotropone), **287**, was prepared in good yields, however, by Wolfe¹⁴⁵. Lithium enolate of triphenyl phosphineacetyl methylene prepared in situ in THF allowed the condensation to proceed via a mixed aldol-intramolecular Wittig reaction.

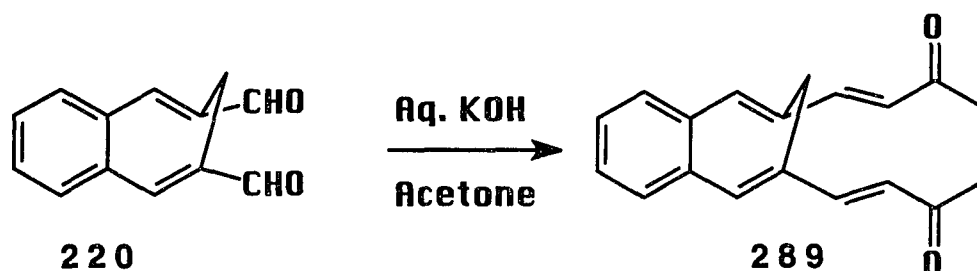


Indirect methods of synthesis have been utilized to synthesize tropone **288** as well. One such method is shown below¹⁴⁶.

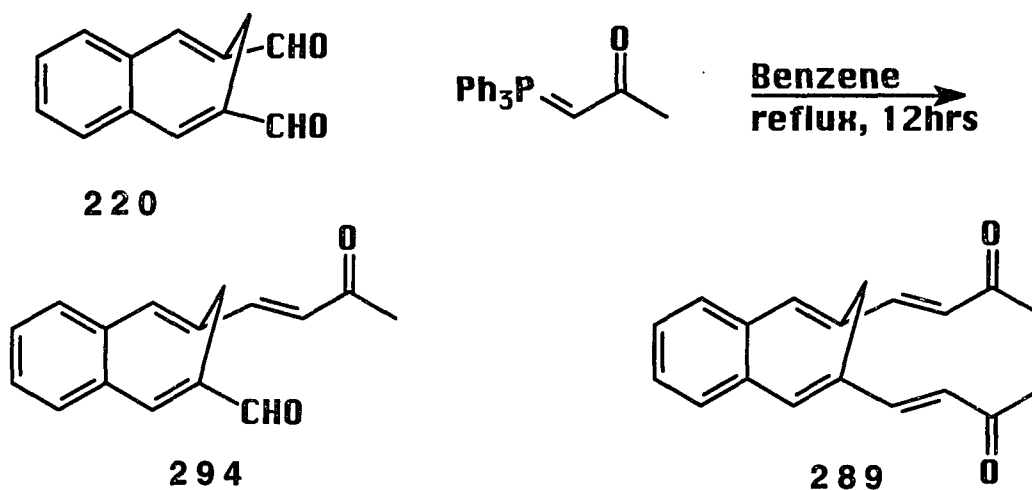


Scheme 60: Synthesis of Homotropone, **288**

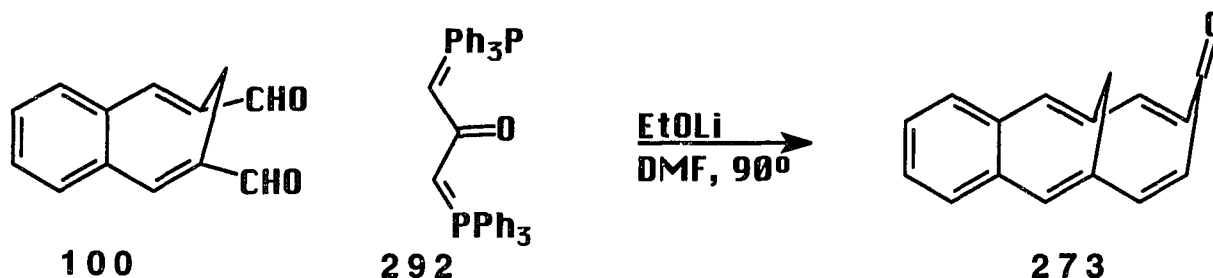
The direct synthesis of **273** was attempted in various ways. Condensation of aldehyde **220** with acetone in aqueous KOH as described earlier yielded only the bis α,β -unsaturated ketone, **289**.



None of **273** was detected in the crude sample. Diketo **289** had been previously obtained by the Wittig reaction of **220** with the stabilized ylid derived from bromoacetone.



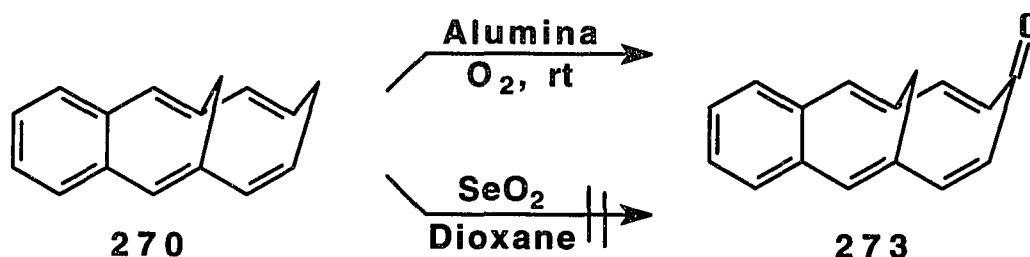
Wittig olefination of **220** with the known phosphonium salt, **292**, derived from 1,3-dichloroacetone and triphenylphosphine yielded **273** in low yield of 0.9% as a light yellow solid.



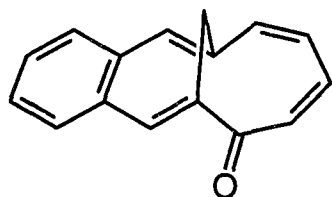
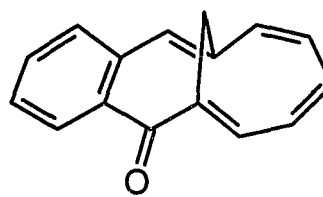
Scheme 61: Synthesis of Homonaphthotropone **273**

The low yield observed is probably due to the tendency of the keto-bisphosphonium salt to condense with formation of trans- rather than cis-alkenes, as supported by the isolation of large amounts of bis product **289**.

Treatment of bis-methano[10]annulene, **270**, with dry activated alumina exposed to air for 12 hours yielded tropone **273** in 5 % yield. However, treatment of **270** with SeO_2 in refluxing dioxane afforded compounds **228** and **229** and no **273**.

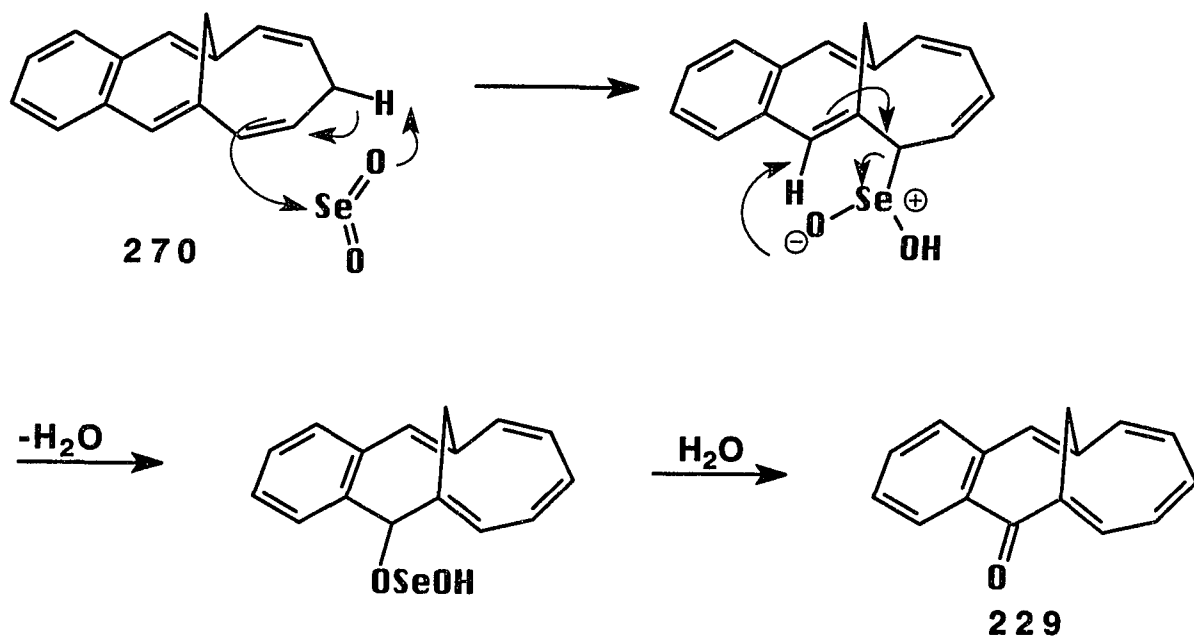
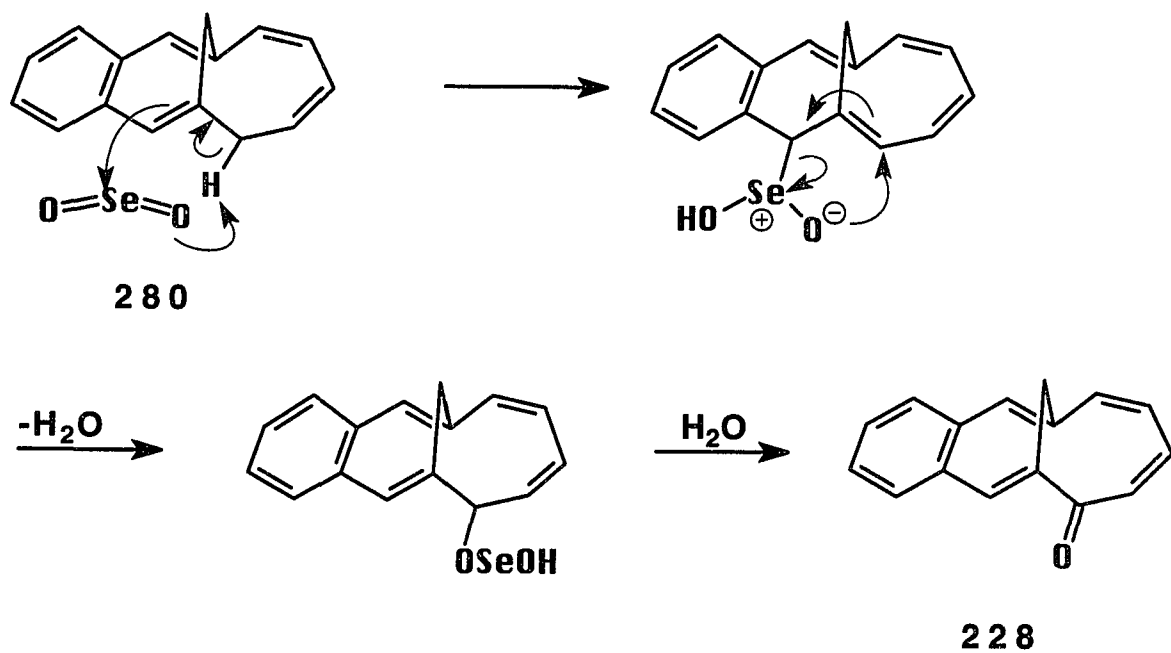


Oxidation of the bismethano **270** with SeO_2 results in the deeply red ketone **229** while oxidation of the asymmetric isomer **280** results in the exclusive formation of the orange ketone **228**. Both ketones exhibit a carbonyl stretch in the IR (1635 and 1651 cm^{-1}) along with a carbonyl resonance in their ^{13}C NMR. The corresponding ^1H NMR assisted by 2D-COSY and MS analysis allowed the determination of their structures.

**228****229**

The oxidation via SeO_2 proceeds through an initial ene-type mechanism followed by a sigmatropic rearrangement as shown in Scheme 62 below.

^1H NMR of the two ketones **228** and **229** are presented in Figure 48.



Scheme 62: Oxidation to Ketones **228** and **229**.

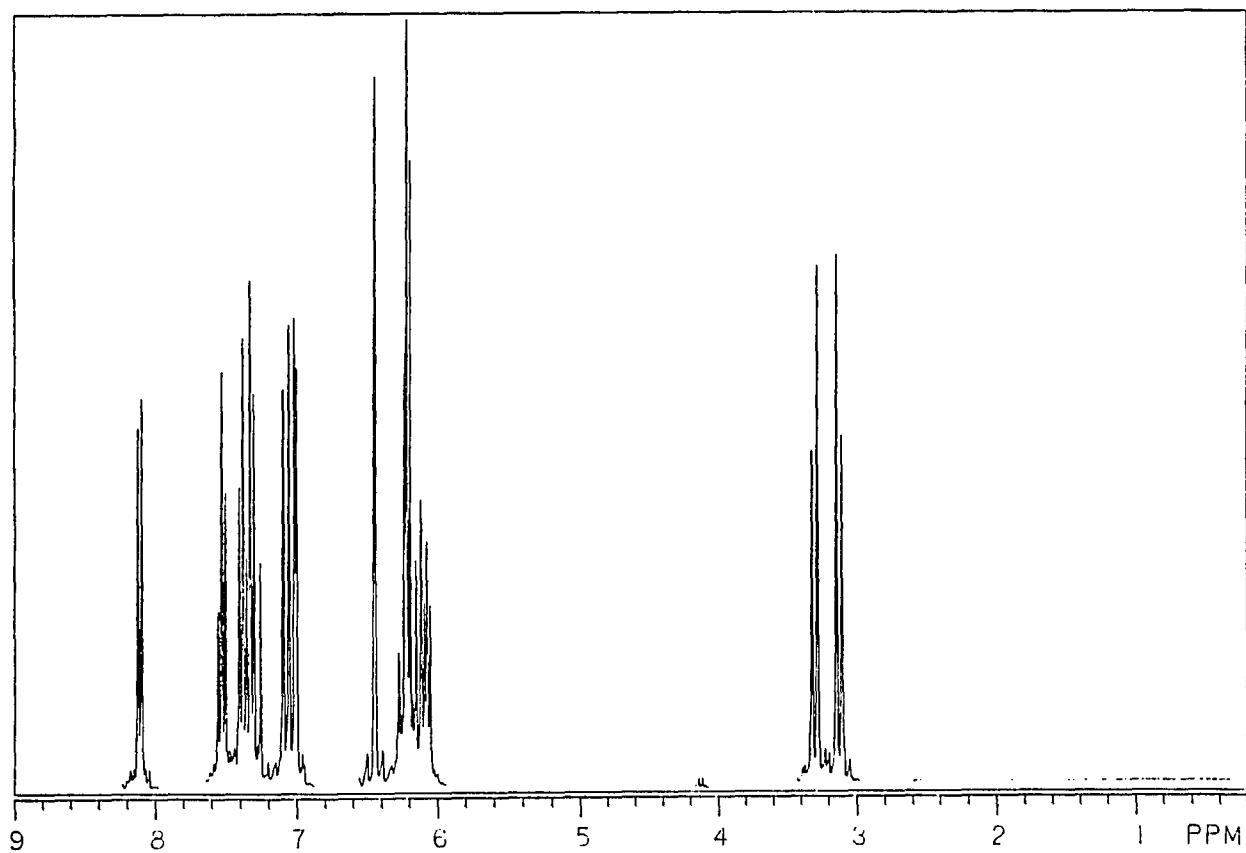
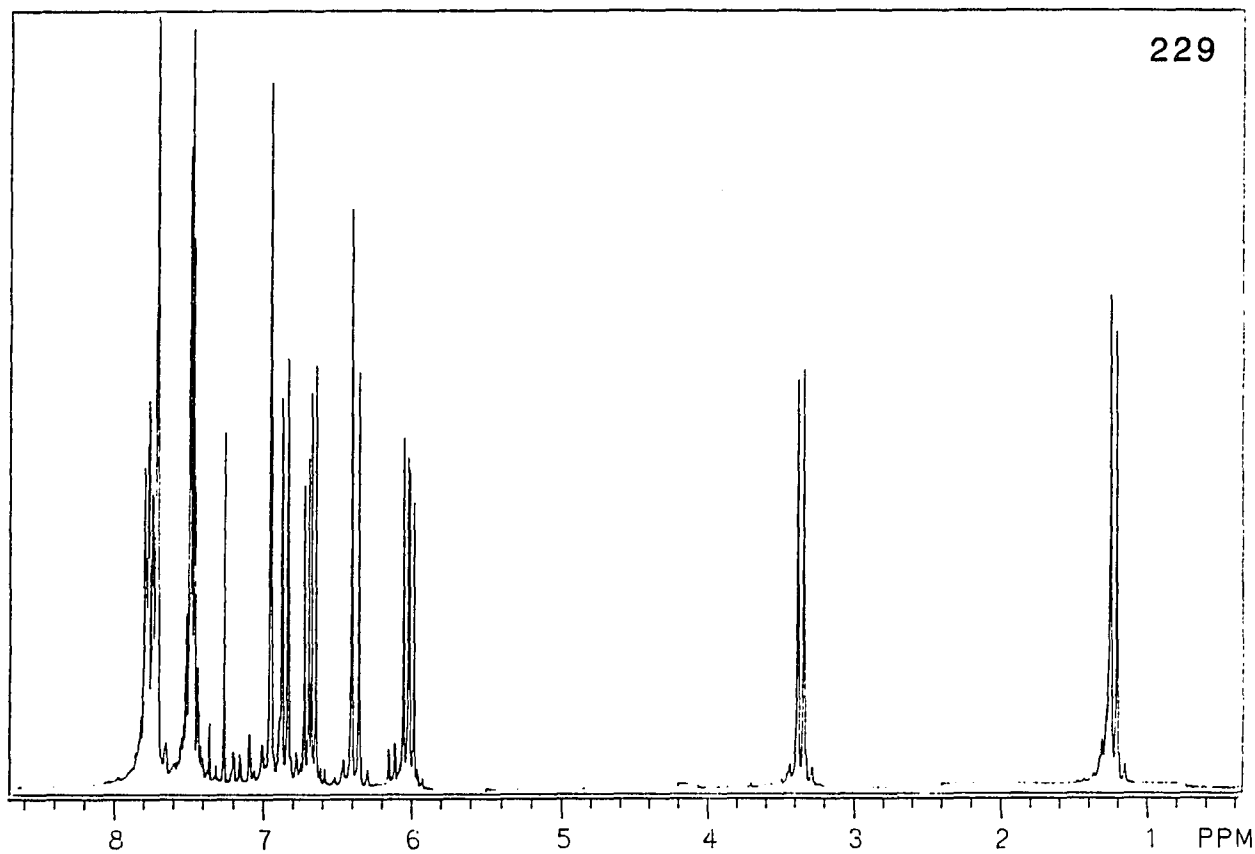
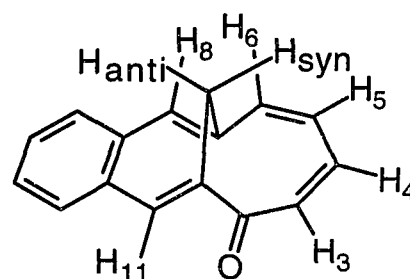


Figure 48: ¹H NMR of ketones 228 and 229 (top to bottom)

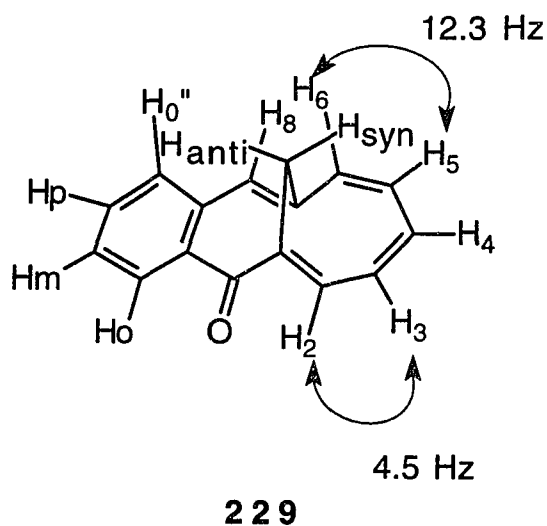
^1H NMR spectrum of **273** exhibits the bridge CH_2 group as an AB quartet at 1.00 ppm (H_{anti} , d, $J=12.3$ Hz) and 2.26 ppm (H_{syn} , dt, $J=12.3$ and 1.5 Hz). H_2 and H_3 appear as a 4H AB quartet at 6.14 (H_3 , d, $J=12.0$ Hz) and 7.19 ppm (H_2 , d, $J=12.0$ Hz), respectively, with H_8 as a singlet at 7.10 ppm. The aromatic AA'BB' quartet is centered at 7.64 ppm.

H_{syn} is clearly influenced by the deshielding of the carbonyl group of **273**. Repositioning of the carbonyl group at position 2 as in **228** removes the apparent deshielding and H_{syn} now shifts 1 ppm to a higher field. The asymmetry of **228** as compared with tropone **273** is exhibited beautifully in the ^1H NMR of **228**. Complete assignment is given in Table 19 below.

proton	Resonance, ppm
H_3	6.38, d, $J=14.7\text{Hz}$
H_4	6.68, dd, $J=14.4, 8.7$
H_5	6.00, dd, $J=13.5, 9.0$
H_6	6.85, d, $J=12.0$
H_8	6.95, s
H_{11}	7.70, s
$\text{H}_{12\text{syn}}$	3.35, d, $J=12.3$
$\text{H}_{12\text{anti}}$	1.22, d, $J=12.3$

**228****Table 19:** ^1H NMR summary of **228**.

The ^1H assignment of ketone **229** is based on the J-J values measured for the triene segment of the molecule, as shown below. The positioning of the carbonyl group α to the benzene ring deshields H_o greatly and thus resolving the aromatic patterns. The similarity observed between the two bridge protons with H_{anti} now being most downfield than ever been observed for any system discussed thus far, results from the unique positioning of the bridge carbon perpendicularly to the plane of the molecule. It has been determined earlier from the x-ray analysis of thiepin oxide **260** and bismethano[10]annulene **270** that the bridge tends to lean away from the benzene ring, thus placing H_{anti} in the rim of the deshielding cone. In **229** such leaning is minimized by the orientation of the double bonds at the two bridgeheads, therefore, placing H_{anti} deeper in the deshielding cone of the annelating benzene ring.



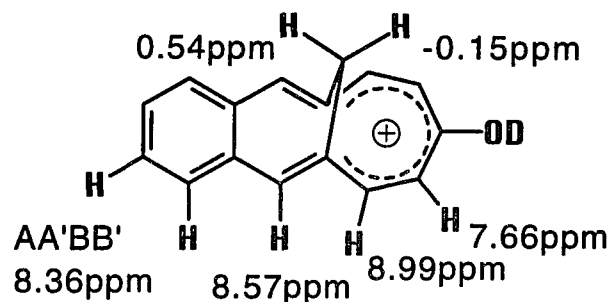
proton	Resonance, ppm
H ₂	7.01, d, J=4.5Hz
H ₃	6.11, m
H ₄	6.11, m
H ₅	6.11, m
H ₆	7.08, d, J=12.3
H ₈	6.45, s
H _{12syn}	3.28, d, J=11.7
H _{12anti}	3.11, d, J=11.7
H _o	8.10, d, J=8.1
H _m	7.39, t, J=7.5, 7.5
H _p	7.53, m
H _o "	7.32, d, J=7.8

Table 20: ¹H NMR summary for ketone **229**.

Examination of the Infra red spectra of the three ketones reveals changes in conjugation and in vibrations arising from conjugated carbonyls. Tropone **273** exhibits a C=O absorption at 1626 cm⁻¹ as compared with 1582 cm⁻¹ determined for tropone itself. Vogel's tropone, **288**, similarly exhibits a CO band at 1607 cm⁻¹. The pattern becomes even more obvious when one realizes that as

delocalization of electrons increases the CO bond order decreases and the absorption moves towards larger frequencies. By this criterion tropone **273** has more delocalization than **288** or tropone itself. Similar tendencies are observed with ketones **228** and **229**. Larger delocalization is expected and indeed observed for **229** (as compared with **228**) for all its bands appear at higher frequencies.

Treatment of **273** in deuterated trifluoroacetic acid and D_2SO_4 resulted in an aromatic cation whose NMR characteristics are similar to those observed with **290**. The diamagnetic character of **273** on treatment with acid is evident from a large downfield shifts observed for all ring protons and a 1.5 ppm upfield shifts of the bridge protons as compared with tropone **273**. Cation **290** sustains a larger diamagnetic ring current and thus exhibits a higher paramagnetic shifts for its bridge protons.



273a

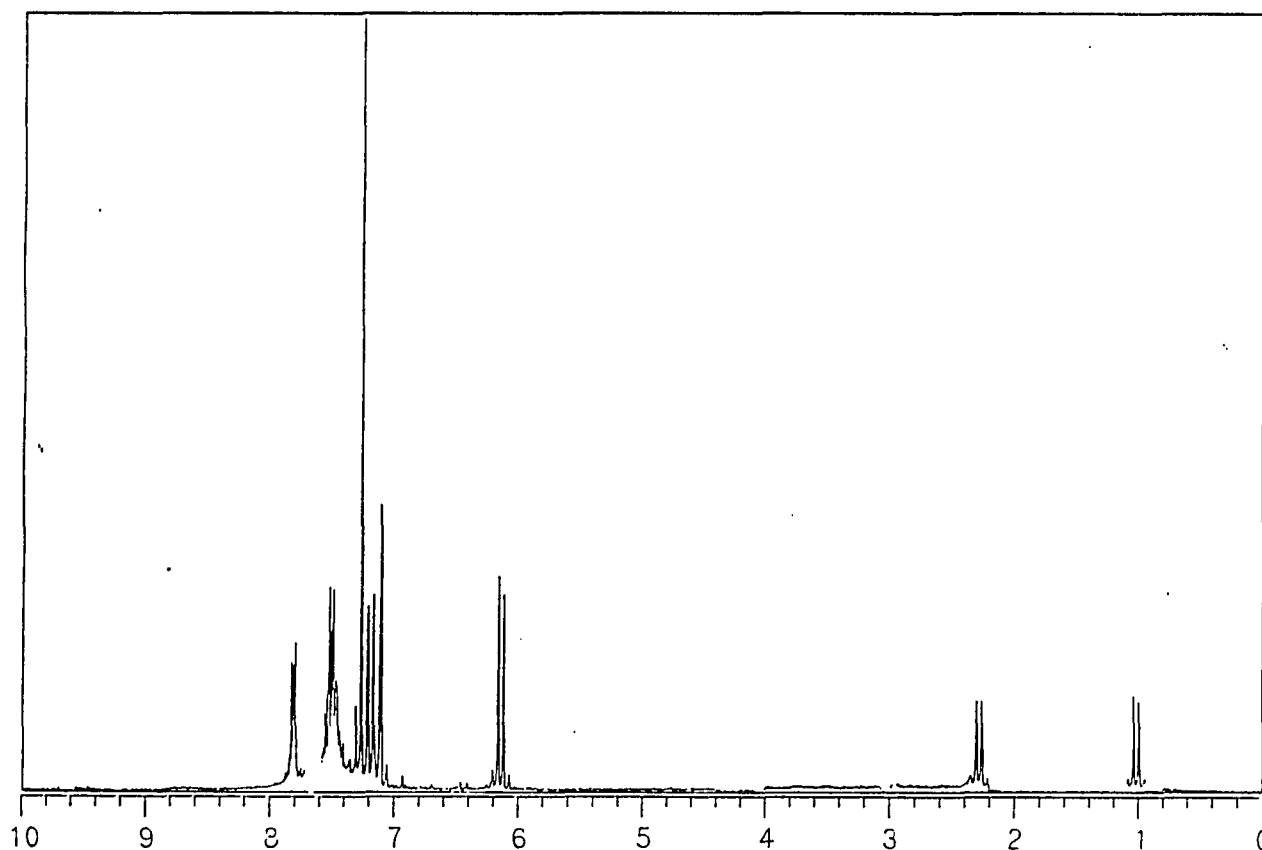
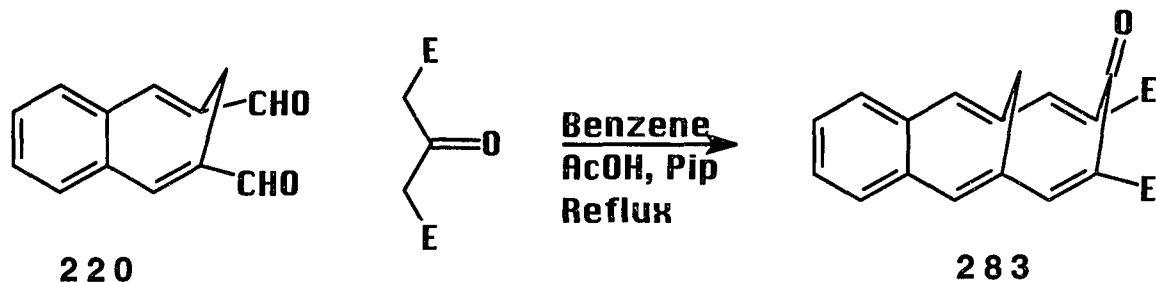


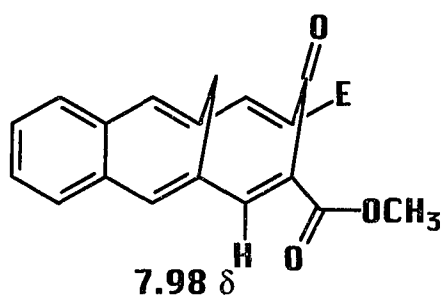
Figure 49: ^1H NMR of **273**.

Attempts to synthesize **283** via an aldol condensation of **220** with dimethyl acetonedicarboxylate, **293**, in basic medium yielded only minute, inseparable amounts of the keto-diester, **283**. However, condensation in a benzene solution containing AcOH and piperidine, under Dean-Stark conditions yielded **283** cleanly as a light yellow solid in 51.6% yield.

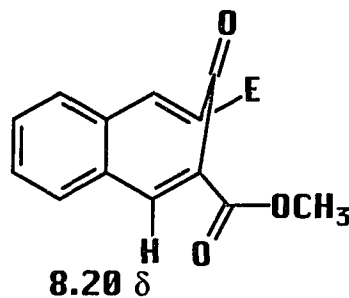


Scheme 63: Synthesis of **283**.

The ¹H NMR of **283** is rather simple. Bridge protons resonate at 1.06 and 2.60 ppm as doublets; H₁₁ at 7.28 ppm and H₂ at 7.98 ppm. The low field resonance of H₂ is due to deshielding by the ester carbonyl group pointing away towards the periphery of the molecule. Similar chemical shift was observed in benzocycloheptatrienone diester¹⁴⁷.



283



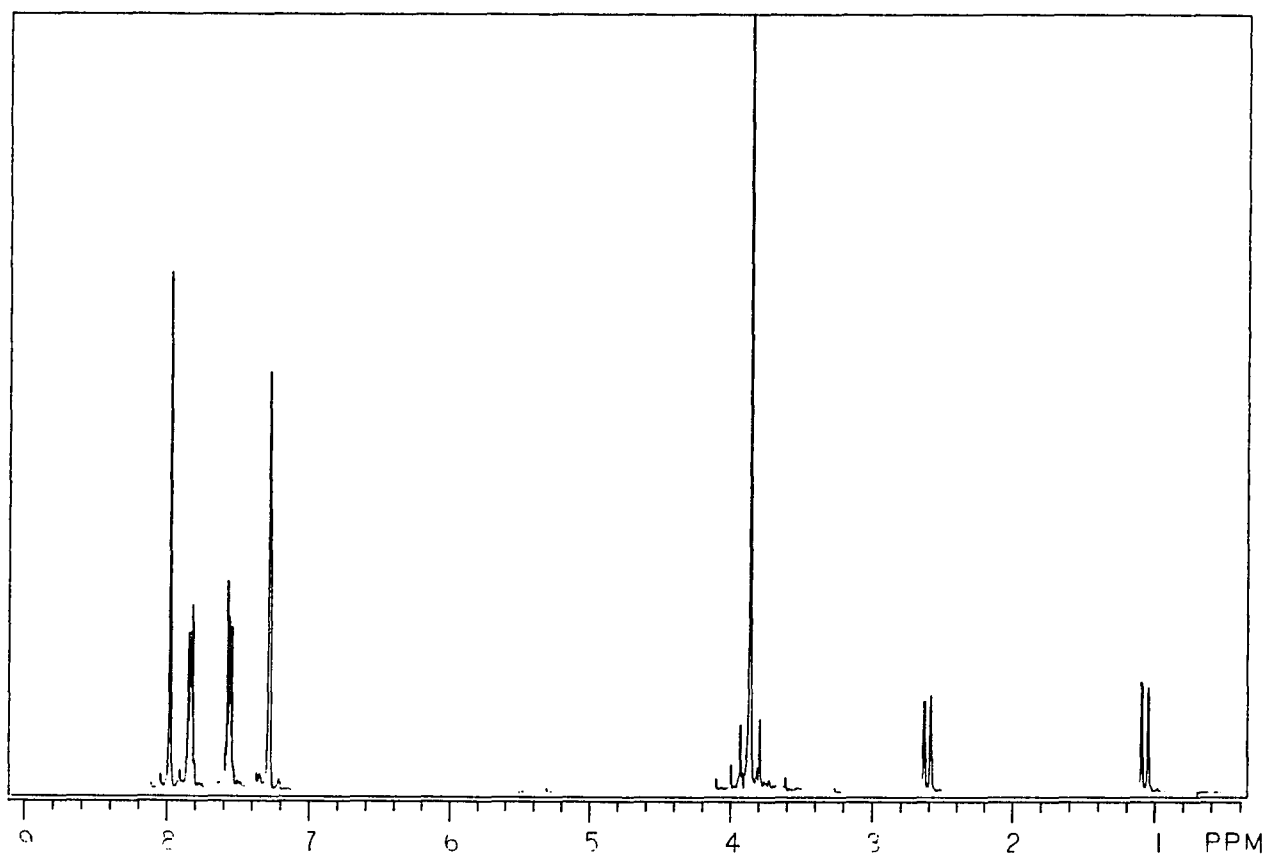
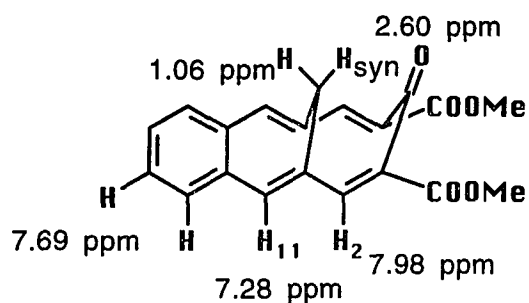
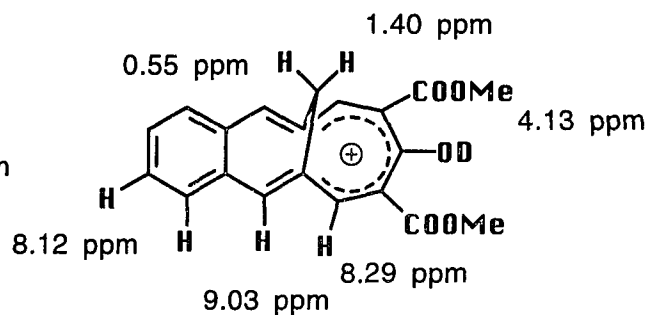


Figure 50: ^1H NMR of **283**.

The ^1H NMR of **283** in trifluoroacetic acid- $\text{d}_1/\text{D}_2\text{SO}_4$ mixture exhibited a down field shift of all ring protons and an upfield shift for the bridge CH_2 protons, as shown below.

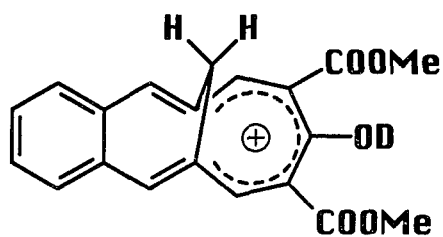
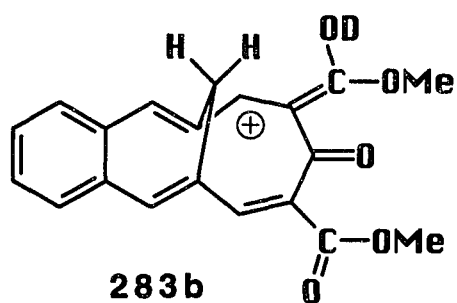
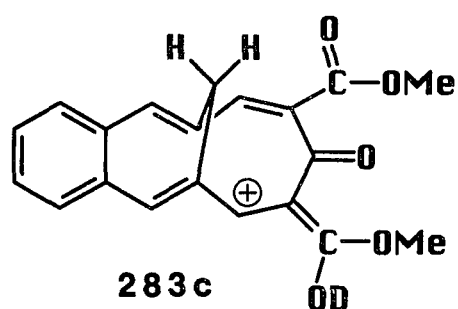
**283****283a**

The chemical shifts are summarized below. Notice the large downfield shift observed for H₁₁ and the relatively large upfield shift observed for H_{syn}. These shifts unequivocally indicate the presence of a diamagnetic ring current in structure **283a**. Furthermore, the lowered diamagnetic ring current in **283a** as compared with **273a** is evident too.

proton	283	283a	Δ ppm	273	273a	Δ ppm
H ₂	7.98 ppm	8.29	-0.31	7.19	8.99	-1.80
H ₃	-----	-----	-----	6.14	7.66	-1.52
H ₁₁	7.28	9.03	-1.75	7.10	8.57	-1.42
H _{syn}	2.60	1.40	+1.20	2.26	-0.15	+2.46
H _{anti}	1.06	0.55	+0.51	1.00	0.54	+0.46
Ar	7.69	8.12	-0.43	7.64	8.36	-0.72
CH ₃	3.89	4.13	-0.24	-----	-----	-----

Table 21: Chemical shift summary for **283** and **283a** (Δ ppm<0 indicates downfield shifts)

On the basis of the diamagnetic ring current observed in cation **290**, the relatively mild shifts observed with **283a** should be seen as resulting from the electron withdrawing capabilities of the carbomethoxy groups. It is reasonable to predict the presence of resonance contributing structures such as **283b** and **283c** which effect electron delocalization and reduce the corresponding ring current.

**283a****283b****283c**

The degree of diamagnetic ring current observed in **283a** as compared with **273a** is clearly smaller. Compound **273a** exhibits Δppm twice as large as those observed in **283a** which indicates increased diamagnetic character in the system.

The resonance of H_{syn} is obviously most affected by substitution at the rim methano bridge (C_4). Heteroatom field effects, deshielding (or shielding) of multiple bonds and steric effects can all determine the relative position of the syn proton, the compression with H_{anti} and therefore, the chemical shift of H_{anti} . Table 22 summarizes the chemical shifts observed in such systems where the resonance of $H_{12\text{syn}}$ and $H_{12\text{anti}}$ are indicative of the effects described above.

In thiepin **IV** one observes the most downfield shift for H_{syn} ; and in tropone **273**, the most upfield. The greater closeness of sulfur's lone pair to H_{syn} as compared with the carbonyl π cloud, deshields H_{syn} in thiepin **IV** by 1.81 ppm as compared with dithiane **215**. The use of **215** as a reference is allowed due to removal of repulsive or other electronic interaction with the corresponding H_{syn} . It is essential to note that the observed chemical shifts of all H_{anti} protons, with the exception of **215**, is at and around 1.2 ppm with thiepin **IV** having its H_{anti} at lowest field. This observation implies that: a. The relative position of the H_{anti} at the rim of the benzene ring is unchanged; b. The bridge CH_2 group in **215** lies tilted away from the polyene system and thus experiences reduced shielding of the H_{anti} ; and c. H_{syn} and H_{anti} in Thiepin **IV** experience the largest measure of deshielding and shielding, respectively, arising from the proximity of H_{syn} and the sulfur atom.

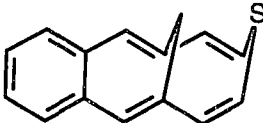
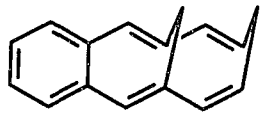
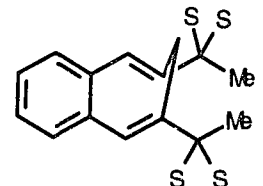
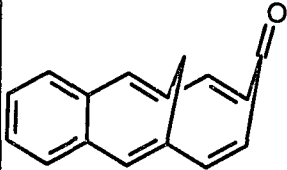
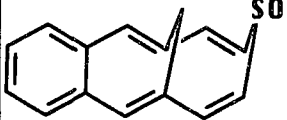
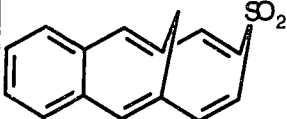
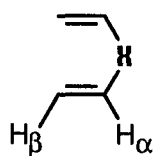
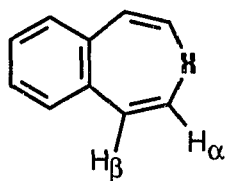
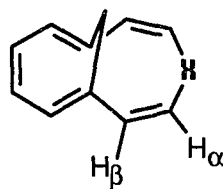
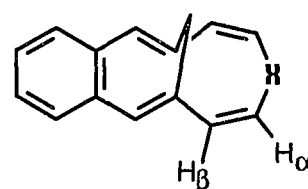
#	structure	Hsyn	Hanti	$\Delta\delta$	J (Hz)
IV		5.72	1.98	3.74	11.9
270		3.88	1.20	2.68	12.0
215		3.91	3.20	0.71	16.2
273		2.26	1.00	1.26	12.3
260		3.06	1.36	1.70	14.0
261		4.06	0.98	3.08	13.7

Table 22: Chemical shift differences of bridge protons

Such steric compression of atoms is also observed in **270**. Here, the diamagnetic effect, observed in **IV**, is removed and a higher field shift is observed for H_{syn} . Nevertheless, proximity to H_{4b} maintains interaction and increased relative deshielding.

When tropone **273** is compared with sulfoxide **260** and sulfone **261**, the chemical shifts clearly indicate the presence of an additional effect which may be held responsible for the low field shifts observed in **260** and **261**. This may be due to changes in paramagnetic ring current, to diamagnetic anisotropy of the C-S bond or to a combination of effects.

The effect of annelation and substitution at position 4 of the systems presented in Table 22 above, may be evaluated by examining chemical shift changes in the vinylic protons at carbons C_2 and C_3 . Table 23 below lists the chemical shifts of the α and β hydrogens in acyclic divinyl systems of type A, Benzo annelated systems of type B, bridged[11]annulene of type C, and benzannulene of type D.

**A****B****C****D**

	A		B		C		D	
X=	H_α	H_β	H_α	H_β	H_α	H_β	H_α	H_β
CH₂	5.71	4.92	5.65	6.45	4.80	6.55	5.39	6.42
S	6.13	5.29	5.91	6.76	4.78	6.45	5.51	6.55
C=O	6.67	5.82	6.61	7.35	6.02	7.18	6.14	7.19
No X	5.25	5.25			5.04	6.41	5.10	6.50

Table 23: ¹H NMR chemical shifts of selected H_α and H_β.

At a first glance it is clear that H_a and H_b show different relative chemical shifts as compared between the acyclic type A structure and any of types B-D structures: In A H_b exhibit upfield positions relative to H_a while in B-D the reverse is true. Secondly, the chemical shift difference, $\Delta\delta$, observed between H_a and H_b increases with conjugation and is influenced by the nature of group X. Divinyl compound **240**, in which group X is removed (type D), exhibits similar chemical shifts. These similarities are consistent with the other resonances in each spectrum. The conclusion that may be drawn is that as **240** has no reason to be considered (homo)aromatic, there is no reason to assume any such stabilization in **IV** and **270**.

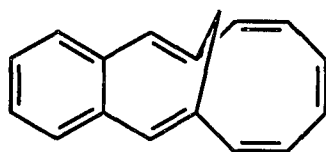
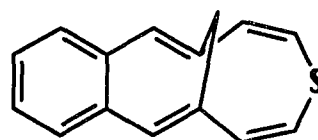
In **273**, however, both H_{α} and H_{β} (types C, D) show ca. 1 ppm downfield shifts as compared with divinyl **240**. This may be looked at as an indication for a diamagnetic ring current resulting from the electron withdrawing properties of the carbonyl group. In fact, Sondheimer¹⁴⁸ predicted that annulenones are expected to be aromatic if they contain $(4n+3)$ -membered ring and non aromatic if they contain $(4n+1)$ -membered ring. Such was the case with cyclopropenone, and with cycloheptatrienone.



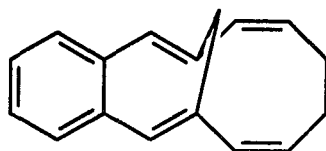
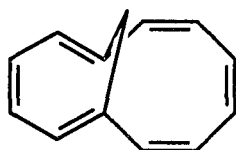
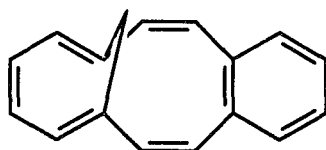
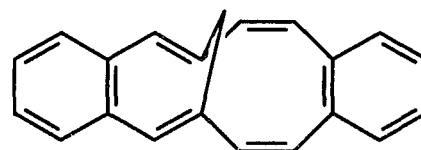
X-ray analysis of Vogel's tropone, **288**, did not yield direct indication as to its aromaticity¹⁴⁹. Bond alternations and nonplanarity were signs of nonaromaticity, yet structural similarities with methano[10]annulene were to indicate otherwise. It is fair, therefore, only to assume a larger diamagnetic ring current in **273** as compared with thiepin **IV** and bismethano[11]annulene **270**. The extent of steric compression, electronic effects and ring currents have been observed with larger ring skeletons such as 1,6-methano [12]annulene. Our observations in this regard are described next.

**2.5.5 SYNTHESIS AND INVESTIGATIONS OF BENZ-
1,6-METHANO [12]ANNULENE , 272.**

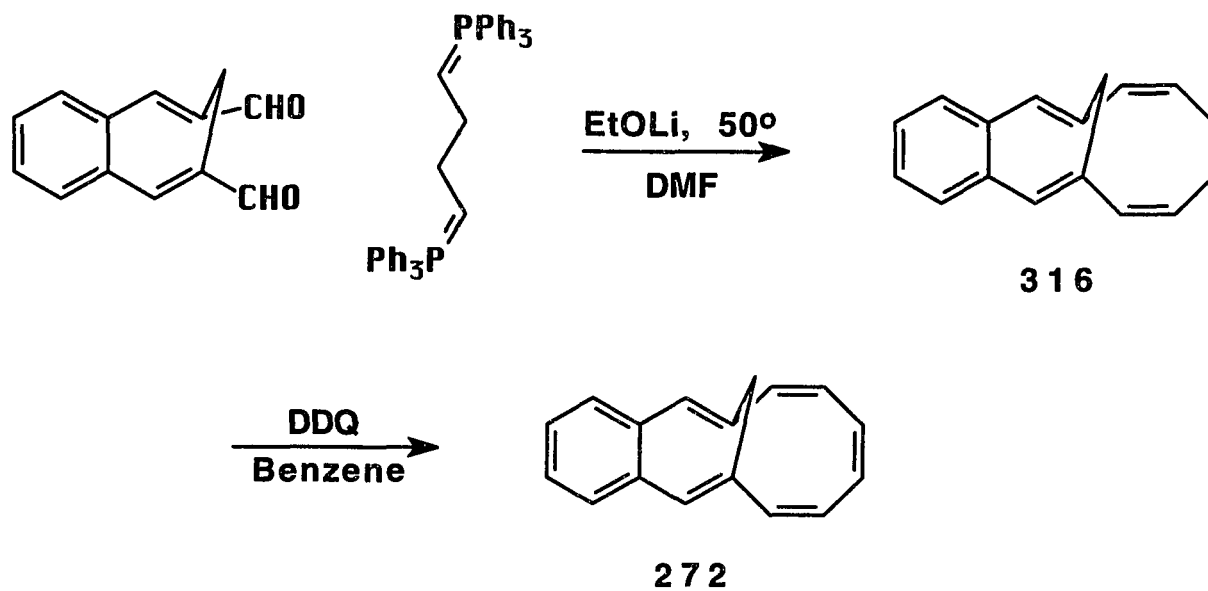
Replacement of a C-C double bond by a sulfur atom (or S, N) in an aromatic system results in the formation of an isoelectric heteroatom aromatic system (e.g. Benzene--thiophene). Thus, it is interesting to investigate the changes resulting from the replacement of a C-C double bond by a sulfur atom in a formally antiaromatic system (similarly to cyclooctatetraene--thiepin) such as **272**. In other words, the synthesis of **272** will allow a fuller comparison of this effect when compared with thiepin **IV**. Both are isoelectric and thus should yield similar effects.

**272****IV**

Moreover, the assessment of paratropicity (degree of anti aromaticity) may come from the comparison of **272** with the dihydro compound **316** and with the nonbenz **317**, Vogel's benz-**318** and dibenz **319**.

**316****317****318****319**

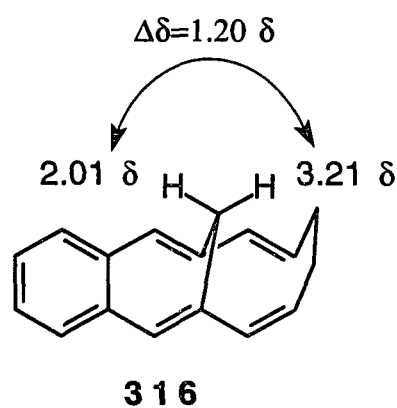
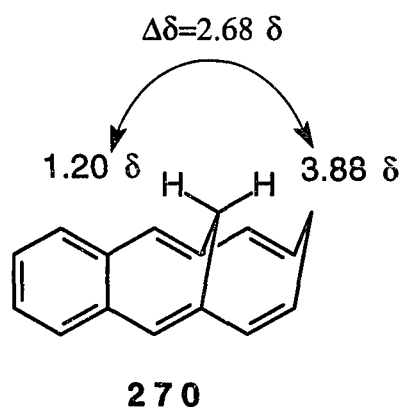
Wittig olefination of 3,4-benzocycloheptatriene-1,6-dialdehyde, **220**, with the bis phosphonium salt derived from 1,4-dibromobutane, yielded **316** in 15% yield as a white solid.



Scheme 64: synthesis of **316** and **272**.

When the reaction was carried out in DMF with sodium ethoxide as base, no ylide formation was observed and the starting material was recovered. It was observed that in these cases dimethylamine was present in the reaction mixture, resulting from the hydrolysis of DMF. No reasonable explanation is available as to the differences in reactivity between sodium and lithium bases under these conditions.

^1H NMR of **316** exhibits the bridge protons as an AB quartet at 2.00 ppm (dd, H_{anti} , $J=13.5$ Hz) and at 3.21 ppm (dt, H_{syn} , $J=13.5$ Hz and $J=1.5$ Hz). H_2 appears as a doublet at 6.53 ppm ($J=11.1$ Hz) while H_3 exhibits higher splitting patterns and appears as a multiplet at 5.92 ppm. The ethylene segment appears as two same-intensity multiplets at 2.28 and 2.38 ppm. NOESY experiment determined a 4% cross-peak between the multiplet at 2.38 ppm and $H_{12\text{syn}}$, which indicates folding within the eight membered ring segment.

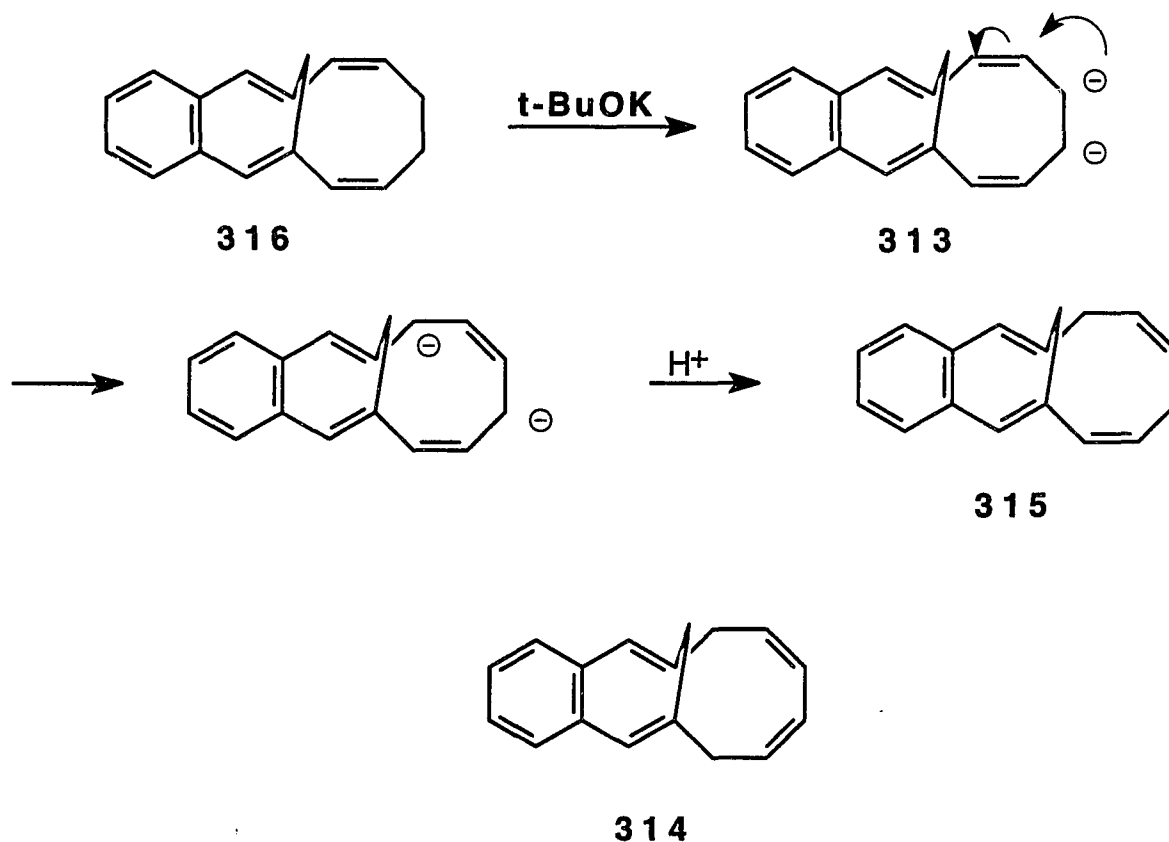


When considered with **270**, it becomes clear that **316** exists in a syn conformation similar to **270**. However, in **316** the $\Delta\delta$ observed

between the bridge protons is smaller than that observed in **270** by $\Delta \Delta\delta$ of 1.20ppm. This supports the lesser crowding of the bridge protons in **316** as the ethylene group reduces H-H repulsion and deshielding as was previously found in **270**.

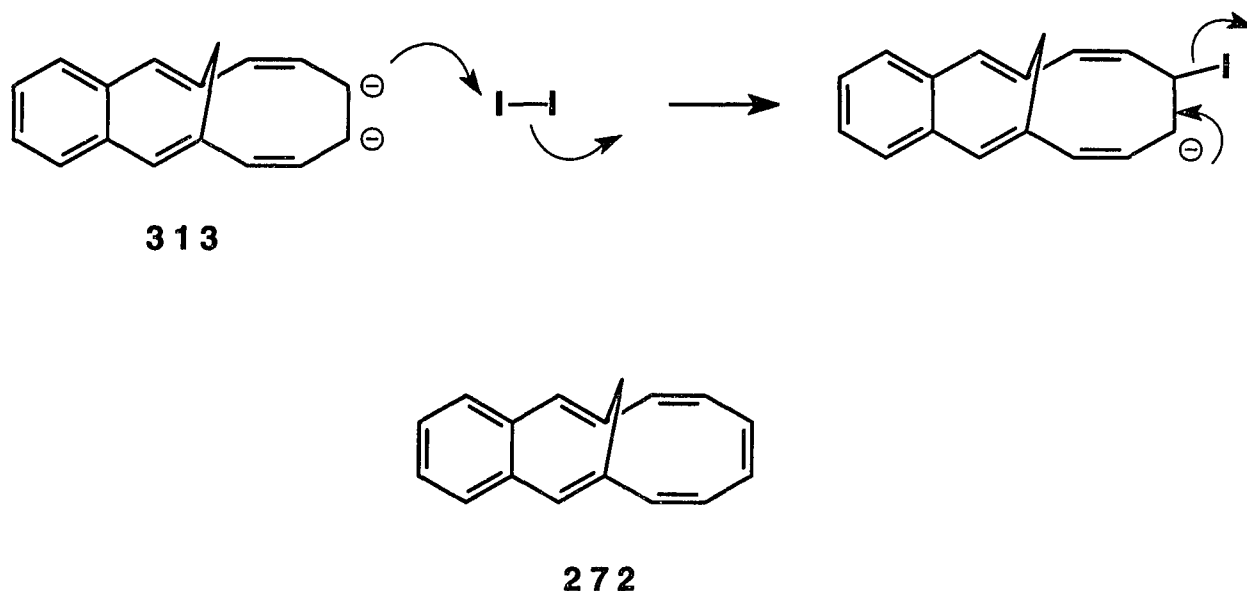
Furthermore, the conformation of **316** clearly seems to position proton H_{anti} away from the shielding field of the benzene ring. This is substantiated by the observed chemical shift of the same proton in compound **280** where the conformation of the molecule is clearly more planar. **272** is expected to show similar tendencies with increased efforts to minimize antiaromaticity.

When the synthesis of dihydro benzmethano[12]annulene, **316**, was attempted with t-BuOK in THF at room temperature, 3 products of molecular weight 220 were obtained, two of which unequivocally identified. Isomers **316** and **315** were identified while the presence of **314** as the third isomer is not fully confirmed. Isomer **316**, the expected product of this Wittig olefination is believed to undergo sequential proton abstraction resulting in the formation of the aromatic dianion **313**, as shown in Scheme 65 below. Protonation of the dianion during work up results in the formation of the three isomers: **315** through protonation at C_4 and C_7 and **314** via protonation at the C_2 and C_7 carbons.



Scheme 65: Isomerization of **316** via dianion **313**.

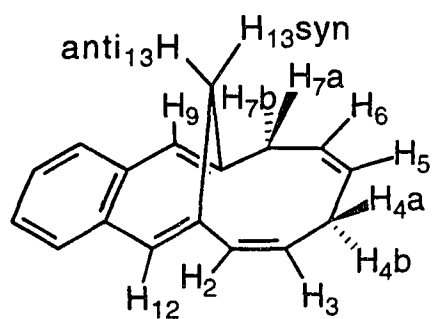
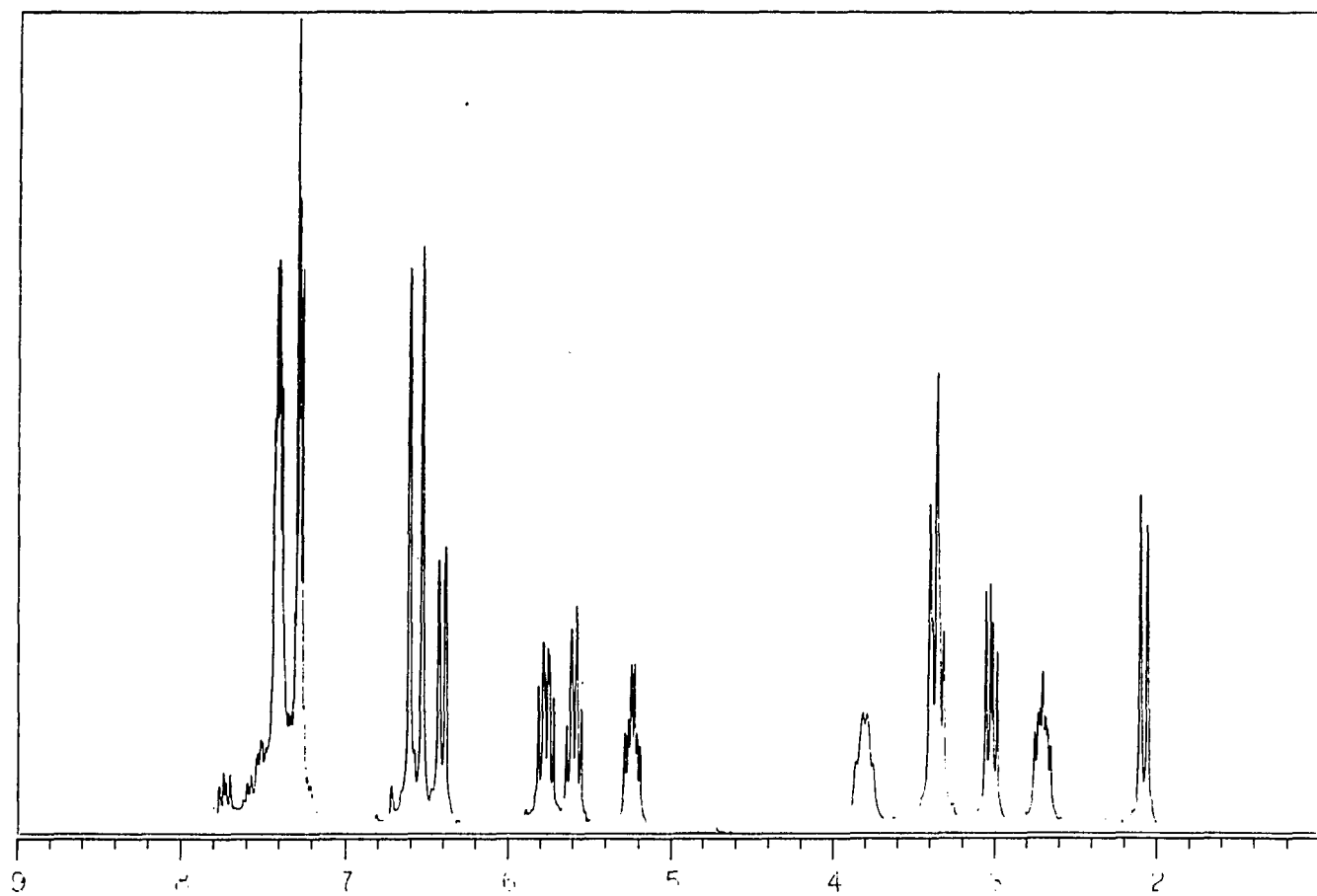
This isomerization has never been detected when the Wittig reaction (Scheme 64) was carried out in DMF with LiOEt as a base. The presence of the aromatic dianion **313** was proven through its oxidation to the [12]annulene with iodine solution, as shown in Scheme 66. When the Wittig solution, prepared in THF with excess *t*-BuOK, is quenched with excess iodine in THF benzmethano[12]annulene **272** is obtained as the major product.



Scheme 66: Oxidation of dianion **313** to antiaromatic [12]annulene **272**.

The mechanism of dianion oxidation depicted in Scheme 66 follows halogenation / dehalogenation sequence. A second mechanism involving two single-electron transfer steps is possible as well.

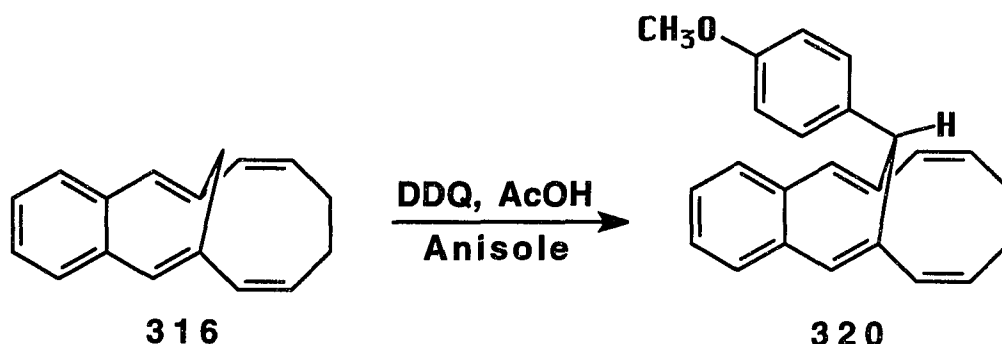
The reduction in the symmetry of isomer **315** is clearly and very dramatically exhibited in its ^1H NMR as compared with that of isomer **316**. The well defined patterns and the well spread spectrum was not assigned with great ease. 2D-COSY and NOESY experiments enabled complete assignment of all protons. ^1H NMR of **315** is shown in Figure 49. The NOESY and COSY correlations are summarized in Table 24 which follows.

**315****Figure 51: ^1H NMR assignments of isomer 315.**

proton	resonance	COSY with	NOE with
H₂	6.36, d	5.74 (H ₃)	2.98 (H _{7b})
H₃	5.74, td	6.36 (H ₂)	2.69 (H _{4b}), 6.36(H ₂)
H_{4a}	3.78, bq	2.69 (H _{4b})	3.35 (H _{13syn}), 2.69 (H _{4b})
H_{4b}	2.69, td	3.78 (H _{4a})	5.21 (H ₅), 5.74 (H ₃), 3.78 (H _{4a})
H₅	5.21, td	5.57 (H ₆)	2.69 (H _{4b}), 5.57 (H ₆)
H₆	5.57, q	5.21 (H ₅), 2.98 (H _{7b}), 3.33 (H _{7a})	5.21 (H ₅), 2.98 (H _{7b}), 3.33 (H _{7a})
H_{7a}	3.33, overlapped t	2.04 (H _{13anti}), 5.74 (H ₃)	2.98 (H _{7b}), 5.57 (H ₆)
H_{7b}	2.98, dd	5.57 (H ₆)	3.33 (H _{7a}), 6.50 (H ₉)
H₉	6.50, s	-----	2.98 (H _{7b})
H₁₂	6.58, s	-----	-----
H_{13syn}	3.35, d	2.04 (H _{13anti})	3.78 (H _{4a})
H_{13anti}	2.04, d	3.35 (H _{13syn})	-----

Table 24: NMR summary of ¹H, COSY and NOESY of isomer **315**.

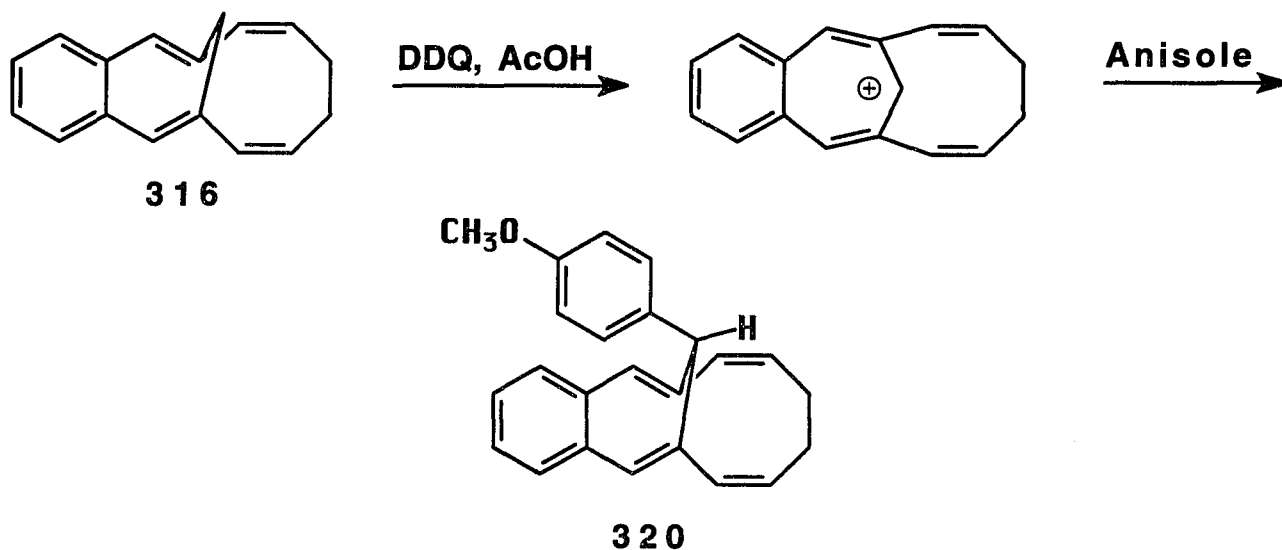
Treatment of **316** with excess DDQ in benzene failed to yield **272**. However, oxidation with DDQ in anisole and in the presence of a few drops of acetic acid afforded a mixture of compounds from which **320** was separated.



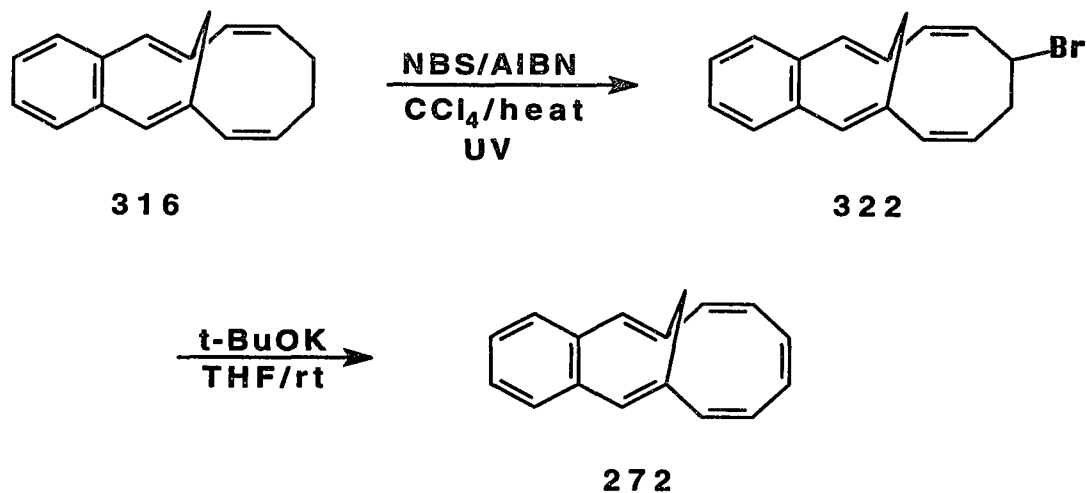
Compound **272** was present in the mixture in minute quantities only. A third compound, white crystalline solid, was isolated and determined to have a molecular weight of 440. Fragmentation in MS resulted in a base peak of 220. This indicates the dimerization of **316** via a still unknown mechanism. The spectra of the dimer, **unknown 324**, is presented in the last section.

The suggested mechanism by which **320** formed is shown below. Initial hydride abstraction by DDQ results in a stable tropylium cation which electrophilically adds to the more favored para position of a solvent molecule.

On the basis of its ^1H NMR and the resonance of the lone bridge proton at 4.98 ppm it was unarguable that the p-anisyl group is positioned over the benzene ring, as shown above. If it were to point



away from the aromatic sextet, the resonance of the lone proton would have been at higher field, as been observed thus far. This intuitive assignment was confirmed by a NOESY experiment. NOE were determined between the bridge proton H_{12} and the two CH_2 groups (4.7%). Methano[12]annulene **272** was finally obtained by a bromination/ elimination sequence as shown below:



Scheme 67: Synthesis of **272** via bromination/elimination

A CCl_4 solution containing **316**, NBS and catalytic amounts of AIBN was heated at reflux and irradiated with a Hanova-mercury lamp over a 2-hour period. The solution containing a mixture of **322** isomers was concentrated in vacuo, redissolved in THF and treated with t-BuOK. **272** was separated as a yellow oil in low yield.

^1H NMR of **272** shows a much simpler pattern resulting from increased simplicity in splitting pattern, as compared with dihydro **316**.

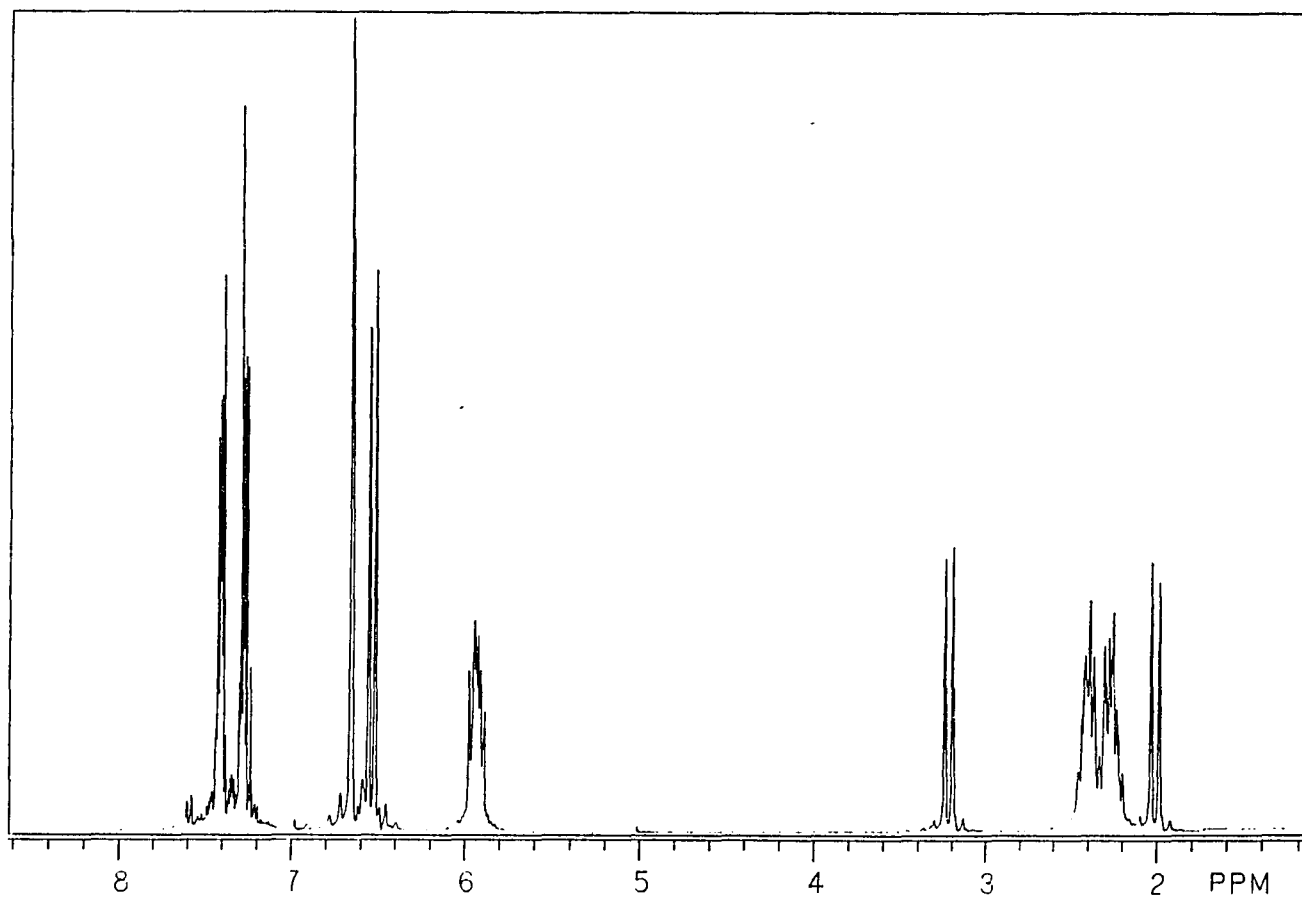


Figure 52: ^1H NMR spectrum of **316**.

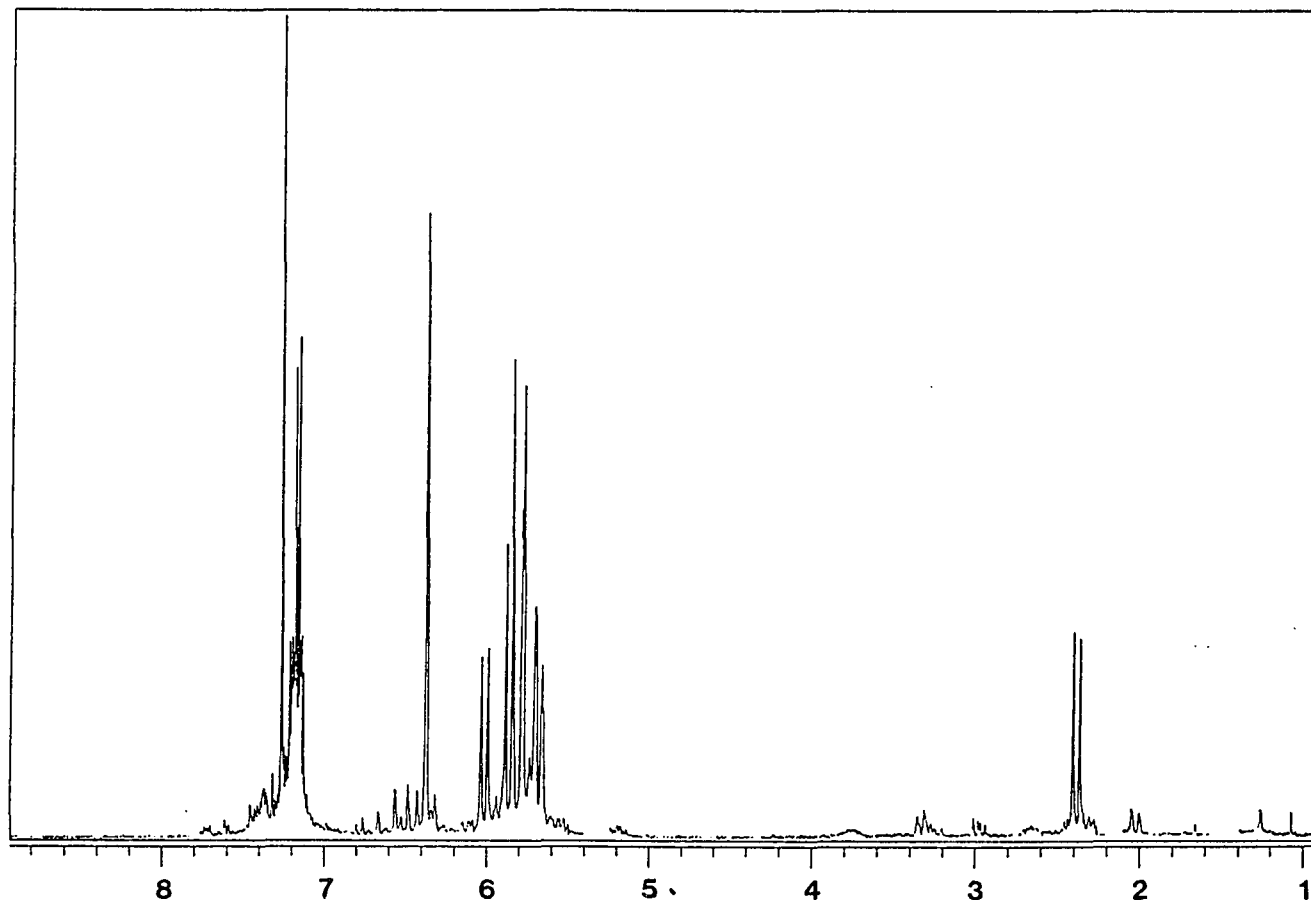
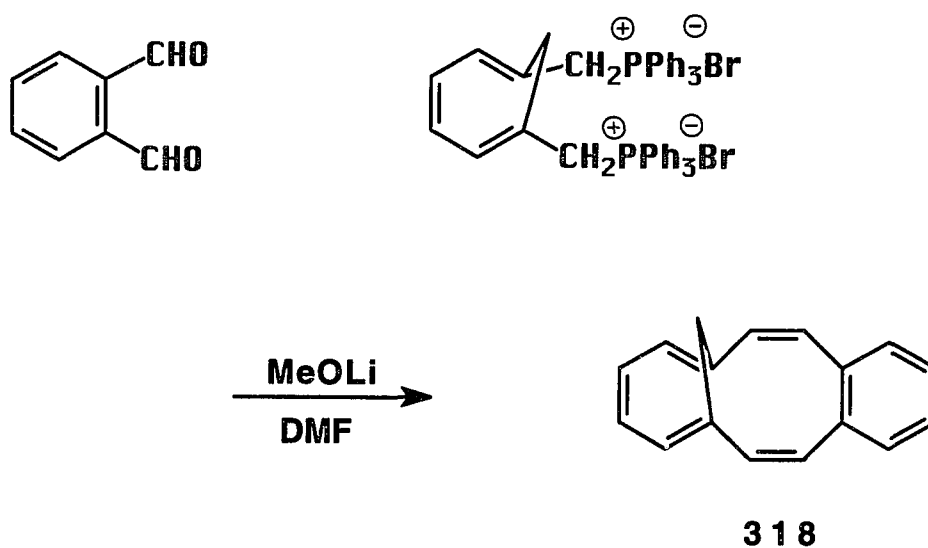


Figure 53: ^1H NMR of [12]annulene **272**.

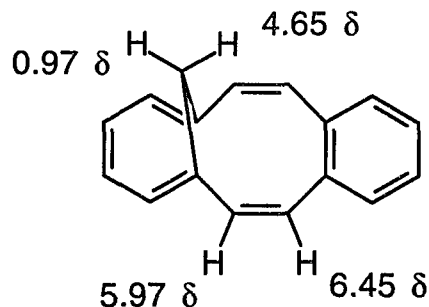
The presence of a paramagnetic ring current in **272** is strongly apparent when compared with its dihydro **316**. A 2.8 ppm downfield shift of H_{syn} exhibited in **272**, the positioning of all ring protons around 5.8 ppm with the benzene protons at higher field are clearly of a paramagnetic character.

Feldmann and Vogel¹⁵⁰ synthesized **318**, a structural isomer of **272**, via a Wittig reaction between o-phthalaldehyde and the bis-phosphonium salt derived from 1,6-bis-(bromomethyl)cycloheptatriene, as shown below.



Scheme 68: synthesis of **318**

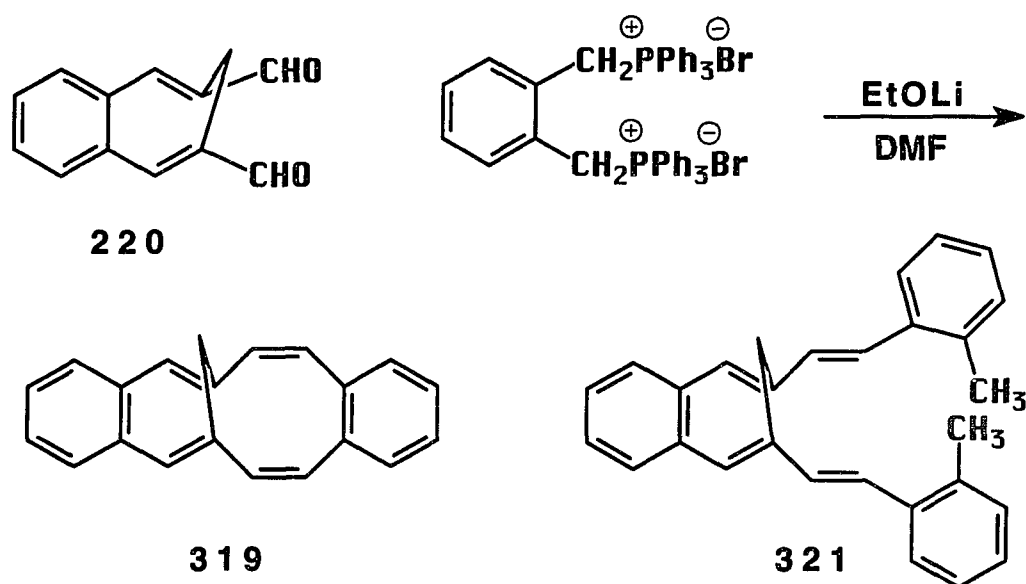
4,5-Benzo-1,8-methano[12]annulene, **318**, exhibited ¹H NMR resonances at 0.97 ppm (H_{anti} -relative to the 8 membered ring), 4.65 ppm (H_{syn}). The vinylic protons resonate at 6.45 and 5.97 ppm as shown below.



The large chemical shift difference between H_{anti} and H_{syn} of 3.68 ppm is clearly not due to ring folding only. If syn-folding were to be large, the chemical shift of H_{syn} would be expected to be of higher field due to shielding from the benzene ring.

Vogel and Mann¹⁵¹ synthesized the parent non-benzo compound **317** which showed a great deal of folding--means by which its antiaromaticity is decreased. In its ^1H NMR spectrum the bridge protons resonate at 7.00 (H_{syn}) and at 2.29 ppm (H_{anti}). The downfield position of H_{syn} is clearly due to increased paratropicity as compared with the benzo compounds **318** and **272**.

When dialdehyde **220** was allowed to condense with phosphonium salt **325** in DMF only small amounts of the dibenz compound **319** were obtained. Several condensation attempts ended with failure to obtain the desired product. In all runs, however, **321** was obtained as the major product.



Scheme 69: Synthesis of dibenzmethano[12]annulene, **319**

Examination of Table 25 yields several conclusions. **272** is clearly antiaromatic. In all cases examined so far, H_{anti} (the proton pointing towards the benzene ring and away from the larger polyenic ring) exhibited a resonance resulting from its positioning over the deshielding cone of the benzene ring. H_{syn} , similarly, was influenced by substitution at the larger ring. In **272**, however, H_{anti} is positioned at a relatively lowfield resonance with H_{syn} 3.64 ppm lower. The level of paratropicity in **272** seems to be expectably higher than that observed in thiepin **IV** which was determined only slightly antiaromatic. The degree of antiaromaticity here may be attributed to a greater conjugation through the double bond of **272**

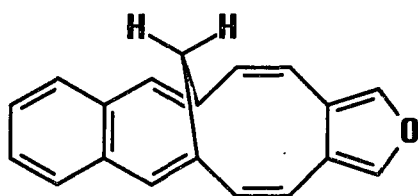
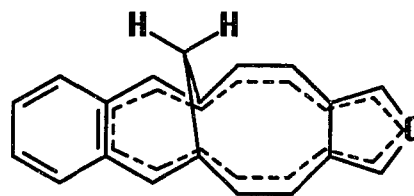
than through the sulfur atom of **IV**.

This paratropicity is, in addition, supported by dibenzmethano [12]annulene **319**. While **272** greatly resembles the non-benz methano[12]annulene **317**, **319** closely resembles monobenz **318**.

Compound	H _{syn} (ppm)	H _{anti} (ppm)	Δppm
317	7.00	2.29	4.71
272	6.01	2.37	3.64
318	4.65	0.97	3.68
319	4.37	1.50	2.87
316	3.21	2.01	1.20
255	4.94	2.09	2.85
IV	5.72	1.98	3.74

Table 25: ¹H NMR resonances for bridge protons as measurements of relative paratropicity

Recently, furano **255** has been synthesized in our lab and was found slightly antiaromatic¹⁵². Examination of Table 22 clearly positions **255** along side dibenz **319**. Similarly to benzene annelation, furan annelation results in bond fixation and ring current reduction. Furano annulene, however, is capable of through-conjugation which adds contributions from oxygen's lone pair. This results in a 16π system with increased paratropicity.

**255**

Two possible explanations may be put forth in order to explain the exceptionally lowfield resonances observed for **272**: 1) Benzannulation at C₁₀-C₁₁ does not contribute to the reduction in paratropicity as much as benzannulation at C₄-C₅ does; and 2) The extent of folding in **272** is large enough to place H_{anti} in the deshielding cone of the benzene ring rather than in its shielding cone. Reduction in paratropicity due to benzannulation relative to the non-benzmethano[12]annulene, **317**, is evident. However, it seems that due to extensive folding which further reduces the ring current, shielding or deshielding by the benzene ring plays a secondary, yet

not less important a role, as well. Methano[12]annulene, **317**, exhibits H_{anti} at 2.29 ppm which is clearly due to paratropicity. Benzannelation at C_4-C_5 as in **318** reduces the paratropicity and shifts H_{anti} by 1.32 ppm to a higher field. Reduction in the antiaromaticity observed in **317** by benzannelation at $C_{10}-C_{11}$, however, shifts H_{syn} to a higher field by 1.0 ppm while slightly deshielding H_{anti} to lower field. This seems to indicate that benzannelation as in **318** reduces paratropicity to a larger extent as compared with annelation of the type observed in **272**. Moreover, dibenz-annelation as in **319** seems to effect paratropicity only to a small extent, and so the largest reduction is indeed observed in **318**.

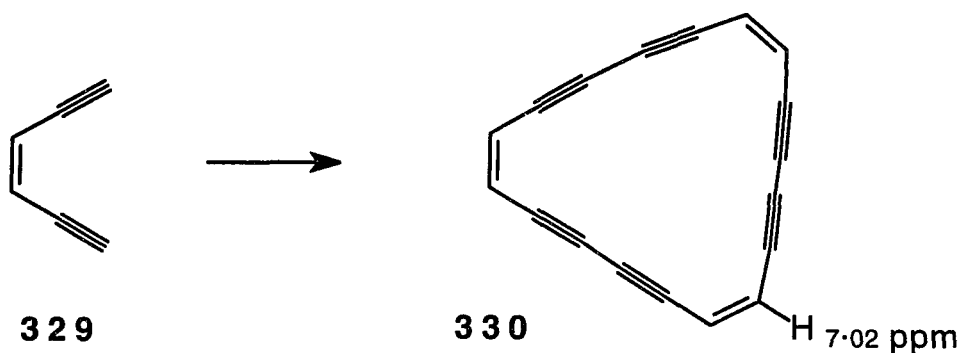
These indications are supported by examination of the ring skeleton resonances. Benz **318** and dibenz-**319** exhibit a lower field resonances for the 8-membered ring skeleton as compared with **317** and **272**. The AA'BB' resonances of the annelating benzene ring in **318** is of highest field which again is in support of the paratropicity argument. Therefore, one can conclude reduction of paratropicity in the order **317**, **272**, **318**, **319** with **317** being strongly paratropic and **319** only very slightly.

The effects on the bridge protons by each other as was discussed earlier should be considered too, but these are much more difficult to assess.

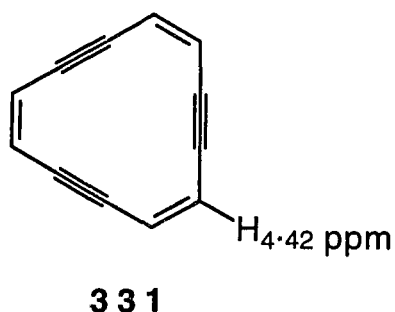
2.6.0 SYNTHESIS AND INVESTIGATIONS OF [30]ANNULENE, 340.

Ever since the classical work of Sondheimer, macrocyclic oligoalkynes have been of continued interest¹⁵³.

1,3,7,9,13,15-hexadehydro[18]annulene, **330** has been synthesized by Sondheimer via cupric acetate oxidation of enediyne **329** in 3.1% yield¹⁵⁴.

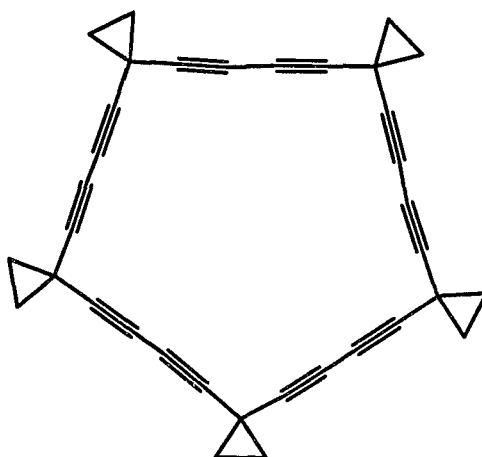


¹H NMR of **330** consisted of a singlet at 7.02 ppm. A down field shift of 2.60 ppm relative to 1,5,9-tridehydro[12]annulene, **331**¹⁵⁵, was consistent with the existence of a diamagnetic ring current in **330**.



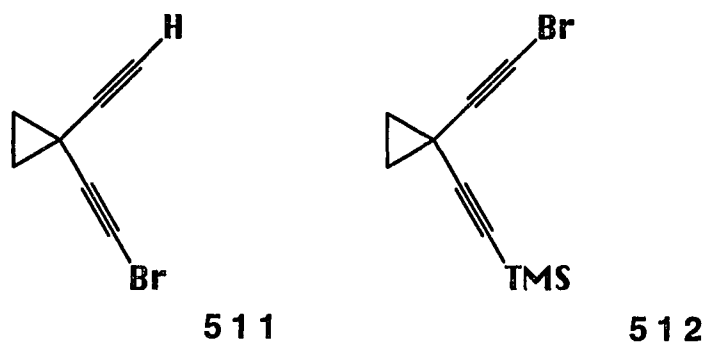
Hexahydroannulene **330** was found to be a crystalline substance that decomposes within a few hours at room temperature or violently upon attempted melting point determination.

More recently, de Meijere and Scott¹⁵⁶ reported the synthesis of series of exploding[n]rotanes, **332**, of interesting structures and chemistry.

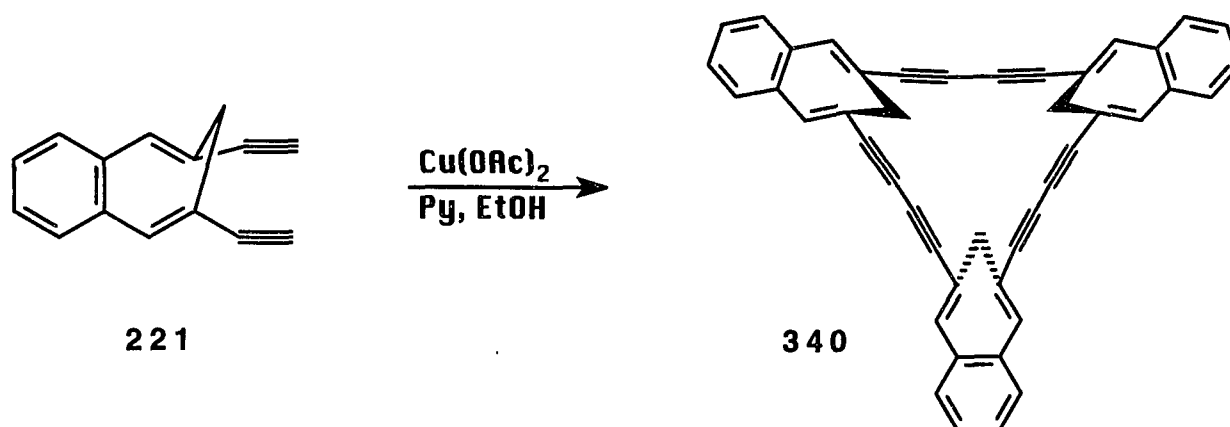


332

Starting from building blocks such as **333** and **334** and utilizing copper catalyzed coupling of the acetylene and successive desilylations, de Meijere et al were able to construct **332** and its higher homologous (5 to 8 cyclopropyl diyne units) in variable yields.



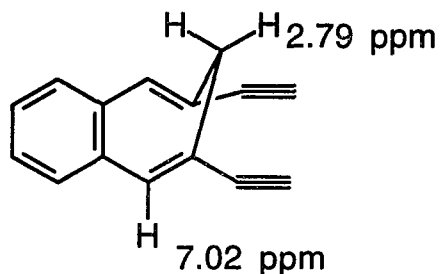
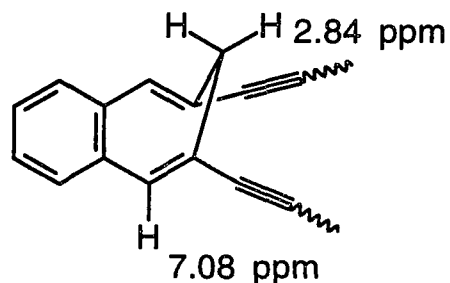
Eglinton type coupling¹⁵⁷ was utilized in the synthesis of trimer **340**, known in short as tribenz-trismethano[30]annulene, the first known methano bridged [30]annulene. 1,6-Diethynyl-3,4-benzcycloheptatriene, **221**, was added to a solution of $\text{Cu}(\text{OAc})_2$, pyridine and ethanol in ether and was allowed to reflux for 45 minutes, then stir over night. From the dark mixture **340** was separated as yellow needles in 25.0% yield.



Scheme 70: synthesis of trimer **340**

The compound is stable in solution but tends to decompose over time. In the solid, it deteriorates to a brown char. No melting point was determined. Similarly to the observations made by de Meijere and Scott, trimer **340** showed an ambiguous MS (EI) spectrum resulting from irregular fragmentation.

Trimer **340** showed, however, a rather simple ^1H NMR consisting of a singlet at 2.84 ppm corresponding to the bridge CH_2 group, a singlet for the CH proton at 7.08 ppm and an AA'BB' quartet at 7.34 ppm for the benzene rings. This spectra indicates the existing ability of the three bridge groups to invert through the ring cavity. Attempts to slow this inversion on the NMR time scale by low temperature experiments, yielded no changes in the spectrum.

**221****340**

Both ^1H and ^{13}C NMR of **340** exhibited no significant chemical shift differences from the monomer **221**. In fact, no differences in the chemical shift of the bridge protons were observed to indicate diamagnetic ring current in this formally 30π electron, aromatic

system; Notice the relatively identical ^{13}C NMR spectra of the trimer and its monomer presented next.

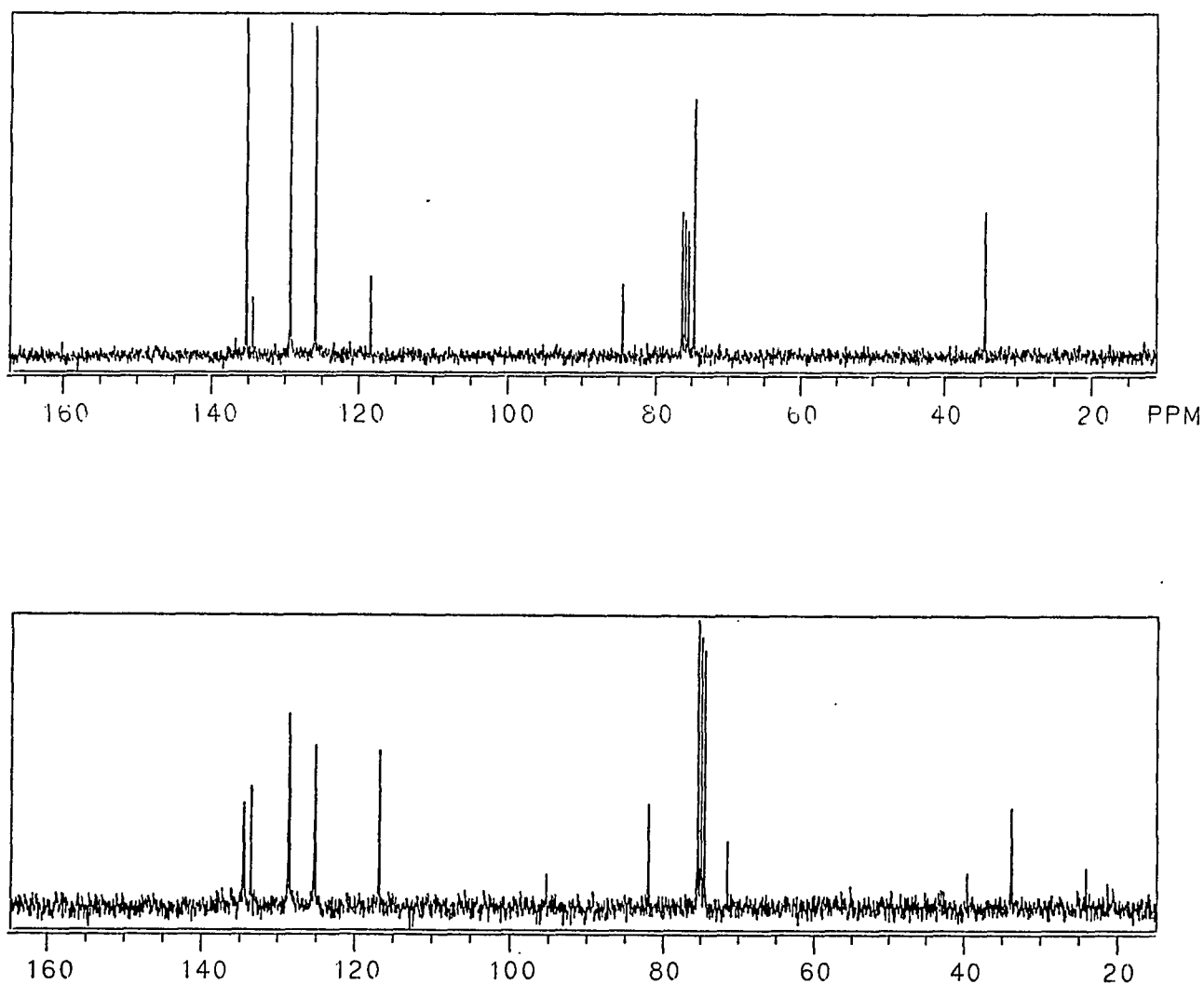


Figure 54: ^{13}C NMR of monomer **221** (top) and [30]annulene **340**.

The resonance energy in the large [30]annulene system is too small to warrant delocalization leading to an observable ring current. that the compound, thus, remains delocalized acetylenic-polyenic system.

On X-ray analysis, the crystals obtained for **340** (recrystallized from hexane/ethyl acetate) were observed to decompose; nevertheless, an unrefined X-ray structure was obtained which showed the trimer to favor a conformation where one bridge CH₂ group is anti to the other two, as shown below. In solution, however, as previously indicated, NMR studies indicated dynamic inversion.

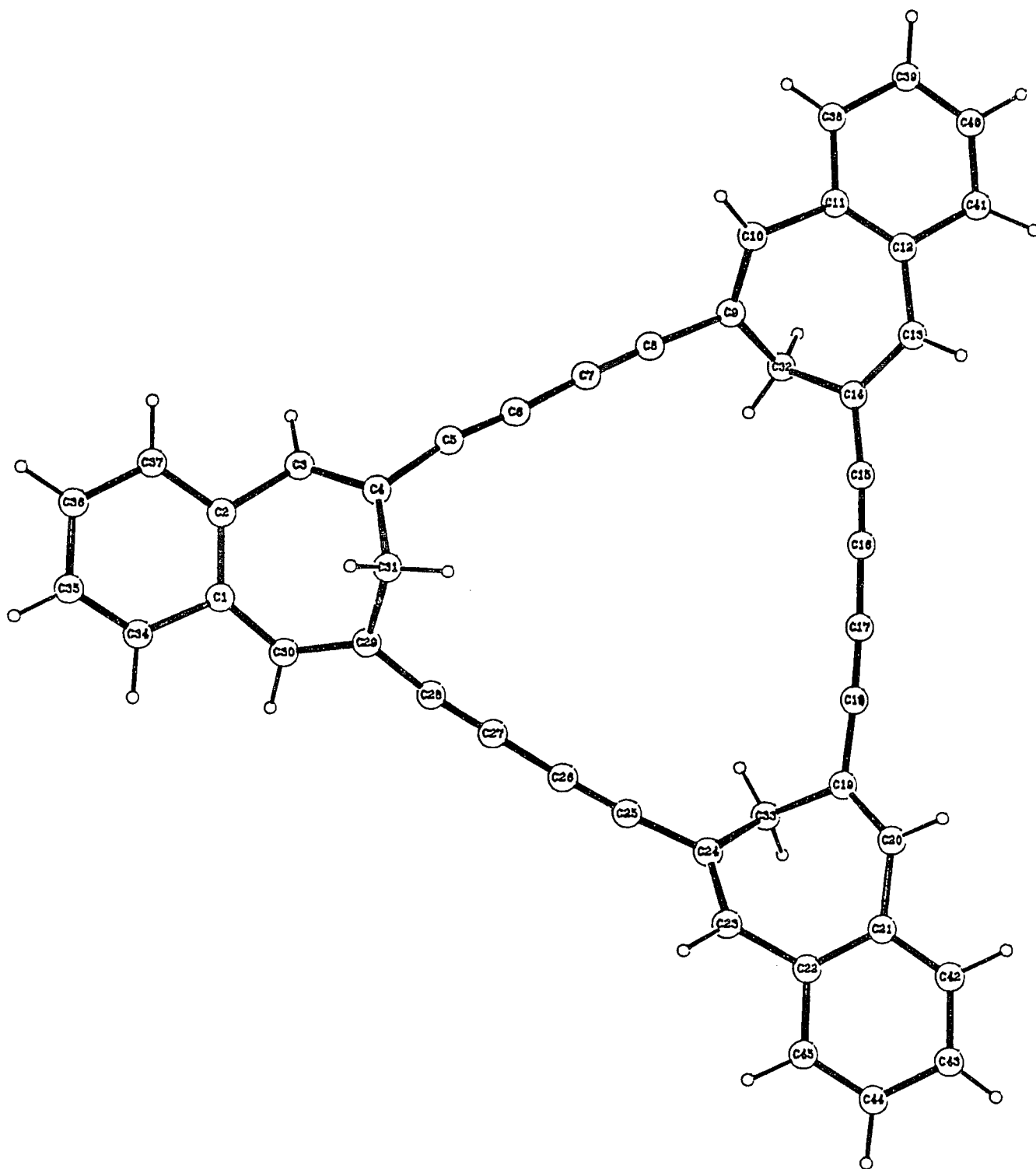
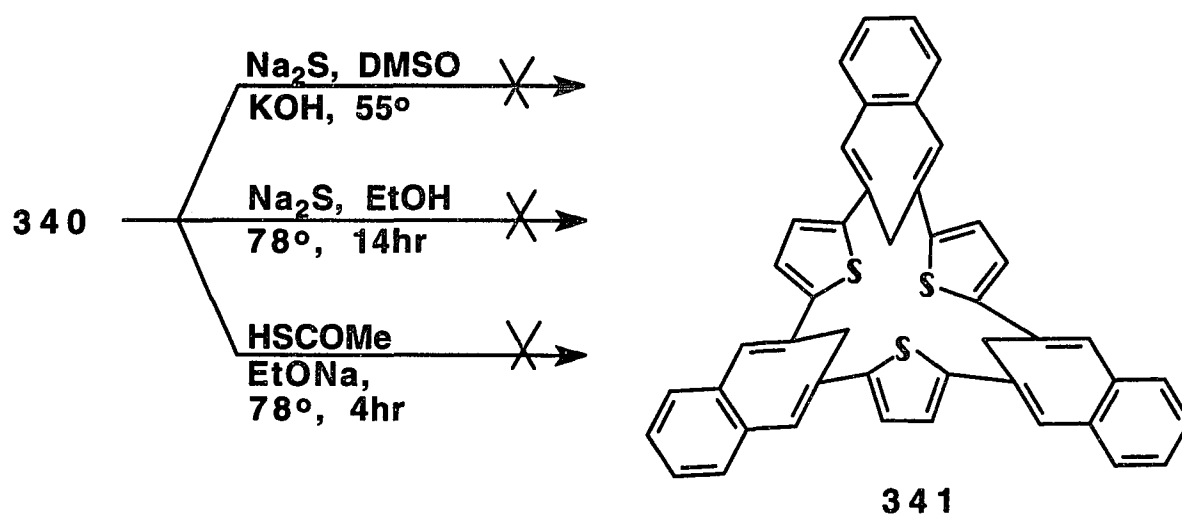


Figure 55: ORTEP drawing of trimer 340.

Sulfide addition to **340** was expected to result in the formation of trithiophene **341**. Several attempts at synthesizing this beautiful molecule failed with recovery of large quantities of the starting material, **340**.



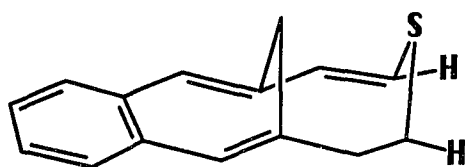
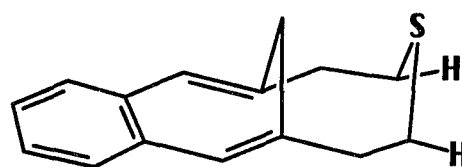
Scheme 71: Attempted synthesis of thiophene trimer **341**.

A GLANCE TO THE FUTURE

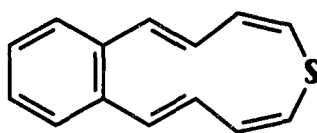
Well, indeed there is still a lot to be done. With the presented facile synthesis of benzcycloheptatriene the compound takes on a reagent status. With the simplicity of conversion the compound opens a great door for the study of aromaticity and antiaromaticity of benzannelated systems. In this regard a few interesting points are worth exploring in a future continuation of this work. Hereby I present my ideas and methodologies that had been considered but never executed.

The investigation of the effects of benzannelation and methano bridging on the thiepin system of type **IV** may be further explored by the synthesis of the three compounds shown below. Dihydro thiepin, **343**, along with tetrahydro thiepin, **344**, may shed more light on the effects of paramagnetic ring current on **IV**. The expected chemical shift differences observed for the vinyl segment in the ^1H NMR as one goes from **344** to **IV** should further support our argument as to the paratropicity that exists in thiepin **IV**. On a more practical basis, tetrahydro thiepin, **344**, may be oxidized to the corresponding sulfone and allow to undergo Ramberg-Bäcklund transformation to the dihydro benz[10]annulene.

The synthesis of both **343** and **344** should proceed smoothly by hydrogenation of Thiepin **IV**.

**343****344**

The non-methano[11]annulene, **345**, is expected to be a sensitive, rather unstable thiepin like system. In fact it is expected to be stable enough for isolation. The synthesis of this compound is of great importance for the understanding of the contribution of methano bridging to antiaromatic systems. Vogel's idea that methano bridging may stabilize an aromatic system such as [10]annulene may be extended to the $4n$ systems. The larger angle deviation that the sulfur atom imposes on the ring system may be sufficient to reduce H-H repulsions inside the ring system.

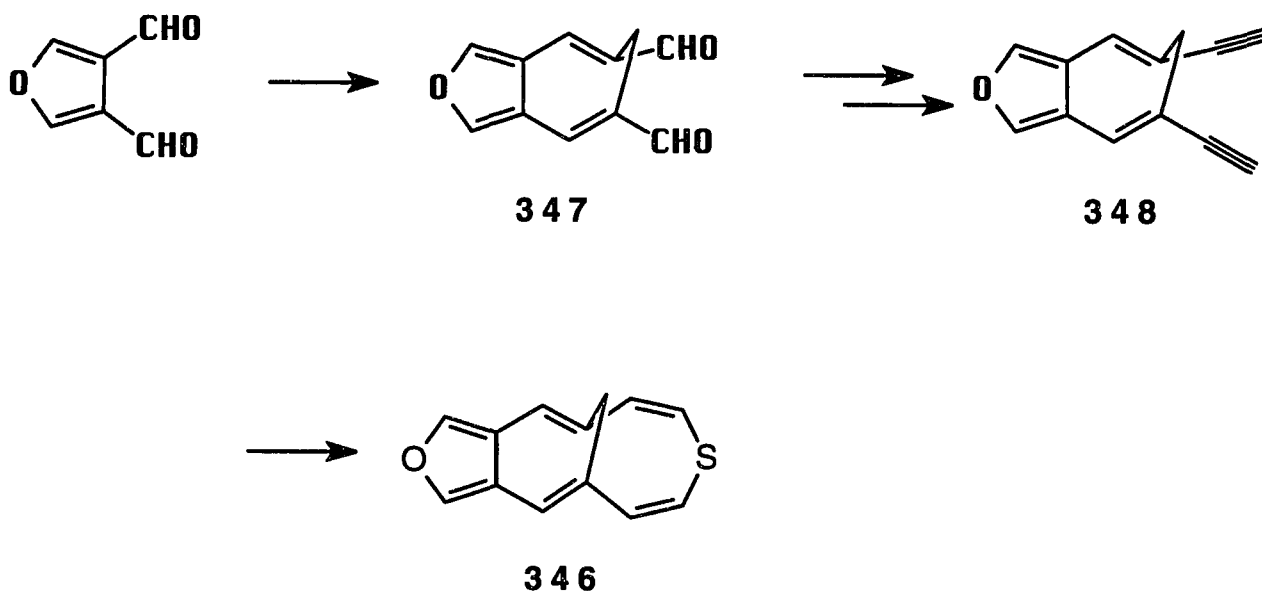
**345**

The synthesis of **345** should proceed readily. Wittig reaction

between o-phthalaldehyde and the phosphonium salt derived from propargyl bromide in the presence of DBU should result in bis-trans eneyne system. Sulfide addition of sodium disulfide to the diyne should proceed smoothly in DMF with suspended KOH pellets, at room temperature.

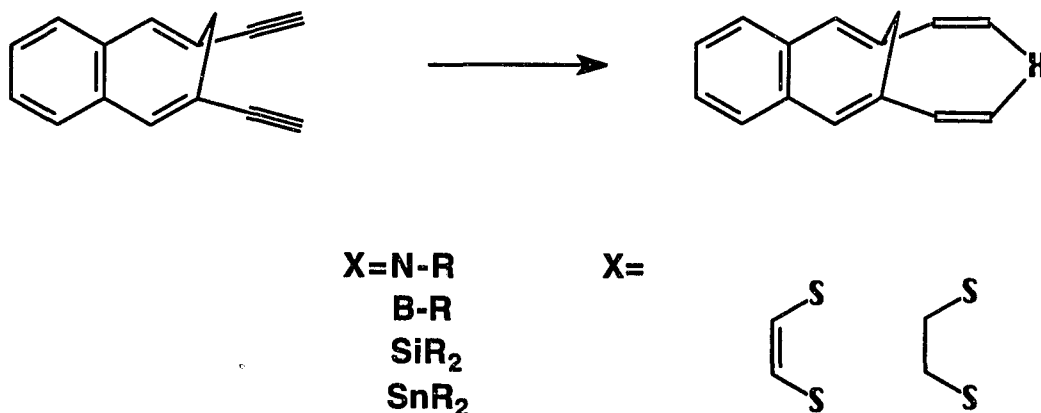
It is possible that under such conditions oxidation may result to yield naphthothiepin as a side product.

The effects of bond fixation and reduction of ring currents by benzannulation may be further examined by the synthesis of furanothiepin **346**.



The synthesis may begin by condensing furan-3,4-dicarboxaldehyde with glutaric dialdehyde under the reaction conditions described herein. Conversion of the new cycloheptatriene system, **347**, to the corresponding diacetylene via the Mckelvie-Fuchs sequence should yield **348** in good yields. Conversion to **346** with sodium sulfide should proceed with no difficulties. Similarly to thiepin **IV** furanothiepin **346** is not expected to extrude sulfur. With **346** bond fixation is larger thus extrusion is less probable. However, **346** may be allowed to extrude sulfur if treated with a dienophile at which time a simple, non annelated system is present. This too may be a method of generating benzmethano[10]annulene.

Several heterosubstituted heteropins can be synthesized easily through nucleophilic addition to diethynyl **221**. A few cases are shown below. These too may contribute to the evaluation of paramagnetic/diamagnetic or rather homoaromatic character of these heterosubstituted [11]annulene.



Treatment of the bismethano[10]annulene **270** with base such as KH or KND₂ in an appropriate media should result in the formation of an antiaromatic 12 π system. The study of this system may too contribute to the determination of the effects imposed by benzannelation and may be a true paramagnetic model to which thiepin **IV** may be compared.

5.0.0 Experimental section

5.1.0 General Procedure

All glassware used in moisture or air sensitive reactions was oven-dried at 125°C overnight then assembled and flushed with nitrogen or argon. A common set-up included a three-neck round bottom flask fitted with a pressure equalizing dropping funnel, a condenser and a thermometer. The condenser was usually fitted with a three-way connecting tube for inert atmosphere inlet and a drying tube containing KOH or CaCl₂. Stirring is achieved by means of a magnetic stirrer or mechanical stirrer equipped with a ground glass oil-sealed shaft. Standard work-up included quenching with cold aqueous solution of acid or base, extraction with an organic solvent such as ether or CH₂Cl₂, drying the organic solvent with magnesium sulfate or sodium sulfate, and evaporation of the organic solvent by rotary evaporation in vacuo at a water aspiration of about 11 torr. Acid or basic neutralization was achieved by the addition of saturated sodium bicarbonate for acid neutralization or dilute HCl for base neutralization.

5.2.0 Spectroscopy

Proton and carbon NMR were collected by a 300MHz General Electric QE-300 Nuclear Magnetic Resonance spectrometer. Variable temperature NMR studies were performed on a Jeol 400MHz spectrometer. 2D-NOESY experiments were all performed on a Varian UnityPlus 500MHz spectrometer. All samples were prepared by dissolving a suitable amount of the compound in a deuterated solvent (usually CDCl_3 , 99.8% D, 0.03% V/V TMS) in a thin walled glass tube. Chemical shifts are reported in ppm downfield from TMS, $\delta=0$, and are expressed in the following order: Chemical Shift (ppm), Multiplicity (s=singlet, d=doublet, t=triplet, b=broad, m=multiplet, etc), Coupling Constants (Hz).

Infra-Red spectra were recorded on a Perkin-Elmer 1600 FTIR and are reported in wave numbers (cm^{-1}). Liquid samples or CCl_4 -soluble samples were examined by placing them between two sodium chloride plates or in solution cells in case of the later. Solid samples were recorded as KBr pellets.

Gas Chromatography-Mass spectra were determined by either of two methods: EI or CI, on a Hewlett-Packard 5890, Series II GC/5989A mass spectrometer. Samples of high molecular weights were analyzed by direct probe inlet. The results are expressed as molecular ion (M^+), and base peak(s) (100%).

X-ray crystal structure determinations were performed on an Enraf-Nonius CAD4 diffractometer (graphite-monochromated Cu K α radiation, ω - 2θ scans). The structures were solved by a multiple-solution procedure and were refined by full matrix least squares. In the final refinement, the nonhydrogen atoms were refined anisotropically. The hydrogen atoms were included in the structure-factor calculations but their parameters are not refined.

Elemental Analysis was used to confirm the exact elemental composition of the hydrocarbons synthesized. Unfortunately, their great tendencies of air oxidation resulted in inaccurate analyses.

Melting points were determined using a Büchi Schmelzpunkbestimmungs instrument in soft-glass capillaries. All melting points are uncorrected.

Thin-layer chromatography was performed using pre-coated plastic sheets of silica gel, 0.25 mm in thickness, supplied by Macherey-Nagel. UV active compounds were observed by 254 nm UV lamp. Non UV-active compounds were observed by phosphomolybdic acid in ethanol.

Solvents were purified as follows:

Tetrahydrofuran:	Distilled over CaH_2 then over potassium metal.
Dichloromethane:	Distilled over CaH_2 .
Ethyl Acetate:	Distilled over CaH_2 .
Hexanes:	Distilled over CaH_2 .
Benzene:	Distilled over CaH_2 .
Toluene:	Distilled over CaH_2 .
Dimethylsulfoxide:	Distilled over CaH_2 .
Diisopropyl amine:	Distilled over sodium metal.
Methanol:	Distilled over magnesium metal.
Acetonitrile:	Distilled over CaH_2 .

5.3.0 Experimental procedures

2,5-Diphenylthiophene (103) In a 250 ml, 2-neck round bottom flask, under a blanket of nitrogen, 0.713g (31 mmoles) sodium metal was added to 20 ml absolute ethanol and allowed to dissolve. Then, 2.28g (30 mmoles) thiolacetic acid in 5 ml ether were added and the solution was allowed to stir for 20 minutes before 1.0g (5.0 mmoles) diphenyl diacetylene, **101**, was added. The solution was refluxed for 2.5 hrs, cooled down, poured on ice and extracted with CH₂Cl₂ (3 x 50 ml). Organic extracts were combined, washed with dilute acid, brine and water, dried over MgSO₄ and evaporated. The crude oil was triturated with hexane to yield 0.150g of **103** as a white solid, and 0.760 g starting material (76.0% yield). **mp**: 148-149° (lit. 149-150); **¹H NMR** (300 MHz, CDCl₃): δ=7.27 (s, 2H), 7.37-7.75 (m, 10); **¹³C NMR**: δ=124.0, 125.7, 127.6, 129.0, 134.5, 143.7; **IR** (CCl₄): 805, 751, 684, 534 452 cm⁻¹; **MS** (EI): M⁺ 236 m/z.

Cis-1,2-bis(benzylmercapto)ethene (104) 500 ml of absolute ethanol in a 1000 ml 2-neck round bottom flask, fitted with an addition funnel, and under an inert atmosphere, were treated with 20.8g (0.904 moles) sodium metal, added in small portions and allowed to completely dissolve. 63.3 g (0.150 moles) Benzylmercaptan was then added in one portion and allowed to equilibrate to a clear, colorless solution. The solution was cooled down to 5° (ice bath) at which time 16.8g (0.174 moles) cis-dichloromethane in 50 ml ethanol were added dropwise over a 25 min period. Solution was let stir at 5° for 10 additional minutes, then refluxed for 3 hours. Reaction mixture was cooled down, poured on ice/dilute acid mixture and was extracted with ether (3 x 70 ml), dried over MgSO₄ and evaporated to yield a yellow oil which crystallized upon addition of hexane. Recrystallization from pentane yielded 43.78g (92.5%) **104** as white solid. **mp**: 60-61° (Lit. 61°) **¹H NMR** (300 MHz, CDCl₃): δ=3.89 (s, 4H), 6.00 (s, 2H), 7.3-7.45 (m, 10H); **¹³C NMR**: δ=39.2, 124.2, 128.3, 129.7, 130.0, 138.7; **IR** (CCl₄): 3023, 1675, 1490, 1451, 1418, 1241, 1069, 815, 699, 659 cm⁻¹; **MS**

(EI): M^+ 272, 91 (100%) m/z .

E,Z-Distyrylsulfide (106) A 250 ml round bottom flask fitted with a reflux condenser and under an atmosphere of argon is charged with 100 ml absolute ethanol, 5.0g (49.0 mmoles) phenylacetylene and 7.9g (35.2 mmoles) sodium sulfide nonahydrate. The solution is stirred at room temperature until all the sulfide is dissolved at which point it is dark. Then the solution is refluxed for 10 hours, poured on ice/dilute acid and extracted with CH_2Cl_2 (45 ml x 3). The combined extracts are dried and evaporated to yield a solid which is crystallized from hexane. **106** is collected as white flakes in total yield of 1.0g (17.1%). **Mp**: 96-97°; **^1H NMR** (300 MHz, CDCl_3): δ = 6.55 (d, 2H, J =10.8 Hz), 6.75 (d, 2H, J =15.6 Hz), 7.35 (m, 10H); **MS** (EI): M^+ 238 (100%) m/z .

cis-1-Acetylmercapto-2-phenylethene(107) In a dry 50 ml, 3 neck round bottom flask added 5 ml n-pentane, 11.51g (0.11 mole) phenylacetylene and 7.75g (0.101 mole) thiolacetic acid. The solution is allowed to reflux for 12 hours, then poured on ice and extracted with ether. The 3 ether extracts (100 ml) are dried and evaporated to yield 14.72g of crude oil which is distilled at 125° (oil bath) to yield 9.69g of colorless oil ($\text{Bp}_{0.025}$ =82°). The oil crystallizes slowly from pentane (53.9% yield). **mp**: 43-44° (Lit. 43-45°); **^1H NMR** (300 MHz, CDCl_3): δ = 2.38 (s, 3H), 6.71 (d, 1H, J =11.0 Hz), 6.93 (d, 1H, J =11.0 Hz) 7.3 (m, 5H); **^{13}C NMR**: δ = 31.9, 118.2, 128.8, 129.6, 129.9, 130.0, 137.4, 192.3; **IR** (Neat): 3038, 1708, 1490, 1445, 1352, 1120, 954, 689, 607 cm^{-1} . **MS** (EI): M^+ 178, 136 (100%).

S-Benzylisothiuronium Chloride (111) A 1 liter round bottom flask is charged with 76.0g (1.0 mole) thiourea and 200 ml of water. The solution is warmed up to assist solubility then treated with 135 ml ethanol and 126.5g (1.0 mole) of benzyl bromide. The thick solution is carefully refluxed for 1.5 hours, cooled and allowed to crystallize on ice. Crystallization occurs within 30 minutes. The white crystals are collected and washed with ethanol. Mother liquor

is concentrated and two additional fractions are collected and recrystallized from 0.2M HCl. Total yield is 176.2g (88.0%). **mp**: 174-175°.

cis, cis-di(benzylmercapto)butadiene (112) METHOD A: In a flame dried 2-liter, 3 neck round bottom flask at -35° condensed 600 ml of triply dried liquid ammonia. Then added 13.6g (0.50 mole) sodium in small portions until the blue color persisted.) 0.400g Fe(NO₃)₃ were not added as fine powder and the mixture was allowed to stir until a brown suspension of NaNH₂ was observed in the flask (about 1.5 hours.) Then, 18.6g (0.15 moles) 1,4-dichloro-2-butyne was added dropwise over a 15 min period. The reaction was noticed exothermic, therefore, cooled to further maintain the temperature at or below -30°. After additional 30 minutes of stirring and after the reaction had turned dark brown, 37.6ml (39.8g, 0.320 mole) benzylmercaptan were added dropwise. Stirring continued for 10 min after the addition was completed, then 300 ml of ether were added and the ammonia was allowed to evaporate. Then saturated solution of ammonium chloride was added, the solution extracted with ether, washed with acid, dried and evaporated to yield the mono acetylene **178** (85.0%) and **112** (10%). **178** Was added without further purification to a 200ml ethanol solution previously treated with 40.1g (0.716 mole) of sodium and 50.5 ml (0.430 mole) benzylmercaptan and allowed to reflux for 3 hours. The reaction is cooled down and treated with hexane. The solid precipitated is collected and recrystallized from hexane to yield 33.0 g (72.8%) of a colorless solid.

mp: 127-128.5° (Lit. 129°); **¹H NMR** (300 MHz, CDCl₃): δ=3.89 (s, 4H), 6.02 (q, 2H, J=2.1, 6.6 Hz), 6.30 (q, 2H, J=2.1, 6.6 Hz), 7.30 (m, 10H); **¹³C NMR**: δ= 38.3, 123.3, 127.0, 127.3, 128.7, 128.9, 137.8; **IR** (CCl₄): 3025, 1595, 1523, 1495, 1453, 1309, 1238, 1066, 916, 673; **MS** (EI): M+ 298, 91 (100%)

Spectral data of 178:

¹H NMR (300 MHz, CDCl₃): δ= 3.38 (d, 1H, J=2.5 Hz), 3.97 (s, 2H), 5.45 (dd, 1H, J=10.8, 2.5 Hz), 6.55 (d, 1H, J=10.8 Hz), 7.3 (m, 5H); **¹³C NMR**: δ= 38.9, 86.5, 105.0, 127.3, 128.0, 130.0, 130.3, 138.2, 142.5; **IR** (neat): 3285, 3028, 2089, 1601, 1560, 1493, 1452, 1242, 1071,

1028, 760, 700 cm^{-1} ;

MS (EI): M^+ 174, 91 (100%).

METHOD B: In a 250ml round bottom flask fitted with a dry ice condenser, under an atmosphere of argon, added 30ml of 50% KOH solution and 3.05g (15.2 mmole) salt **111** and let stir until all the salt had dissolved. Then lowered temperature to 0° and added 0.420g (2.53 mmole) 2,7-dimethyl-3,5-octadiyne-2,7-diol in 15 ml of ethanol. Let stir at 0° for one additional hour, then warmed up and refluxed for 3 hours. Solid was observed in the bottom of the flask upon cooling. Poured on ice without acidification and extracted with CH_2Cl_2 (3 x 45 ml) to yield an orange oil. Chromatography on silica gel (5:1 hexane:ethyl acetate) yielded 0.75g (16.0%) of **112** and 0.90g (37.7%) of **180** as a sensitive solid.

Spectral data of 180:

^1H NMR (300 MHz, CDCl_3): δ = 1.35 (s, 6H), 3.8 (s, 2H), 3.9 (s, 2H), 5.2 (bs, 1H), 6.2 (d, 1H), 6.5 (t, 1H), 6.9 (d, 1H), 7.2 (m, 10H); **IR** (CCl_4): 3442, 2974, 1600, 1494, 1453, 733, 699 cm^{-1} .

When the reaction is carried out identically but at room temperature, hemimercaptal **181** is obtained in 27.7% yield as a brown solid. **^1H NMR** (300 MHz, CDCl_3): δ = 1.38 (s, 6H), 3.83 (s, 2H), 7.09 (s, 1H), 7.4 (m, 5H); **^{13}C NMR**: δ =30.0, 42.5, 76.0, 128.5, 129.5, 130.5, 132.5, 139.0; **IR** (CCl_4): 3296, 2967, 1494, 1453, 1356, 1157, 967, 706 cm^{-1} .

When the reaction is carried out identically but at refluxing temperature, **182** is obtained in 81.1% yield. **mp**: $41-42.5^\circ$; **^1H NMR** (300 MHz, CDCl_3): δ = 3.15 (s, 4H), 3.87 (s, 4H), 7.3 (m, 10H); **^{13}C NMR**: δ = 19.3, 35.8, 79.3, 127.3, 128.7, 129.2, 137.8; **IR** (CCl_4): 3028, 2911, 1601, 1493, 1453, 1229, 1070, 698 cm^{-1} .

1-(N,N-dimethylamino)naphthalene (114) 14.5g (0.101 mole) 1-aminonaphthalene is added to a 500 ml round bottom flask containing 50 ml of water and 34.0g (0.404 mole) sodium bicarbonate. The heterogenous solution is allowed to stir while 34 ml (45.3g, 0.360 mole) dimethylsulfate is added portionwise over a 25 minute period. At this point, the reaction is quite exothermic. When carbon dioxide evolution stops (20 minutes), the reaction is

treated with 70 ml of 10% KOH and allowed to reflux for 1.5 hours. pH is adjusted to ~9 at the end of the reflux period, the solution is extracted with ether. Extracts are combined, dried over MgSO₄, and evaporated to yield a red oil. Distillation on a pump yields 10.9g of a colorless oil (63.0%). **bp**: 85° at 0.02 torr. **¹H NMR** (300 MHz, CDCl₃): δ= 2.85 (s, 6H), 7.01 (d, 1H), 7.4 (m, 4H), 7.77 (d, 1H), 8.21 (d, 1H); **¹³C NMR**: δ= 46.3, 115.1, 124.0, 125.3, 126.3, 126.8, 126.9, 129.5, 130.0, 136.0, 152.0.

Cis-2,3-bis(β-benzylmercaptovinyl)naphthalene (115) Into a dry 25 ml round bottom flask was added 5 ml absolute ethanol and 0.160g (6.4 mmole) sodium metal. The sodium was allowed to dissolve, then the solution was charged with 0.8g (6.4 mmoles) benzylmercaptan and was allowed to equilibrate. At the end of a 30-minute period 0.28g (1.6 mmoles) 2,3-diethynylnaphthalene was added dissolved in 5 ml of ethanol. The solution was refluxed for 2.5 hours, poured on ice and extracted with CH₂Cl₂ with out neutralization. Organic layers were combined (50 ml), dried over MgSO₄ and evaporated. The resulting brown oil was chromatographed on silica gel (5:1 hexane:ethyl acetate) to yield 0.870g (55.2%) of **115** as a colorless solid (recrystallized from ether). Alternatively, salt **111** may be used in a water solution in place of benzylmercaptan in ethanol, employing an identical set of conditions. **mp**: 126-127°; **¹H NMR** (300 MHz, CDCl₃): δ= 3.98 (s, 4H), 6.60 (d, 2H), 6.39 (d, 2H), 7.35 (m, 10H), 7.41 (q, 2H), 7.80 (q, 2H), 7.95 (s, 2H); **¹³C NMR**: δ= 39.2, 124.4, 126.1, 127.4, 127.6, 127.7, 127.8, 128.7, 129.1, 132.2, 133.3, 137.6; **MS** (EI): M⁺ 424 m/z.

Cis-(β-benzylmercaptovinyl)benzene (117) Similarly to the preparation of **115** above, **117** was prepared in 93.2% yield as a colorless oil. **bp**: 122° at 0.005 torr; **¹H NMR** (300 MHz, CDCl₃): δ= 3.99 (s, 2H), 6.24 (d, 1H), 6.41 (d, 1H), 7.25 (m, 10H); **¹³C NMR**: δ= 39.7, 126.0, 126.2, 126.9, 127.5, 128.4, 128.8, 129.1, 137.0, 137.5; **IR** (neat): 3026, 2922, 1598, 1492, 1443, 1361, 1242, 1071, 1028, 836, 773, 698 cm⁻¹.

Cis-1,2-bis(Z-2-phenylvinylmercapto)ethene (118) 50 ml absolute ethanol and 1.35g (58.7 mmole) were added under argon to a 200 ml round bottom flask and stirred until all metal had dissolved. Next, 1.5g (8.43 mmole) of cis-1-acetylmercapto-2-phenylethene was added in one portion. When all the solid had dissolved, the temperature was lowered to 5° (ice bath) and 0.400g (4.13 mmole) cis-1,2-dichloromethane in 10 ml ethanol were added dropwise over a 15 minute period. Upon complete addition, the reaction is refluxed for 4 hours and is worked up with water and extracted with ether. The ether layer are washed off with dilute acid, dried and evaporated to yield a yellow oil. Chromatography on silica gel (5:1 hexane:ethyl acetate) yields 0.86g (70.3%) of **118** as white needles. **mp:** 79-80°; **¹H NMR** (300 MHz, CDCl₃): δ= 6.33 (d, 2H, J=10.7 Hz), 6.36 (s, 2H), 6.54 (d, 2H, J=10.7 Hz), 7.4 (m, 10H); **¹³C NMR:** δ= 125.0, 125.3, 128.1, 128.3, 129.5, 129.8; **IR** (CCl₄): 3023, 1597, 1542, 1490, 1443, 1359, 1288, 1102, 821, 771, 734, 683 cm⁻¹; **MS** (EI): M⁺ 296, 283 (100%) m/z.

Bis(Z-2-phenylvinylmercapto)methane (119) 20 ml methanol and 0.200g (8.70 mmole) were added under argon to a 100 ml round bottom flask and stirred until all metal had dissolved. Then, 1.0g (5.6 mmole) of cis-1-acetylmercapto-2-phenylethene was added in one portion. When all the solid had dissolved added 1.56g (8.9 mmole) dibromomethane in 5 ml methanol. Let stir at room temperature for one hour then reflux for 45 minutes. Ice water was added to the cooled reaction mixture, followed by 25 ml of CH₂Cl₂. Layers were separated, aqueous layer extracted with 2 additional portions of methylene chloride, and the extracts were dried and evaporated. Chromatography on silica gel (5:1 hexane:ethyl acetate) yielded 0.670g (84.2%) of **119** as a white solid. **mp:** 57-59°; **¹H NMR** (300 MHz, CDCl₃): δ=4.06 (s, 2H), 6.42 (d, 2H, J=10.8 Hz), 6.58 (d, 2H, J=10.8 Hz), 7.34 (m, 10H); **¹³C NMR:** δ= 41.2, 125.0, 128.2, 128.7, 129.4, 129.7, 137.7; **IR** (CCl₄): 3023, 2921, 1599, 1491, 1443, 1359, 1202, 1076, 1028, 694 cm⁻¹; **MS** (EI): M⁺ 284, 149 (100%), 115 (100%).

Bis(Z-2-phenylvinyl)disulfide (120) 20 ml methanol and 0.100g (4.34 mmole) were added under argon to a 100 ml round bottom flask and stirred until all metal had dissolved. Then, temperature was lowered to -20° at which time 0.450g (2.53 mmole) of cis-1-acetylmercapto-2-phenylethene was added in one portion. When all the solid had dissolved added iodine solution (in MeOH) to the equivalent point. When no more I₂ was decolorizing, warmed the solution to room temperature and continued the addition of the iodine solution, again to an equivalent point. Let the solution stir at room temperature for 30 minutes, then poured into water and extracted with methylene chloride (3 x 25 ml). Dried the organic extracts and evaporated to yield a solid. Crystallization from n-pentane yielded 0.30g (87.9%) of **120** as a white solid. **Mp**: 57-59°; **¹H NMR** (300 MHz, CDCl₃): δ= 6.41 (d, 1H, J=10.8 Hz), 6.53 (d, 1H, J=10.8 Hz), 7.36 (m, 10H); **¹³C NMR**: δ= 128.7, 129.5, 130.0, 132.1, 136.9; **IR** (CCl₄): 3025, 1601, 1491, 1444, 1347, 843, 692 cm⁻¹; **MS** (EI): M⁺ 270, 236 (100%).

6,7-dibromo-1,4-dihydronaphthalene-1,4-epoxide (123) 11.81g (30 mmoles) 1,2,4,5-tetrabromobenzene and 20 ml distilled furan were dissolved in 200 ml freshly distilled toluene and the solution was cooled to -30° in a 500 ml 3-neck round bottom flask under argon. To the cooled solution, added now, dropwise, over a period of 70 minutes, 13.2 ml (2.5 M in hexane, 33 mmoles) BuLi. The resulting yellow solution was warmed up slowly to room temperature, treated with 3 ml of methanol and washed with water. Extraction with CH₂Cl₂, followed by chromatography of the resulting solid, yielded 7.00g (77.3%) of endoxide **123** as a white solid which crystallizes beautifully from hexane. **mp**: 115-116° (Lit. 115-117°); **¹H NMR** (300 MHz, CDCl₃): δ= 5.69 (s, 2H), 7.00 (s, 2H), 7.48 (s, 2H); **¹³C NMR**: δ=150, 142, 126, 120, 82; **IR** (KBr): 3025, 1569, 1430, 1313, 1276, 1082, 995, 848, 702, 577 cm⁻¹; **MS** (EI): M⁺ 302, 193 (100%), 191 (100%).

6,7-dibromo-1,2,3,4-tetrahydro-1,4-epoxide (124) 3.85g (12.7 mmoles) of endoxide **123** are dissolved in 45 ml of distilled

ethyl acetate and placed in an hydrogenation unit. The unit is evacuated and flushed 5 times with argon gas before 100 mg of 10% Pd-c is added and the unit is saturated with hydrogen gas. When no more hydrogen is consumed (290 ml), the solution is removed, Pd is filtered off and the ethyl acetate is evaporated. The resulting oily solid is chromatographed (5:1 hexane:ethyl acetate) to yield 3.30g (85.4%) of **124** as a white solid. **mp**: 96-98°; **¹H NMR** (300 MHz, CDCl₃): δ= 1.24 (m, 2H), 2.15 (m, 2H), 5.40 (m, 2H), 7.55 (s, 2H); **¹³C NMR**: δ= 26.3, 78.4, 122.3, 124.2, 146.7; **IR** (CCl₄): cm⁻¹; **MS** (EI): M+ 304, 276 (100%).

2,3-diethynylnaphthalene (130) METHOD A: 2.20g (8.10 mmole) of **133** was added to a 200 ml round bottom flask, under argon, previously charged with 30 ml distilled DMF and 30 ml 1N KOH solution. The solution is allowed to vigorously stir at room temperature for 2 hours. The solution is then poured on a 1:1 mixture of water and ether, it is shaken and the organic layer separated, dried and evaporated. **130** is then distilled off on a pump yielding 0.50g (44.2%) of a colorless oil. Residual DMF may be removed by hexane extraction of the distilled compound.

METHOD B: A 250ml round bottom flask purged with nitrogen is introduced with 250ml of freshly distilled THF and is cooled to -78° on a dry ice/acetone bath. 2.30g (4.67 mmoles) of **140** is added to the flask and stirred. Next, 8.4 ml (21 mmoles, 4.2 equivalents) of a 2.5M solution of BuLi in hexane are added dropwise over a period of 20 minutes through a dropping funnel. The solution turns red, then dark, and is allowed to stir at -78° for 1 hour after the addition is completed, then slowly warm up to room temperature. Stirring is continued for an additional hour at the end of which period it is treated with 100 ml of a 1:1 mixture of ice water and 2N HCl. The layers are separated, extracted with ether, dried and evaporated. The dark oily residue is chromatographed on silica gel (5:1 hexane:ethyl acetate) to obtain 0.380g of **130** in 46.2% yield.

mp: 113-114°; **¹H NMR** (300 MHz, CDCl₃): δ= 8.00 (s, 2H), 7.61 (AA'BB', 4H), 3.28 (s, 2H); **¹³C NMR**: δ= 80.6, 122.3, 127.7, 132.4, 133.1, 133.2; **IR** (CCl₄): 3284, 1616, 1245, 903, 750, 609 cm⁻¹; **MS**

(EI): M^+ 176 (100%).

Naphthalene-2,3-dicarboxaldehyde (131) 6 ml glacial acetic acid, 9 ml water, 10 drops piperidine and 6.5g (48.5 mmoles) phthalaldehyde are added successively to a 100 ml round bottom flask and stirred. Then 8.0g (50.0 mmoles) 2,5-diethoxytetrahydrofuran is added in one portion and the mixture is refluxed for 12 hours. The dark solution is now cooled down and treated with a 1:1 mixture of methylene chloride and water. When all solid is dissolved, the solution is extracted with 2 x 25 ml of CH_2Cl_2 , washed with NaHCO_3 , dried over MgSO_4 and evaporated. The crude brown solid obtained is then dissolved in 15 ml of CH_2Cl_2 and treated with ethanol and hexane. The solid is collected, washed with ethanol and the trituration is repeated two additional times. The solid collected is dried and sublimed at 100° (0.1 torr) to yield 1.76g (19.8%) of **131**. The residual solid is heated at 160° (0.1 torr) to yield 0.480g of **139** as a yellow solid.

Spectral data of 131: mp: $131\text{--}132^\circ$; ^1H NMR (300 MHz, CDCl_3): $\delta = 7.76$ (q, 2H), 8.05 (q, 2H), 8.45 (s, 2H), 10.64 (s, 2H); ^{13}C NMR: $\delta = 129.5, 129.9, 132.8, 134.3, 134.4, 192.3$; IR (CCl_4): 3036, 2860, 1759, 1682, 1619, 1464, 1448, 1333, 1246, 1173, 1090, 1029, 1000, 905, 848 cm^{-1} ; MS (EI): M^+ 184 m/z.

Spectral data of 139: mp: 220° (Lit. 217°); ^1H NMR (300 MHz, CDCl_3): $\delta = 7.66$ (q, 2H), 8.09 (q, 2H), 8.62 (s, 2H), 8.64 (s, 2H), 10.65 (s, 2H); ^{13}C NMR: $\delta = 127.6, 128.5, 129.4, 130.8, 132.0, 133.7, 136.2, 192.2$; IR (CCl_4): 3035, 2860, 1691, 1381, 1181, 1096 cm^{-1} ; MS (EI): M^+ 234 m/z.

2,3-dibromonaphthalene (132) METHOD A: Into a 100 ml round bottom flask 6 ml of 85% phosphoric acid was added and let warm to 90° . Then added 2.40g P_2O_5 and stirred vigorously. When all the solid dissolved, 1.10 g (3.6 mmole) of **124** was added in one portion. Upon addition the reaction turned dark gray. After 5 minutes at 90° , TLC analysis indicated the absence of **124**. Poured the hot solution on ice/water, diluted with base and extracted with CH_2Cl_2 . The organic

layers were combined and washed with dilute base, brine and water, dried over MgSO_4 and evaporated. Recrystallization of the crude solid from ethanol yielded 0.89g (86.4%) of **132** as a white solid.

METHOD B: 10 ml of distilled benzene added to a 50 ml round bottom flask under argon and treated with 0.300g (0.99 mmole) of endoxide **123**. The solution was vigorously stirred while 0.500g (1.37 mmoles) $\text{Fe}_2(\text{CO})_9$ was added in one portion. The solution was stirred at 60° until all of the solid was dissolved, then at reflux for 14 hours. As the iron complex was formed the solution turned black. At the end of a 14 hour period, poured the solution on ice and extracted it with 3 x 25 ml of benzene. Evaporation of the dried benzene extracts yielded 0.280g (98.9%) of **132** as a white solid. GC-MS as well as NMR did not indicate the presence of any impurities. **mp:** $138-140^\circ$ (Lit. $139-140^\circ$); **^1H NMR** (300 MHz, CDCl_3): $\delta = 7.55$ (q, 2H), 7.75 (q, 2H), 8.19 (s, 2H); **^{13}C NMR:** $\delta = 122.0, 126.9, 127.2, 132.2, 133.1$; **IR** (KBr): 1569, 1484, 1425, 1306, 1196, 1098, 948, 887, 858, 755 cm^{-1} ; **MS** (EI): $\text{M}^+ 286, 28$ (100%).

Naphthalene-2,3-bis(trimethylsilylacetylene) (133) Into an oven dried 250 ml round bottom flask added under an atmosphere of nitrogen 35 ml of freshly distilled piperidine, 1.50g (5.18 mmoles) **132**, 1.98g (20.5 mmoles) trimethylsilylacetylene and let stir for 10 minutes. Then added 50 mg tetrakis (triphenyl phosphine) palladium (0) and 25 mg of CuI. The solution is stirred at room temperature for 30 minutes, then at reflux for 20 hours. The dark solution is poured on water, extracted with CH_2Cl_2 and concentrated to yield a brown oil. Chromatography on silica gel (5:1 hexane:ethyl acetate) and recrystallization from hexane yields 0.930g (56.0%) of **133** as colorless flakes. **mp:** $96-97^\circ$; **^1H NMR** (300 MHz, CDCl_3): $\delta = 0.30$ (s, 18H), 7.55 (q, 2H), 7.95 (q, 2H), 8.00 (s, 2H); **^{13}C NMR:** $\delta = 0.01, 103.5, 122.3, 127.4, 127.7, 132.4, 132.6, 132.7$; **IR** (CCl_4): 2959, 2153, 1250, 1156, 873, 844 cm^{-1} ; **MS** (EI): $\text{M}^+ 320\text{ m/z}$.

2,3-bis(β,β -dibromovinyl)naphthalene (140) 150 ml of freshly distilled CH_2Cl_2 in an oven dried 500 ml round bottom flask, under an atmosphere of nitrogen is cooled to -5° (ice bath). 7.17g (21.6 mmoles) CBr_4 in 50 ml CH_2Cl_2 and 11.33g (43.2 mmoles)

triphenyl phosphine in a separate 50 ml of CH_2Cl_2 are added successively, to the flask. The resulting red solution is stirred for additional 5 minutes before a solution of 2.0g (10.8 mmoles) **131** in 30 ml solvent is added dropwise over a 5 minute period. At the end of the addition, the color of the solution discharges. The reaction is stirred for additional 10 minutes, then is hydrolyzed with 100 ml of ice water. The layers are separated, and the water layer extracted with 3 x 45 ml of methylene chloride. The organic extracts are combined, dried, and evaporated to yield an oily mixture. The sample is filtered through a 30cm silica column to yield a white solid. The solid is sublimed at 150° (0.1 torr) to yield 3.0g (56.5%) of **140** as a colorless solid. mp: $121-122^\circ$; ^1H NMR (300 MHz, CDCl_3): δ = 7.51 (AA'BB', 4H), 7.52 (s, 2H), 7.99 (s, 2H); ^{13}C NMR: δ = 93.1, 127.1, 127.9, 128.4, 132.0, 132.4, 135.2; IR (KBr): 3006, 1591, 1282, 1147, 949, 905, 840, 789, 745, 677, 611, 524, 477 cm^{-1} ; MS (EI): M^+ 492, 336 (100%) m/z.

Naphtho[2,3-d]thiepin (I) **METHOD A:** To a 50 ml 2-neck, round bottom flask under nitrogen, added 15 ml absolute ethanol, 0.260g (1.47 mmoles) **130** and 2.63g (10.0 mmoles) $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$. The solution was allowed to stir at room temperature for 12 hours. Examination of an aliquot indicated only starting material. Then the solution was refluxed for 12 hours, while being monitored by TLC. A new high R_f spot developed as the reaction proceeded. The reaction was quenched with ice water, extracted with ether and the crude sample examined before purification. NMR and TLC indicated the sole presence of anthracene. Chromatography yielded 140 mg of anthracene (53.6%)

METHOD B: A 50 ml round bottom flask under an atmosphere of argon was charged with 30 ml of freshly distilled DMF, 0.25g (1.42 mmoles) **130** and 2.70g (10.3 mmoles) $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$. The solution was stirred at room temperature for 2 days and was determined to contain only starting material (NMR, TLC, GC-MS). Then, it was heated at 100° and monitored by TLC. After 6 hours TLC indicated the absence of all starting material. The solution was poured on 75 ml of ice water and extracted with ether. The crude sample was again examined prior to purification and was found to contain only

anthracene.

Naphtho[2,3-e]1,2-dithiocin (II) **METHOD A:** Into a dry 50 ml round bottom flask under an atmosphere of argon added 5 ml of distilled DMF, 53.0 mg (0.68 mmoles) anhydrous $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$ and 22.0 mg (0.68 mmoles) sulfur. The mixture which immediately turned dark red was allowed to stir at room temperature for 15 minutes before 100 mg (0.57 mmoles) of **130** in 3 ml DMF were added in one portion. The solution was allowed to stir at room temperature over night (14 hours) then poured on water and extracted with ether. NMR examination of the ether extract after hydrolysis and work up showed only unreacted starting material and anthracene. When the reaction is carried out at 120° (15 minutes), no unreacted starting material was detected. 80Mg of anthracene were isolated by chromatography (78.8%).

METHOD B: 0.800g (3.04 mmoles) $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$ is added to 6 ml water in a 50 ml round bottom flask , followed by 97 mg (3.04 mmoles) sulfur. The mixture is allowed to reflux until a brown-orange solution is obtained. Then 0.260g (1.47 mmoles) of **130** are added and the reaction is monitored by TLC. 5 minutes after addition, TLC indicates the absence of starting material. The solution is poured on ice and extracted with ether. The organic layers are dried and evaporated to yield anthracene. Chromatography separates 50 mg of anthracene.

1,2-Dithiin (166) 15 ml freshly distilled methanol were delivered into a 100 ml round bottom flask under argon and were treated with 0.320g (14 mmols) sodium metal. When all the metal had dissolved, cooled solution to -15° and added 1.01g (5.0 mmoles) of diacetate **179**. Within 10 minutes all of the solid was dissolved and the solution turned light yellow. Iodine solution in methanol was then added slowly, drpwise over a period of 20 minutes to a clear equivalent point. Immediate precipitation of NaI was observed. Allowed the solution to warm slowly to room temperature, at which point it was poured on water and extracted with ether. Ether extracts were combined (75 ml), washed with dilute HCl , dried and

evaporated on a rotary evaporator with water bath at 30°. 0.450g of a red oil was obtained (77.6%). Sample was kept in dilute solutions at -30°. **¹H NMR** (300 MHz, CDCl₃): δ= 6.07 (dd, 2H), 6.29 (dd, 2H); **IR** (CCl₄): 3023, 1683, 1539, 1301, 1069, 964, 846, 717, 622 cm⁻¹; **MS** (EI): M⁺ 116 (100%) m/z.

Z,Z-1,4-acetylmercaptobutadiene (179) 100 ml of freshly distilled THF are added to an oven dry, water free round bottom flask under an atmosphere of nitrogen. 1.01g (0.144 moles) lithium metal is then added as small pieces and the solution is cooled to -50° at which time 25.68g (0.149 moles) of DMAN **114** in 35 ml THF are added dropwise. The blue color appears within 10 minutes. When all of DMAN is added, the solution is stirred vigorously at -50° for 4 hours. Then, the temperature is lowered to -70° and 6.58g (22.0 mmoles) **112** in 35 ml THF are added within 1 hour. The blue solution is stirred at -70° for an additional one hour then treated with 6 ml (8.30g, 106.8 mmoles) acetyl chloride in 15 ml THF. At the end of the addition the now yellow solution is warmed up to room temperature and stirred for at least 1 additional hour. Water is added and the solution is extracted with ether. The separate ether extracts are then washed with 2N HCl, dried and evaporated to yield a white solid which is carefully crystallized from an hexane/ether mixture to form 3.55g of **179** (79.9% yield). The aqueous layer is basified to pH 9 and extracted with ether to yield 19.20g (74.8% recovery) of DMAN **114**.

mp: 148-149° (Lit. 148); **¹H NMR** (300 MHz, CDCl₃): δ= 2.43 (s, 6H), 6.37 (dd, 2H, J=8.7, 2.0 Hz), 6.79 (dd, 2H, J=8.7, 2.0 Hz); **¹³C NMR:** δ= 31.9, 122.1, 125.9, 191.5; **IR** (CCl₄): 1705, 1357, 1303, 1132, 966, 683, 636 cm⁻¹; **MS** (EI): M⁺ 202, 43 (100%) m/z.

1,2,3,4-tetrathiane (185) A 300 ml round bottom flask fitted with a dropping funnel and an argon inlet is charged with 100 ml THF and cooled down to 0°. 5 ml (5.62g, 59.7 mmoles) 1,2-ethanedithiol in 15 ml THF and 5.92g (137.0 mmoles) 80% NaH are added successively and allowed to stir for 30 minutes. Next, 11.0 ml (18.5g, 137.0 mmoles) S₂Cl₂ in 35 ml THF are added dropwise over a

45 minute period. The solution is then warmed up and stirred 12 hours at room temperature. The solution is then poured on water, the layers separated and the water layer extracted with ether. The ether extracts are then washed with brine, dried over MgSO_4 and evaporated. The resulting yellow solid is crystallized with difficulties from ether to yield 7.0g (75.1%) of a white solid. **mp**: 64.5-66°; **^1H NMR** (300 MHz, CDCl_3): δ = 2.84 (d, 2H, J =11.5 Hz), 3.78 (d, 2H, J =11.7 Hz); **^{13}C NMR**: δ = 31.6; **IR** (CCl_4): 2905, 1556, 1394, 1280, 1078, 906, 661 cm^{-1} ;

1,2,3,4-tetrathiin (186) Into a 250 ml 3-neck round bottom flask, under argon, added 100 ml freshly distilled THF and 6.89g (50 mmoles) disodium-cis-dimercaptoethylene and let the suspension stir for 30 minutes. The solution was then cooled down with an ice bath while 7.42g (4.4 ml, 55 mmoles) freshly distilled S_2Cl_2 in 25 ml THF were added dropwise over a 20-minute period. The solution was then warmed up and stirred at room temperature overnight. The insoluble solid that formed was filtered out through gravity filtration and was washed extensively with ether. The ether was washed with brine and water and was concentrated. An aliquot was removed, evaporated to dryness to yield a yellow solid which was partially soluble in chloroform. Decomposition of **186** takes place on concentration. **^1H NMR** (300 MHz, CDCl_3): δ = 6.92 (s); **^{13}C NMR**: δ = 119.9; **IR** (CCl_4): 2960, 2863, 1265, 1112, 1025, 790, 644 cm^{-1} ; **MS** (EI): M^+ 154, 90 (100%) m/z .

1,3-dithiane (295) 3.0G (15.1 mmoles) of dialdehyde**220**, 4.89g (4.5 ml, 45.3 mmoles) 1,3-propane dithiol, 10 mg TsOH dissolved in 150 ml benzene contained in a 250 ml round bottom flask fitted with a Dean-Stark trap. The solution was refluxed under argon overnight. 7.0 ml of water were collected and drawn off at the end of a 15-hour period. The brown solution was cooled, poured on saturated sodium bicarbonate, washed with water, and extracted with benzene and dried. Evaporation in vacuo yielded a solid/oil mixture which was dissolved in ethanol, washed with 1M NaOH and then dried to yield **295** as a white solid. (5.70g, 76.8% yield.) **MP**: 131-132°; **^1H NMR**

(300 MHz, CDCl_3): δ =1.94 (m, 2H), 2.12 (m, 2H), 2.74 (s, 2H), 2.95 (m, 8H), 4.95 (s, 2H), 6.81 s, 2H), 7.34 (AA'BB'); ^{13}C NMR: δ = 25.9, 31.6, 33.5, 53.4, 126.9, 128.9, 129.0, 130.9, 136.3, 138.5 ppm; IR (CCl_4): 2894, 1480, 1420, 1272, 1170, 757 cm^{-1} ; MS (EI): M^+ 378, 272(100%) m/z .

Methylation of 1,3-dithiane 295 (215) 1.0g (2.65 mmoles) of **295** dissolved in 50 ml of freshly distilled THF and allowed to cool down under an atmosphere of argon to -50° (dry ice/acetone bath). Then added 2.7 ml (6.75 mmoles, 2.5M solution in hexane) BuLi, dropwise over a period of 10 minutes. The brown/yellow solution resulting from the addition of the base was stirred at -50° for additional hour, then warmed up to -40° at which time 0.850g (6.75 mmoles) dimethyl sulfate was added dissolved in 15 ml THF, over a 15-minute period. The deeply green solution was warmed up slowly and allowed to stir at room temperature for 1 hour. Solution quenched with water/dilute acid, extracted with dichloromethane, washed with bicarbonate and dried to yield an oil. Chromatography on a silica column (elution with 1:1 ethyl acetate:hexane) resulted in the difficult separation of a white solid identified as the mono-methylated **296** and a colorless oil identified as the bis methylated **215**, in a 2:1 ratio. **296**: mp: $189-190.5^\circ$; ^1H NMR (300 MHz, CDCl_3): δ =1.5 (m, 12H), 1.71 (s, 3H), 2.70 (s, 2H), 5.09 (s, 1H), 6.89 (s, 1H), 7.18 (s, 1H), 7.20 (m, 4H); IR (CCl_4): 2965, 2898, 1741, 1548, 1480, 1418, 1366, 1276, 1241, 1178, 1056, 897 cm^{-1} ; MS (EI): M^+ 392 (100%) m/z . **215**: ^1H NMR (300 MHz, CDCl_3): δ =1.72 (s, 6H), 1.8 (m, 12H), 3.25 (d, 1H, $J=16.2$, 0.7 Hz), 3.92 (d, 1H, $J=16.2$ Hz), 7.3 (2H, overlapped), 7.3 (AA'BB', 4H); IR (CCl_4): 2926, 1421, 1367, 1275, 1058, 908, 732 cm^{-1} ; MS (EI): M^+ 406, 300 (100%) m/z .

3,4-benzcycloheptatriene-1,6-dicarboxaldehyde (220) A 100 ml round bottom flask under argon is charged with 6ml glacial acetic acid, 3 ml of water, 10 drops of piperidine and 10 g (74.5 mmoles) o-phthalaldehyde. While stirring, 15.2 ml (12.6g, 126 mmoles) of a 50% aqueous 1,5-glutaric dialdehyde are added in one portion and the thick solution is allowed to reflux for 4 hours. As

the reaction progresses, the solution changes color and solid precipitates. The dark orange solution is then quenched with water, and all of the precipitated solid is dissolved in CH_2Cl_2 . The layers are separated and the water fraction is extracted with 3 x 50 ml of additional CH_2Cl_2 . The organic extracts are washed with saturated sodium bicarbonate solution, dried and evaporated to yield a thick oil/solid mixture. The residue is re-dissolved in solvent and triturated slowly with hexane. Light yellow solid precipitated and thus collected. The filtrate is again evaporated, dissolved in CH_2Cl_2 and triturated. The cycle is repeated 4 times in total to yield a pale yellow solid. Recrystallization from methanol and sublimation (120° , 0.1 torr) yields 9.52g (64.6%). **mp:** $178\text{--}179^\circ$; **^1H NMR** (300 MHz, CDCl_3): $\delta = 3.26$ (s, 2H), 7.31 (s, 2H), 7.35 (m, 4H), 9.59 (s, 2H); **^{13}C NMR**: $\delta = 17.3$, 129.6, 132.2, 134.9, 139.8, 147.3, 191.2; **IR** (CCl_4): 2833, 1671, 1631, 1438, 1182, 902 cm^{-1} ; **MS** (EI): $M^+ 198$ (100%) m/z ; **UV**: $\lambda_{\text{max}} = 300, 304, 308$ nm.

naphthalene-2,3-dicarboxaldehyde (131) condensation with 1,5-glutaric dialdehyde: 0.63g (3.42 mmoles) **131**, 2 ml acetic acid, 10 drops piperidine and 2.10 ml (1.02g, 10.26 mmoles) of a 50% aqueous solution of 1,5-glutaric dialdehyde are mixed together, as described before for the synthesis of **220**, and allowed to reflux for 4.5 hours. The solution is quenched with water, extracted with CH_2Cl_2 , neutralized, dried and evaporated. The residue is chromatographed on silica gel (1:1 hexane:ethyl acetate) to yield 0.340g of a yellow solid (40.0%). **mp:** $204\text{--}205^\circ$; **^1H NMR** (300 MHz, CDCl_3): $\delta = 3.44$ (s, 2H), 7.47 (s, 2H), 7.70 (AA'BB', 4H), 7.98 (s, 2H), 9.59 (s, 2H); **^{13}C NMR**: $\delta = 19.4$, 128.9, 129.0, 132.0, 133.8, 134.2, 140.7, 149.4, 192.6; **IR** (CCl_4): 1663, 1627, 1440, 1408, 1345, 1193, 973, 917 cm^{-1} ; **MS** (EI): $M^+ 248$ (100%) m/z ;

thiophene-2,3-dicarboxaldehyde (223) condensation with 1,5-glutaric dialdehyde: 1.0g (7.13 mmoles) **223**, 2 ml acetic acid, 10 drops piperidine and 2.30 ml (1.15g, 11.50 mmoles) of a 50% aqueous solution of 1,5-glutaric dialdehyde are mixed together, as

described before for the synthesis of **220**, and allowed to reflux for 4.5 hours. The solution is quenched with water, extracted with CH_2Cl_2 , neutralized, dried and evaporated. The residue is redissolved and triturated with hexane to yield 0.220g of a canary yellow solid (15.1%). **mp**: 192-193°; **^1H NMR** (300 MHz, CDCl_3): δ = 3.29 (s, 2H), 7.28 (d, 1H, J =5.1Hz), 7.44 (s, 1H), 7.49 (s, 1H), 7.64 (d, 1H, J =5.1 Hz), 9.56 (s, 1H), 9.58 (s, 1H); **^{13}C NMR**: δ = 18.6, 130.6, 130.9, 134.1, 135.0, 139.2, 139.8, 141.1, 191.0, 191.7; **IR** (CCl_4): 3119, 2837, 1666, 1601, 1501, 1425, 1414, 1236, 1212, 1171, 1130, 899 cm^{-1} ; **MS** (EI): M^+ 204 (100%) m/z ;

2,3-dichlorothiophene-3,4-dicarboxaldehyde (224)

condensation with 1,5-glutaric dialdehyde: 0.410g (1.95 mmoles) **224**, 1 ml acetic acid, 4 drops piperidine, 2 ml water and 2.50 ml (1.25g, 12.50 mmoles) of a 50% aqueous solution of 1,5-glutaric dialdehyde are mixed together, as described before for the synthesis of **220**, and allowed to reflux for 4.5 hours. The solution is quenched with water, extracted with CH_2Cl_2 , neutralized, dried and evaporated. The residue is chromatographed on silica gel (1:1 hexane:ethyl acetate) to yield 50 mg of a whit solid (9.4%). **mp**: 218-219°; **^1H NMR** (300 MHz, CDCl_3): δ = 3.47 (s, 2H), 7.28 (s, 2H), 9.57 (s, 2H); **^{13}C NMR**: δ = 20.0, 127.0, 130.8, 132.5, 137.9, 192.6; **IR** (CCl_4): 2831, 2725, 1674, 1638, 1444, 1247, 1228, 1160, 1111, 991 cm^{-1} ; **MS** (EI): M^+ 272, 243 (100%), 245 (100%) m/z ;

1,4-Bis(2-furyl)-2,3-diformylbutadiene (225) 3.0g (31.2 mmoles) furfural, 2.40g (15.0 mmoles) 2,5-diethoxytetrahydrofuran, 2 ml acetic acid, 3 ml water and 2.0g potassium acetate are stirred together and allowed to reflux for 12 hours. The solution is quenched with water, extracted with CH_2Cl_2 , neutralized with NaHCO_3 , dried and evaporated. The residue is chromatographed on silica gel (1:1 hexane:ethyl acetate) to yield 0.480g of a white solid (13.2%), crystallized from hexane. **mp**: 128-130°; **spectral data match published**.

3,4-Benzcycloheptatriene-1,6-dialdehyde dihydrazone

(232) 25ml of absolute ethanol in a 50 ml round bottom flask under argon were treated with 0.400g (2.02 mmoles) of **220** and 2.5 ml of hydrazine. The solution was allowed to stir under reflux for 2 hours. The lemon-yellow solution was then cooled down and the solid collected. The mother liquor was concentrated to recover more of the product. Recrystallization from EtOH yielded 0.270g of **232** as an off-white solid (59.2%). mp: 193-195°; ¹H NMR (300 MHz, CDCl₃): δ= 3.31 (s, 2H), 5.56 (bs, 4H), 6.64 (s, 2H), 7.28 (AA'BB', 4H), 7.53 (s, 2H); ¹³C NMR (DMSO): δ= 21.2, 125.4, 128.4, 129.7, 135.1, 137.1, 140.5; IR (CCl₄): 3368, 3284, 3225, 2995, 1626, 1567, 1473, 1429, 1239, 1098, 935, 858 cm⁻¹;

3,4-benzcycloheptatriene-1,6dialdehyde di-p-tosyl

hydrazone (233) 25ml of absolute ethanol in a 50 ml round bottom flask under argon were treated with 0.400g (2.02 mmoles) of **220** and warmed to 50°. Then, 0.782g (4.20 mmoles) p-toluene sulfonylhydrazine dissolved in 10 ml of warm ethanol were added in one portion and the mixture refluxed for one hour. The solution was then cooled down and the solid collected. Recrystallization from EtOH yielded 0.920g of **233** as an off-white solid (85.9%). mp: 196-197°; ¹H NMR (300 MHz, DMSO): δ= 2.17 (s, 6H), 3.01 (s, 2H), 6.66 (s, 2H), 7.14 (m, 4H), 7.18 (d, 4H, J=8.1 Hz), 7.46 (s, 2H), 7.64 (d, 4H, J=8.1 Hz), 11.13 (s, 2H); ¹³C NMR (DMSO): δ= 20.4, 126.8, 127.0, 128.9, 130.6, 134.4, 134.6, 135.3, 135.8, 142.5, 148.6; IR (KBr): 3500, 3201, 1596, 1449, 1364, 1313, 1160, 1058, 960, 925, 873, 812, 759, 701, 577 cm⁻¹;

3,4-benzcycloheptatriene-1,6-dioxime (235) 0.660g (3.33 mmoles) of **220** added to 50 ml EtOH in a 200 ml round bottom flask under argon, and allowed to stir while 0.600g (8.63 mmoles) hydroxyl amine·HCl in 40 ml of water were added in two portions. 1.2g (30 mmoles) NaOH were then added in 3 portions over a 25 minute period. The solution was brought to reflux and kept for one hour. Then it was cooled down, poured on cold HCl/water solution

and the precipitated solid collected. Solid was washed with water and let dry to obtain 0.510g (67.1%) of a white solid. **mp**: 215-216°; **¹H NMR** (300 MHz, DMSO): δ = 3.22 (s, 2H), 6.87 (s, 2H), 7.34 (AA'BB', 4H), 7.88 (s, 2H), 11.14 (s, 2H); **¹³C NMR**: δ = 21.2, 126.5, 130.1, 133.1, 133.7, 134.8, 149.8; **IR** (CCl₄): 3531, 3320, 1619, 1477, 1401, 1268, 948, 871, 701, 605 cm⁻¹; **MS** (PCI): M⁺ (+18) 246, 228 (100%) m/z;

1,6-dicyano-3,4-benzcycloheptatriene (236) 0.340g (1.5 mmoles) **235** in a 20 ml of distilled acetic anhydride were treated with 1.4g of anhydrous potassium acetate and were allowed to reflux at 120° for 20 minutes. The solution was poured on ice and extracted with CH₂Cl₂, washed with sodium bicarbonate solution, dried and evaporated. The crude dinitrile **236** was recrystallized from chloroform to yield 0.230g (79.8%) of colorless needles. **mp**: 226-227°; **¹H NMR** (300 MHz, CDCl₃): δ = 2.94 (s, 2H), 7.37 (s, 2H), 7.47 (AA'BB', 4H); **¹³C NMR**: δ = 27.6, 106.5, 115.4, 127.7, 129.7, 132.0, 141.9; **IR** (CCl₄): 2206, 1615, 1551, 906 cm⁻¹; **MS** (EI): M⁺ 192 (100%) m/z.

1,6-bis(β,β-dibromovinyl)-3,4-benzcycloheptatriene (237)
A solution of 17.5g (66.6 mmoles) of triphenylphosphine in 250 ml distilled CH₂Cl₂, at 5°, is treated with 11.0g (33.3 mmoles) CBr₄ in 50 ml CH₂Cl₂. The resulting red solution is allowed to stir for 5 minutes before 3.3g (16.6 mmoles) of **220** in 25 ml of CH₂Cl₂ are added dropwise over a 5-minute-period. The solution is stirred for 10 additional minutes, poured on ice/water and the layers are separated. The aqueous layer is extracted with additional CH₂Cl₂ (2x35 ml), the organic layers combined, dried and evaporated. Filtration of the oily residue through a 35cm silica gel column (5:1 hexane:ethyl acetate) yields 8.39g (63.4%) of **237** as a slowly crystallizing pale yellow oil. **mp**: 68-69°; **¹H NMR** (300 MHz, CDCl₃): δ = 2.84 (s, 2H), 6.93 (s, 2H), 7.19 (s, 2H), 7.33 (AA'BB', 4H); **¹³C NMR**: δ = 30.8, 89.9, 126.8, 130.7, 132.4, 134.0, 135.7, 137.8; **IR** (CCl₄): 3012, 2954, 1564, 1480, 949, 896, 878, 787, 750 cm⁻¹; **MS** (EI): M⁺

506, 189 (100%) m/z;

1,6-divinyl-3,4-benzcycloheptatriene (240) METHOD A: 0.35g (0.70 mmoles) of **237** in 5 ml of freshly distilled DMF were added to a suspension of 1.90g Zn in 15 ml DMF under reflux. The reflux was continued for 2 hours at which time TLC indicated the absence of **237** in the reaction mixture. The reaction was cooled down, poured on ice and extracted with 3x50 ml of ether. The combined ether layers were dried and evaporated to yield a yellow oil. Chromatography on silica gel (5:1 hexane:ethyl acetate) yielded 0.135g (48.1%) of **240** as a colorless oil.

METHOD B: To a 3-neck 500 ml round bottom flask, maintained under argon, and containing 100 ml of anhydrous ether, 17.8g (50.0 mmoles) methyltriphenylphosphonium bromide are added. The temperature is lowered to 0° and 20.4ml (51.0 mmoles, 2.5M solution in hexane) BuLi is added dropwise over a one-hour period. The yellow solution is now warmed to room temperature and stirred for 4 hours. Next, 2.0g (10.1 mmoles) of dialdehyde **220** in 75 ml THF are added dropwise in 10 minutes. The solution is allowed to stir for 4 hours at ambient temperature, then is poured on ice water and extracted with ether. The combined ether layers are dried over MgSO₄ and evaporated to yield a yellow oil. Chromatography on silica gel (5:1 hexane:ethyl acetate) yielded 0.560g (28.5%) of **240** and 0.300g (15.2%) of monoaldehyde-monovinyl **269**. **240**: ¹H NMR (300 MHz, CDCl₃): δ= 2.67 (s, 2H), 5.10 (d, 2H, ³J_{vic/cis}=10.6 Hz), 5.46 (d, 2H, ³J_{vic/trans}=17.3 Hz), 6.47 (dd, 2H, ³J_{vic/trans}=14.0 Hz, ³J_{vic/cis}=9.0 Hz), 6.58 (s, 2H), 7.21 (AA'BB', 4H); ¹³C NMR: δ= 22.8, 113.1, 126.0, 130.3, 130.4, 136.3, 138.0, 138.3; IR (neat): 3009, 1722, 1622, 1597, 1479, 1449, 1262, 1028, 988, 895, 872, 845, 799, 750 cm⁻¹; MS (EI): M⁺ 194, 179 (100%) m/z; **269**: ¹H NMR (300 MHz, CDCl₃): δ= 2.98 (s, 2H), 5.23 (d, 1H, J=10.0 Hz), 5.77 (d, 1H, J=17.0 Hz), 6.47 (dd, 1H, J=9.0 Hz, 14.0 Hz), 6.62 (s, 1H), 7.30 (m, 4H), 7.49 (s, 1H), 9.59 (s, 1H); ¹³C NMR: δ= 20.7, 116.2, 127.2, 129.7, 130.4, 131.7, 132.1, 138.3, 139.6, 140.0, 148.2, 192.0; IR (neat): 2956, 2816, 1676, 1628, 1442, 1368, 1312, 1215, 1178, 1138, 1108, 987, 956, 906, 877, 754 cm⁻¹; MS (EI): M⁺ 196, 167 (100%) m/z.

1,6-diethynyl-3,4-benzcycloheptatriene (221) 4.37g (8.63 mmoles) **237** were dissolved in 250 ml of freshly distilled THF, under argon. The solution is stirred and cooled down to -78° (dry ice/acetone) then treated with 15.2 ml (38.0 mmoles, 2.5M in hexane) BuLi, dropwise over a period of 40 minutes. At the end of the addition the solution is kept at -78° for an additional hour then warmed to room temperature and stirred for two additional hours. Hydrolysis with acid/water results in the formation of a yellow solution which is extracted with CH_2Cl_2 . The resulting oily residue is chromatographed then crystallized (hexane) to yield 1.64g of **221** as a white solid (53.6%). mp: $102-103^{\circ}$; $^1\text{H NMR}$ (300 MHz, CDCl_3): $\delta = 2.79$ (s, 2H), 2.99 (s, 2H), 7.02 (s, 2H), 7.29 (d, 4H); $^{13}\text{C NMR}$: $\delta = 34.2, 74.6, 84.4, 118.3, 125.9, 129.3, 134.4, 135.3$; IR (CCl_4): 3310, 3062, 2088, 1479, 952, 885, 667 cm^{-1} ; MS (EI): M^+ 190, 189(100%) m/z; UV: $\lambda_{\text{max}} = 304 \text{ nm}$.

thiepin (IV) A 200 ml round bottom flask charged with 90 ml of absolute ethanol and 1.17g (6.15 mmoles) **221**. The solid is allowed to dissolve then 3.0g (11.40 mmoles) Na_2S nonahydrate is added, and the dark solution is refluxed for 12 hours. The mixture is then poured on ice and extracted with CH_2Cl_2 . The organic layers are combined, dried and evaporated to yield a brown solid. Chromatography on silica gel (5:1 hexane:ethyl acetate) yielded 0.490g (35.7%) of a yellow solid characterized as **IV**. (Recrystallization possible from ethanol). mp: $108-110^{\circ}$; $^1\text{H NMR}$ (300 MHz, CDCl_3): $\delta = 1.98$ (d, 1H, $J = 11.9 \text{ Hz}$), 5.51 (d, 2H, $J = 10.1 \text{ Hz}$), 5.72 (dt, 1H, $J = 11.9 \text{ Hz}$, $J = 0.7 \text{ Hz}$), 6.50 (d, 2H, $J = 9.8 \text{ Hz}$), 6.50 (s, 2H), 7.29 (AA'BB', 4H); $^{13}\text{C NMR}$: $\delta = 23.8, 114.7, 126.3, 128.9, 130.7, 131.9, 133.0, 137.6$; IR (CCl_4): 2982, 2849, 1652, 1608, 1508, 1453, 1303, 1242, 1181, 1136, 1025, 825 cm^{-1} ; MS (EI): M^+ 224, 191(100%) m/z; UV: $\lambda_{\text{max}} = 296, 348, 420 \text{ nm}$.

Thiepin-S-oxide (260) 0.100g (0.5 mmoles) **IV** in 15 ml of CH_2Cl_2 at 0° were treated with 0.103g (0.51 mmoles, 85%) of m-CPBA in 10 ml CH_2Cl_2 , added slowly over a 1 hour period. TLC indicated the

absence of **IV** and the presence of a low R_f spot. The solution was treated with saturated NaHCO_3 solution and extracted with CH_2Cl_2 . Evaporation yielded a white solid which was chromatographed on silica (ethyl acetate) to yield 0.08g (66.6%) of a white solid. **mp**: $>300^\circ$; **^1H NMR** (300 MHz, CDCl_3): δ = 1.36 (d, 1H, J =14.0 Hz), 3.06 (dt, 1H, J =14.0, 1.03 Hz), 5.66 (d, 2H, J =10.4 Hz), 6.73 (d, 2H, J =10.4 Hz), 6.92 (s, 2H), 7.50 (AA'BB', 4H); **^{13}C NMR**: δ = 28.1, 127.6, 129.1, 131.4, 131.5, 131.9, 133.2, 136.6; **IR** (CCl_4): 854, 1112, 1259, 1562, 2995 cm^{-1} ;

Thiepin-S-dioxide (261) 0.100g (0.5 mmoles) **IV** in 15 ml of CH_2Cl_2 at 0° were treated with 0.103g (0.51 mmoles, 85%) of *m*-CPBA in 10 ml CH_2Cl_2 , added slowly over a 1 hour period. TLC indicated the absence of **IV**. The solution was treated with saturated NaHCO_3 solution and extracted with CH_2Cl_2 . Evaporation yielded a white solid which was chromatographed on silica (1:1 hexane:ethyl acetate) to yield 0.03g (23.4%) of a white solid. **mp**: $>305^\circ$ (sublimes at 210° , 0.025 torr); **^1H NMR** (300 MHz, CDCl_3): δ = 0.98 (d, 1H, J =13.7 Hz), 4.06 (d, 1H, J =13.7 Hz), 6.28 (d, 2H, J =11.4 Hz), 7.14 (d, 2H, J =11.4 Hz), 7.20 (s, 2H), 7.70 (AA'BB', 4H); **^{13}C NMR**: δ = 26.9, 128.6, 129.0, 130.5, 132.6, 134.9, 137.0, 141.1; **IR** (CCl_4): 3038, 1557, 1367, 1276, 1107, 866 cm^{-1} ; **MS** (EI): M^+ 256, 192(100%) m/z ; **UV**: λ_{max} =286, 312, 316, 320 nm.

E,Z-Distyrylsulfide-S-oxide (262) 0.110g (0.5 mmoles) **106** in 15 ml THF are treated with 15ml of a 50% sodium metaperiodate solution in water. The solution is stirred at room temperature over night, then extracted with ether. The ether extracts (40 ml in total) are dried, evaporated and chromatographed (1:1 hexane:ethyl acetate) to yield 0.10 g of a white solid (78.7%). **mp**: $68-69^\circ$; **^1H NMR** (300 MHz, CDCl_3): δ =; **^{13}C NMR**: δ =; **IR** (CCl_4): 3024, 1603, 1573, 1492, 1446, 1038, 965, 776, 747, 690 cm^{-1} ; **MS** (EI): M^+ 254, 91(100%) m/z ; **UV**: 304 nm.

E,Z-Distyrylsulfide-S-dioxide (263) 0.500g (2.1 mmoles) **106** in 25 ml CH₂Cl₂ at 0° are treated with 0.420g (2.43 mmoles) 85% m-CPBA in 5 ml CH₂Cl₂. The solution is stirred at 0° for one hour then at room temperature for 30 minutes. TLC indicates that large amounts of starting material are still present, thus a second portion of m-CPBA is added (0.420g). Let stir at room temperature for 5 hours then poured on water, washed with saturated sodium bicarbonate and extracted with CH₂Cl₂. The organic extracts (100 ml in total) are dried, evaporated and chromatographed (1:1 hexane:ethyl acetate) to yield 0.450 g of a white solid (79.4%). **mp**: 88-89°; **¹H NMR** (300 MHz, CDCl₃): δ=; **¹³C NMR**: δ= 123.9, 126.1, 126.3, 126.8, 127.8, 128.0, 128.8, 129.0, 130.2, 130.3, 139.5, 141.6; **IR** (CCl₄): 3055, 1732, 1613, 1575, 1493, 1448, 1298, 974, 861, 816, 749, 689 cm⁻¹; **MS**(EI): M+ 270, 205(100%) m/z; **UV**: λ_{max}=302 nm.

1,6-Bis(Z-2-benzylmercapto vinyl)-3,4-Benzcycloheptatriene (361) 35 ml absolute ethanol, in a 150 ml round bottom flask under argon, were treated with 0.460g (20 mmoles) sodium metal. When all of the metal had dissolved, added 1.94g (1.8 ml, 15.6 mmoles) benzylmercaptan and allowed the mixture to equilibrate for 30 minutes. Next, added 0.5g (2.6 mmoles) **221** in 10 ml of ethanol and the solution is refluxed for 3 hours. The solution is poured on NaOH/water solution, washed extensively with conc. NaOH and extracted with CH₂Cl₂, dried and evaporated. The oily residue is chromatographed (5:1 hexane:ethyl acetate) to yield 0.90g of a light yellow oil (79.6%). **¹H NMR** (300 MHz, CDCl₃): δ= 2.82 (s, 2H), 3.94 (s, 4H), 6.12 (s, 4H), 6.76 (s, 2H), 7.28 (m, 14H); **¹³C NMR**: δ= 34.1, 38.8, 124.7, 125.4, 126.2, 126.3, 127.6, 128.0, 128.9, 129.6, 135.3, 135.6, 136.3; **IR** (CCl₄): 3026, 2955, 1559, 1493, 1453, 1371, 1241, 1043, 853, 749, 702 cm⁻¹;

1,6-Bis[Z-2-(p-methoxytolyl-α-mercaptovinyl)]-3,4-Benzcycloheptatriene (362) 100 ml absolute ethanol, in a 250 ml round bottom flask under argon, were treated with 0.580g (25.2 mmoles) sodium metal. When all of the metal had dissolved, added

3.16g (20.5 mmoles) p-methoxytoluene thiol and allowed the mixture to equilibrate for 30 minutes. Next, added 1.30g (6.84 mmoles) **221** in 50 ml of ethanol and the solution is refluxed for 4.5 hours. The solution is poured on NaOH/water solution, washed extensively with conc. NaOH and extracted with CH₂Cl₂, dried and evaporated. The brown solid residue is chromatographed (5:1 hexane:ethyl acetate) to yield 1.59g of a light yellow oil (46.7%). **¹H NMR** (300 MHz, CDCl₃): δ= 2.84 (s, 2H), 3.80 (s, 6H), 3.92 (s, 4H), 6.13 (s, 4H), 6.78 (s, 2H), 6.89 (d, 4H, J=8.7 Hz), 7.26 (d, 4H, J=8.7 Hz), 6.28 (AA'BB', 4H); **¹³C NMR**: δ= 35.0, 36.2, 39.8, 55.8, 114.6, 126.3, 127.0, 127.6, 130.7, 131.2, 137.2, 137.0; **IR** (neat): 3002, 2954, 2834, 1732, 1609, 1510, 1463, 1439, 1301, 1240, 1175, 1033, 830, 750 cm⁻¹;

1,6-Bis[Z-2-(2-trimethylsilyl) ethylmercaptovinyl]-3,4-benzcycloheptatriene (367) 45 ml of anhydrous DMF added to a 100 ml 3-neck-round bottom flask under argon then treated with 2 pellets of KOH. The solution is stirred for 30 minutes before 0.570g (3.0 mmoles) **221** and 1.0g (7.4 mmoles) trimethylsilylethane thiol are added. The dark solution is stirred at room temperature for 2 hours, then poured on water and extracted with CH₂Cl₂. The combined organic layers are washed with dilute acid, dried and evaporated to yield a yellow oil. Chromatography (5:1 hexane:ethyl acetate) yields 1.10 g (80.3%) of a light yellow oil which crystallizes into a white solid. **mp**: 58-57°; **¹H NMR** (300 MHz, CDCl₃): δ= 0.04 (s, 18H), 0.95 (m, 4H), 2.76 (m, 4H), 2.88 (s, 2H), 6.16 (s, 4H), 6.80 (s, 2H), 7.30 (m, 4H); **IR** (CCl₄): 2951, 1558, 1418, 1248, 1161, 1014, 838, 747, 690 cm⁻¹; **MS**(EI): M⁺ 458, 73(100%) m/z

Monovinyl-chlorovinyl (291) To a 100ml 3-neck round bottom flask under an atmosphere of argon, containing 50 ml of ether at -40° added 1.39g (4.0 mmoles) of (chloromethyl) triphenylphosphonium chloride. To this suspension added an LDA solution [prepared by the addition of 2.2 ml (5.5 mmoles, 2.5M) BuLi to a THF solution containing 0.5g (4.95 mmoles) diisopropylamine] and stirred for 20 minutes. To the orange solution now added the

monovinyl-monoaldehyde **269** (prepared as described for **240**) in 25 ml THF. Upon addition the solution turned red. Warmed solution to room temperature and allowed to stir for two additional hours. The dark solution was now poured on water, extracted with ether. Evaporation of the dry ether extracts yielded an oily solid which was chromatographed on silica gel (5:1 hexane:ethyl acetate) to yield 0.170g of a yellow oil whose ^1H and ^{13}C NMR indicated the presence of two products. GC-MS confirmed the presence of a 1:2 mixture of cis and trans **291**. The mixture was not separable.

9-Benzobicyclo[5.4.1]dodeca-2,5,7,9,11-pentaene (270) and 9-Benzobicyclo[5.4.1]dodeca-3,5,7,9,11-pentaene (280) A solution of 1.99g (10.0 mmoles) of **220** and 8.71g (12.0 mmoles) of trimethylenebis(triphenylphosphonium bromide) in 300 ml of freshly distilled DMF was warmed at 80° while a solution of lithium ethoxide (0.21g Li in 50 ml absolute ethanol) was added dropwise over a 12-hour period. The resulting dark solution is cooled and poured onto 600ml of ice water containing 5 ml of conc. HCl. The solution is extracted with ether (3x300 ml), and the ether extracts are dried and evaporated. Chromatography of the resulting yellow oil on silica gel (elution with hexane) results in the isolation of 0.360g (17.2%) of **270** as a yellow solid and 0.290g (14.0%) of **280** as a yellow oil. **270**: mp: 101-102°; ^1H NMR (300 MHz, CDCl_3): δ =1.20 (d, 1H, J=12.0 Hz), 3.05 (dt, 1H, J=10.0, 16.5 Hz), 3.88 (dd, 1H, J=12.0, 0.5 Hz), 4.05 (m, 1H), 5.39 (dq, 2H, J=5.2, 10.8, 11.0 Hz), 6.42 (dd, 2H, J=2.6, 11.5 Hz), 6.64 (s, 2H), 7.50 (AA'BB', 4H); ^{13}C NMR: δ = 27.4, 27.5, 120.2, 126.1, 126.3, 131.1, 133.1, 137.1; IR (CCl_4): 3010, 1580, 1484, 1465, 1391, 1016, 846 cm^{-1} ; MS (EI): M^+ 206, 191(100%) m/z; **280**: ^1H NMR (300 MHz, CDCl_3): δ =3.66 (d, 1H, J=10.2 Hz), 3.82 (d, 1H, J=7.8 Hz), 4.22 (d, 1H, J=10.5 Hz), 5.66 (m, 4H), 6.11 (s, 1H), 6.53 (d, 1H, J=12.0 Hz), 7.02 (s, 1H), 7.05 (m, 4H); ^{13}C NMR: δ = 35.9, 22.8, 119.7, 123.4, 125.7, 126.2, 126.5, 127.1, 130.4, 131.6, 131.7, 137.2, 137.3, 139.3, 140.8, 159.3; IR (CCl_4): 3005, 1639, 1623, 1480, 1453, 1410, 1261, 835, 734 cm^{-1} ; MS (EI): M^+ 206, 191(100%) m/z;

When the reaction is carried out at 50°, **270** is collected as the sole

product in 24.9% yield. The use of sodium ethoxide as a base was found fruitless.

Isomerization of 280 70mg (0.34 mmoles) of **280** are dissolved in 5 ml t-BuOH and added to a 25 ml round bottom flask containing t-BuOK solution (prepared from dissolving 31 mg potassium in 5 ml alcohol). The solution is refluxed under argon for 3 hours, then quenched with water and extracted with ether. The ether layers are combined, dried and evaporated to yield a red oil. GC-MS analysis indicates the presence of 65.7% **270** and 34.3% **280**. The mixture is purified by chromatography without the separation of the isomers. The ratio of the **270/280** is found unchanged.

Isomerization of 270 30mg (0.15 mmoles) of **270** added to t-BuOK in t-BuOH, prepared as before, and refluxed for 3 hours. Work-up as before and GC-MS analysis determines the resulting red oil to contain 74.5% of **270** and 25.5% of **280**.

Benzbicyclo[5.4.1]dodecapentaenylum cation (290) 15 ml of distilled CH₂Cl₂ in a 50 ml round bottom flask under argon, are treated with 0.250g (1.21 mmoles) of **270**, or **280** and 1.15g (3.5 mmoles) of solid trityl tetrafluoroborate. The solution immediately changes color to blue/green and is allowed to stir for 45 minutes at room temperature. The solution is then treated with cold, anhydrous ether and the precipitated solid is collected. The green solid is added to boiling ether and then filtered out while hot. The insoluble solid is dried and collected as a green/blue solid in variable yields (22.2%-58.8%). mp: >250°; ¹H NMR (300 MHz, CD₃CN): δ= -1.20 (s, 2H), 8.32 (q, 2H), 8.54 (t, 2H, J=10.8 Hz), 8.92 (t, 1H, J=11.4 Hz), 8.94 (q, 2H), 9.38 (s, 2H), 9.60 (d, 2H, J=9.9 Hz).

1,6-Bis(E-2-acetoxyvinyl)-3,4-benzcycloheptatriene (289)

METHOD A: 0.990g (5.0 mmoles) of dialdehyde **220** and 6.56g (20.6 mmoles) of acetylmethylene triphenylphosphorane added to 35 ml of freshly distilled toluene in a 50 ml round bottom flask under argon. The solution is allowed to reflux for 13 hours, then it is cooled down

and hydrolyzed with water. Extraction with CH_2Cl_2 (3x50 ml) results in a yellow solution which is dried and evaporated to yield a lemon-yellow solid. Chromatography on silica gel (5:1 hexane:ethyl acetate) yields **289** as a light yellow solid in 80.0% yield (1.10g). When the reaction is refluxed for shorter periods of time, monoaldehyde **294** is separated as well.

METHOD B: A solution of 1.0g (5.05 mmoles) of **220** and 0.290g (5.0 mmoles) acetone in 20 ml ethanol are added slowly to a 15ml of 10% KOH previously placed in a 50 ml round bottom flask. As the ethanolic solution is added, precipitate forms. The suspension is stirred for 10 minutes, then poured on water, neutralized with dilute acid, and extracted. The combined ether layers are dried and evaporated to yield a yellow solid. Chromatography yields 0.290g of recovered **220**, 0.78g (62.2%) **289** and 0.200g (23.6%) of monoaldehyde **294**. **289**: mp: 139.5-141°; ^1H NMR (300 MHz, CDCl_3): δ =2.36 (s, 6H), 2.83 (s, 2H), 6.50 (d, 2H, J =16.0 Hz), 7.02 (s, 2H), 7.33 (d, 2H, J =16.0 Hz), 7.43 (AA'BB', 4H); ^{13}C NMR: δ = 22.2, 25.8, 124.4, 125.7, 129.1, 133.6, 133.9, 136.2, 142.3, 195.9; IR (CCl_4): 1676, 1582, 1356, 1323, 1257, 1173, 986, 858, 750 cm^{-1} ; MS (EI): M^+ 278, 43 (100%) m/z ; **294**: mp: 105-107°; ^1H NMR (300 MHz, CDCl_3): δ =22.7 (s, 3H), 2.93 (s, 2H), 6.65 (d, 1H, 16.0 Hz), 6.90 (s, 2H), 7.23 (d, 1H, J =16.0 Hz), 7.34 (m, 4H); ^{13}C NMR: δ = 21.0, 29.0, 127.4, 128.0, 129.6, 131.8, 134.5, 136.9, 137.2, 137.5, 137.6, 139.4, 143.7, 147.5, 191.3, 198.2; IR (CCl_4): 3016, 2918, 2818, 1680, 1639, 1610, 1586, 1439, 1357, 1310, 1251, 1216, 1181, 1140, 1110, 969, 911, 828, 758, 734 cm^{-1} ; MS (EI): M^+ 238 (100%) m/z ;

6-benz-4,9-methano[11]annulenone-2,11-dimethylester

(283) In a 250 ml round bottom flask fitted with a Dean-Stark trap dissolved 2.0g (10.1 mmoles) of **220** in 50 ml of benzene. 1.83g (10.5 mmoles) dimethyl acetonedicarboxylate, 2 ml glacial acetic acid and 15 drops of piperidine were then added and the solution was maintained at reflux for 5 hours. The solution was poured on water and washed with NaHCO_3 . Extraction with CH_2Cl_2 yielded a yellow solid which was crystallized from methanol. 1.75g of **283** was collected (51.6%) as a light yellow solid. The solid may be sublimed

at 190° (0.1 torr). **mp**: 238-239°; **¹H NMR** (300 MHz, CDCl₃): δ=1.04 (d, 1H, J=13.5 Hz), 2.58 (d, 1H, J=13.5 Hz), 3.85 (s, 6H), 7.28 (s, 2H), 7.57 (AA'BB', 4H), 7.97 (s, 2H); **¹³C NMR**: δ= 29.7, 53.3, 127.8, 128.2, 129.9, 131.7, 133.3, 136.6, 142.0, 165.4, 195.7; **IR** (CCl₄): 1713, 1695, 1669, 1592, 1433, 1277, 1221, 1144, 1077, 994, 858, 748 cm⁻¹; **MS** (EI): M⁺ 336, 277 (100%) m/z;

Benzmethano[12]annulene (272) METHOD A: 50 mg (0.23 mmoles) of dihydro[12]annulene **316** dissolved in 20 ml of distilled anisole and heated under reflux with excess DDQ. With the disappearance of starting material observed by TLC, the reaction was cooled down, filtered and concentrated. GC-MS, NMR did not indicate the presence of **272**.

METHOD B: The method used above was repeated with the addition of 20 drops of acetic acid to a 340 mg (1.68 mmoles) solution of **316** in anisole containing 450mg DDQ. The solution is refluxed for 12 hours, filtered, washed and concentrated to yield a yellow oil (10% yield) identified as **320**. **¹H NMR** (300 MHz, CDCl₃): δ=2.42 (m, 4H), 3.61 (s, 3H), 5.95 (m, 2H), 4.98 (s, 1H), 6.50 (dd, 2H, J=8.1, 1.8 Hz), 6.80 (d, 2H, J=11.1), 6.84 (s, 2H), 6.94 (d, 2H, J=8.1 Hz), 7.18 (AA'BB', 4H) ; **¹³C NMR**: δ= 28.4, 47.6, 55.6, 113.1, 126.3, 128.2, 130.2, 130.9, 132.3, 133.2, 135.8, 136.2, 141.2, 157.8; **IR** (CCl₄): 3010, 2934, 1507, 1246, 1175, 1040, 908, 876 cm⁻¹; **MS** (EI): M⁺ 336, 277 (100%) m/z;

METHOD C: 650 mg (2.95 mmoles) of dihydro **316** dissolved in 60 ml of distilled CCl₄, treated with 1.3g NBS and AIBN were refluxed and irradiated with a mercury lamp for 4 hours. Then the insoluble solid was filtered off, solvent evaporated and the residue was dissolved in 75 ml THF. The THF solution now treated with 0.8g t-BuOK to yield a deep red solution which was stirred under nitrogen overnight. Water was added, layers separated and the water re-extracted with ether. Evaporation and chromatography on silica gel (hexane) yielded a slowly decomposing yellow oil in 10% yield. **272**: **¹H NMR** (300 MHz, CDCl₃): δ=2.37 (d, 1H), 5.77 (m, 4H), 5.99 (dt, 1H), 6.36 (s, 2H), 7.15 (AA'BB', 4H) ; **MS** (EI): M⁺ 218, 202 (100%) m/z;

Ketones (228) and (229) 0.270g (1.31 mmoles) of a mixture of **270** and **280** dissolved in 50 ml of distilled dioxane is treated with 0.60g (5.4 mmoles) selenium dioxide and refluxed for 12 hours. The solution is then cooled down, poured on water and extracted with methylene chloride. The organic layers are combined, dried and evaporated to yield a thick oil. Chromatography on silica gel (5:1 hexane:EtOAc) separates a 0.140 g of a red oil identified as ketone **229** (48.6% yield) followed by a 0.120 g of a dark orange oil identified as **228** (41.6% yield). **229**: ^1H NMR (300 MHz, CDCl_3): δ =3.10 (d, 1H), 3.28 (d, 1H), 6.15 (m, 3H), 6.45 (s, 1H), 7.01 (d, 1H), 7.08 (d, 1H), 7.32 (d, 1H), 7.38 (t, 1H), 7.53 (m, 1H), 8.11 (d, 1H); ^{13}C NMR: δ = 31.9, 123.4, 126.0, 127.3, 127.7, 129.6, 131.1, 131.4, 132.4, 132.5, 136.2, 137.6, 140.5, 141.9, 152.1, 192.5; IR (neat): 3006, 1651, 1604, 1531, 1467, 1282, 1257, 1160, 1112, 988, 889, 842, 717, 654 cm^{-1} ; MS (EI): M^+ 220, 205 (100%) m/z ; **228**: ^1H NMR (300 MHz, CDCl_3): δ =1.22 (d, 1H), 3.35 (d, 1H), 6.01 (dd, 1H), 6.38 (d, 1H), 6.68 (dd, 1H), 6.85 (d, 1H), 6.95 (s, 1H), 7.70 (s, 1H), 7.60 (m, 4H); ^{13}C NMR: δ = 27.7, 123.1, 127.5, 128.1, 128.5, 131.6, 131.9, 132.2, 133.4, 134.7, 134.8, 137.5, 138.4, 138.9, 193.9; IR (CCl_4): 3009, 2926, 1733, 1635, 1584, 1540, 1446, 1407, 1315, 1257, 1169, 1049, 990, 921, 850, 756 cm^{-1} ; MS (EI): M^+ 220, 205 (100%) m/z ;

6-benz-4,9-methano[11]annulenone (273) METHOD A: A 500 ml round bottom flask, fitted with a condenser, an addition funnel and under an atmosphere of nitrogen, 300 ml of freshly distilled DMF, 3.0g (15.15 mmoles) **220** and 13.0g (20.0 mmoles) phosphonium salt derived from dibromoacetone. The solution was warmed to 90° with stirring, then treated with lithium ethoxide (prepared by dissolving 0.350g Li in 35 ml EtOH) added dropwise over an 8-hour period. The solution was allowed to stir over night then poured on ice water and extracted with ether. The combined ether layers (3x120ml) were dried and evaporated to yield a brown oily solid. Chromatography on silica gel (1:1 hexane: ethyl acetate) yielded 0.030g (0.9%) of **273** as a yellow solid and large quantities of **289**. **METHOD B:** 0.200 g of a mixture of **270** and **280** dissolved in dichloromethane and loaded on neutral alumina. The powder resulting

is allowed to sit for 6 hours at room temperature, exposed to oxygen. Chromatography on hexane followed by elution with a 5:1 mixture of hexane:ethylacetate results in the separation of **273** in 20% yield. **273**: ^1H NMR (300 MHz, CDCl_3): δ = 1.00 (d, 1H, J =12.3 Hz), 2.50 (dt, 1H, J =1.5, 12.3 Hz), 6.14 (d, 2H, J =12.0 Hz), 7.10 (s, 2H), 7.18 (d, 2H, J =12.3 Hz), 7.66 (AA'BB', 4H); ^{13}C NMR: δ = 32.6, 127.4, 128.2, 128.3, 131.5, 132.6, 137.0, 138.2, 196.6; IR (CCl_4): 2960, 1680, 1625, 1260, 1095, 1019, 854 cm^{-1} ; MS (EI): M^+ 220, 192 (100%) m/z ;

Dihydro-2H-benzmethano[12]annulene (316) METHOD A: 450 ml freshly distilled DMF placed in a 500 ml round bottom flask were treated with 7.38g (10 mmoles) of tetramethylene phosphonium salt and 1.98g (10 mmoles) of dialdehyde **220**. The solids are dissolved and then treated with 50 ml ethanol in which excess lithium was dissolved. The addition proceeds for 7 hours then the solution is stirred overnight. The now dark solution is poured on ice water containing acid, extracted with ether and washed. Ether layers are evaporated to yield a dark oil which is chromatographed on silica gel (hexane) to yield **316** as a white solid in 15 % yield. mp: 65-66°; ^1H NMR (300 MHz, CDCl_3): δ = 1.99 (d, 1H), 2.25 (m, 2H), 2.40 (m, 2H), 3.20 (dt, 1H), 5.93 (m, 2H), 6.53 (d, 2H), 6.65 (s, 2H), 7.35 (AA'BB', 4H); ^{13}C NMR: δ = 29.0, 32.9, 126.5, 130.0, 131.6, 132.9, 134.3, 137.0, 137.7; IR (neat): 3006, 2933, 2839, 1595, 1474, 1433, 857, 737, 712 cm^{-1} ; MS (EI): M^+ 220 (100%) m/z ;

METHOD B: 3.7g (5.0 mmoles) of the phosphonium salt was suspended in 150 ml of freshly distilled THF and was treated with 1.86g (16.0 mmoles) freshly sublimed t-BuOK. The suspension turned deep red then stirred for 20 minutes and treated, at room temperature with 0.98g (5.0 mmoles) of dialdehyde **220** dissolved in 50 ml THF. Addition proceeds for 45 minutes at the end of which the solution is dark. Let stir overnight then worked up with water/acid, extracted with ether and washed with water and brine. The ether layers were combined, dried and evaporated to yield some insoluble solid. Chromatography on silica gel (elution with 2% ethylacetate in hexane) separated 60 mg of **315** (5.4%) as a thin film of yellow oil,

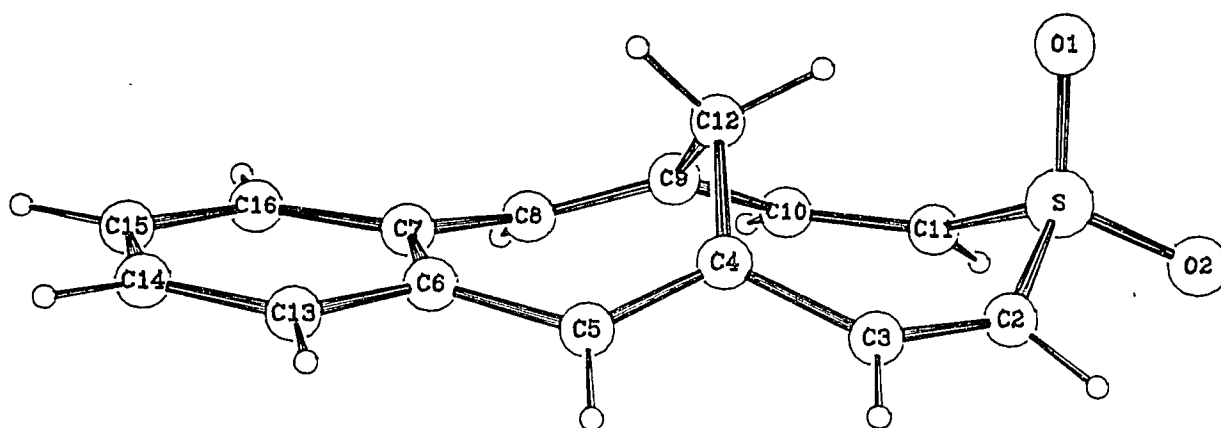
and **316** in 8% yield. **315**: ^1H NMR (300 MHz, CDCl_3): δ = 2.04 (d, 1H), 2.69 (td, 1H), 2.98 (dd, 1H), 3.33 (t, 1H), 3.35 (d, 1H), 3.78 (m, 1H), 5.21 (td, 1H), 5.57 (q, 1H), 5.74 (td, 1H), 6.36 (d, 1H), 6.50 (s, 1H), 6.58 (s, 1H) 7.23 (m, 4H); ^{13}C NMR: δ = 27.6, 33.6, 36.7, 123.7, 124.7, 125.2, 125.9, 126.2, 126.3, 129.8, 130.7, 131.2, 134.3, 136.6, 137.4, 138.0, 138.7; MS (EI): M^+ 220 (100%) m/z ;

3,4,9,10-dibenz-1,6-methano[12]annulene (319) 250ml of doubly distilled DMF in a 500 ml 3-neck round bottom flask is treated under a blanket of nitrogen with 0.990g (5.0 mmoles) of dialdehyde **220** and 4.0g (5.07 mmoles) xylene phosphonium salt. When all is dissolved, 50 ml of ethanol containing 0.20g of dissolved lithium (28.6 mmoles) are added dropwise over a period of 4 hours. The resulting yellow/orange solution turns black at the end of the addition. The dark solution is allowed to stir at room temperature for additional 18 hours, then poured on ice/acid mixture and extracted with ether. Ether extracts are combined, washed with bicarbonate solution, water, dried and evaporated to yield a dark oil residue. Chromatography on silica gel (hexane) separates 20 mg of **319** as a white solid (1.5% yield). ^1H NMR (300 MHz, CDCl_3): δ = 1.50 (d, 1H, J =10.9 Hz), 4.37 (d, 1H, J =10.9 Hz), 5.83 (d, 2H, J =6.11 Hz), 6.04 (d, 2H, J =6.12 Hz), 6.53 (s, 2H), 7.40 (AA'BB', 4H);

1,9,21-tribenz-4,29:9,14:18,24-trismethano-5,7,15,17,25,27-hexadehydro[30]annulene (340) A dry 3-neck, 300 ml round bottom flask, under an atmosphere of argon, is charged with 1.20g (6.7 mmoles) anhydrous $\text{Cu}(\text{OAc})_2$, 60 ml of freshly distilled pyridine, 60 ml EtOH and 10 ml ether. The solid is allowed to suspend while 0.190g (1.0 mmoles) **221** in 50 ml of a 1:1 solution of pyridine and ethanol are added dropwise over a 4-hour period. The dark green solution is allowed to reflux for 45 minutes and stir at room temperature overnight. The insoluble solid is filtered off through sintered glass funnel, then the solution is poured on an ice cold mixture of 70 ml 50% H_2SO_4 , ice and 60 ml ether. When all the ice is melted, three layers are observed. The top brown, ether layer is removed and the solution is re-extracted with 2x90 ml of ether.

The combined ether layers are washed with dilute base, water then dried and evaporated at bath temperatures of 30°. The resulting yellow solid is chromatographed on silica gel (5:1 hexane: ethyl acetate) to yield a rather insoluble yellow solid which crystallizes in the elution medium ($R_f=0.15$), forming yellow needles, 20.2% yield. **mp:** >250°; **^1H NMR** (300 MHz, CDCl_3): $\delta=2.84$ (s, 6H), 7.08 (s, 6H), 7.34 (AA'BB', 12H); **^{13}C NMR:** $\delta=34.5$, 72.6, 82.5, 118.0, 125.2, 128.5, 133.4, 135.0;

**^1H NMR, ^{13}C NMR, IR AND MS OF SELECTED
COMPOUNDS**



1. X-ray sample T161 was submitted on December 8, 1995.
2. P. Main, S. Fiske, S. Hull, L. Lessinger, G. Germain, J. P. Declercq, M. Woolfson, (1982). MULTAN 11/82. University of York, England and University of Louvain, Belgium.

Table I. X-ray Data for RB-2 at 295 K

Formula	C ₁₅ H ₁₂ O ₂ S
Formula weight	256.326
Crystal size (mm)	0.09 x 0.10 x 0.20
Crystal system	Monoclinic
Space group	<i>P</i> 2 ₁ / <i>n</i>
<i>a</i> (Å)	11.029(3)
<i>b</i> (Å)	12.726(1)
<i>c</i> (Å)	8.686(1)
β (°)	99.74(1)
<i>V</i> (Å ³)	1201.6(3)
<i>Z</i>	4
<i>d</i> _{calc} (g cm ⁻³)	1.417
μ (Cu <i>K</i> α) (cm ⁻¹)	22.58
Absorption correction	numerical
min transmission (%)	60.27
max transmission (%)	86.47
Maximum θ (°)	60
Unique reflections	1783
Observed reflections [<i>I</i> > 3.0 σ (<i>I</i>)]	1498
Number of variables	163
<i>R</i>	0.039
<i>R</i> _w	0.054
($\Delta\rho$) _{max} (e Å ⁻³)	0.19
($\Delta\rho$) _{min} (e Å ⁻³)	-0.36

Table II. Final Atomic Parameters for RB-2

315

Atom	x	y	z	B (Å ²)
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S	0.14711 (6)	0.15545 (5)	0.11747 (8)	3.59 (1)
O1	0.1554 (2)	0.2111 (1)	0.2634 (2)	4.36 (4)
O2	0.0289 (2)	0.1584 (2)	0.0160 (3)	5.15 (5)
C2	0.2497 (3)	0.2090 (2)	0.0031 (3)	4.10 (6)
C3	0.3734 (3)	0.2087 (2)	0.0201 (3)	3.81 (6)
C4	0.4630 (2)	0.1618 (2)	0.1419 (3)	3.04 (5)
C5	0.5773 (2)	0.1381 (2)	0.1162 (3)	3.40 (5)
C6	0.6637 (2)	0.0701 (2)	0.2151 (3)	3.24 (5)
C7	0.6271 (2)	-0.0185 (2)	0.2972 (3)	3.19 (5)
C8	0.5008 (2)	-0.0519 (2)	0.2891 (3)	3.20 (5)
C9	0.4025 (2)	0.0125 (2)	0.2748 (3)	2.88 (5)
C10	0.2807 (2)	-0.0278 (2)	0.2213 (3)	3.18 (5)
C11	0.1782 (2)	0.0215 (2)	0.1532 (3)	3.25 (5)
C12	0.4268 (2)	0.1281 (2)	0.2923 (3)	3.02 (5)
C13	0.7894 (2)	0.0857 (2)	0.2154 (3)	4.07 (6)
C14	0.8778 (3)	0.0229 (3)	0.2997 (3)	4.77 (7)
C15	0.8430 (3)	-0.0637 (3)	0.3806 (3)	4.73 (7)
C16	0.7199 (3)	-0.0844 (2)	0.3760 (3)	4.11 (6)
H2	0.208	0.247	-0.093	4.9
H3	0.408	0.246	-0.063	4.6
H5	0.605	0.170	0.022	4.1
H8	0.485	-0.129	0.295	3.8
H10	0.279	-0.107	0.223	3.8
H11	0.107	-0.025	0.108	3.9
H12A	0.351	0.166	0.310	3.6
H12B	0.495	0.142	0.381	3.6
H13	0.816	0.145	0.152	4.9
H14	0.967	0.039	0.303	5.7
H15	0.907	-0.110	0.441	5.7
H16	0.696	-0.148	0.430	4.9

 The parameters of the hydrogen atoms were not refined.

Standard deviations are in parentheses.

Anisotropically refined atoms are given in the form of the isotropic equivalent displacement parameter defined as:
 $(4/3) * [a^2 * B(1,1) + b^2 * B(2,2) + c^2 * B(3,3) + ab(\cos\gamma) * B(1,2) + ac(\cos\beta) * B(1,3) + bc(\cos\alpha) * B(2,3)]$.

Table III. Final Anisotropic Thermal Parameters (U's) for RB-2

316

Atom	U(1,1)	U(2,2)	U(3,3)	U(1,2)	U(1,3)	U(2,3)
S	0.0399(3)	0.0342(3)	0.0614(4)	0.0045(3)	0.0059(3)	0.0034(3)
O1	0.061(1)	0.0372(9)	0.070(1)	0.0078(8)	0.0190(8)	-0.0063(8)
O2	0.040(1)	0.061(1)	0.088(1)	0.0044(9)	-0.008(1)	0.012(1)
C2	0.054(2)	0.046(1)	0.055(1)	0.005(1)	0.005(1)	0.014(1)
C3	0.054(2)	0.040(1)	0.051(1)	-0.000(1)	0.010(1)	0.010(1)
C4	0.043(1)	0.029(1)	0.042(1)	-0.006(1)	0.006(1)	-0.002(1)
C5	0.045(1)	0.043(1)	0.041(1)	-0.009(1)	0.007(1)	-0.001(1)
C6	0.040(1)	0.046(1)	0.037(1)	-0.003(1)	0.007(1)	-0.010(1)
C7	0.040(1)	0.044(1)	0.037(1)	0.002(1)	0.004(1)	-0.006(1)
C8	0.044(1)	0.035(1)	0.041(1)	0.001(1)	0.004(1)	0.002(1)
C9	0.041(1)	0.034(1)	0.035(1)	-0.004(1)	0.0074(9)	0.0015(9)
C10	0.043(1)	0.029(1)	0.049(1)	-0.002(1)	0.009(1)	-0.001(1)
C11	0.038(1)	0.031(1)	0.054(1)	-0.002(1)	0.008(1)	-0.003(1)
C12	0.043(1)	0.034(1)	0.038(1)	-0.004(1)	0.006(1)	-0.005(1)
C13	0.043(1)	0.061(2)	0.053(1)	-0.007(1)	0.013(1)	-0.011(1)
C14	0.040(1)	0.081(2)	0.060(1)	-0.001(1)	0.008(1)	-0.017(1)
C15	0.043(2)	0.077(2)	0.055(2)	0.012(1)	-0.002(1)	-0.007(1)
C16	0.049(2)	0.058(2)	0.047(1)	0.010(1)	0.002(1)	-0.001(1)

 The form of the anisotropic displacement parameter is:

$\exp\{-2\pi^2[h^2a^{*2}U(1,1) + k^2b^{*2}U(2,2) + l^2c^{*2}U(3,3) + 2hka^*b^*U(1,2) + 2hla^*c^*U(1,3) + 2klb^*c^*U(2,3)]\}$, where a^* , b^* , and c^* are reciprocal lattice constants.

Table IV. Bond Distances (Å) for RB-2

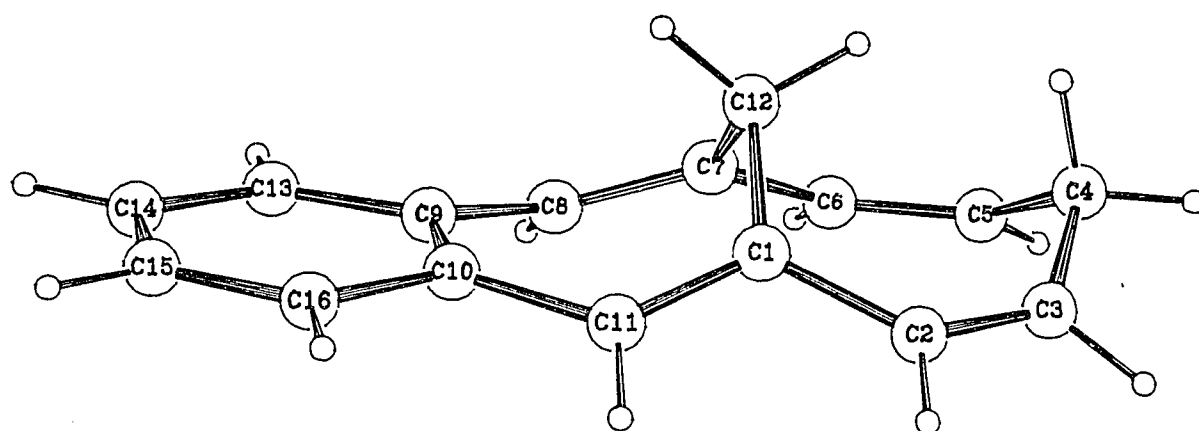
317

Atom 1	Atom 2	Distance	Atom 1	Atom 2	Distance
=====	=====	=====	=====	=====	=====
S	O1	1.441(2)	C6	C13	1.400(4)
S	O2	1.445(2)	C7	C8	1.447(4)
S	C2	1.764(3)	C7	C16	1.407(4)
S	C11	1.756(2)	C8	C9	1.349(3)
C2	C3	1.348(4)	C9	C10	1.439(3)
C3	C4	1.449(3)	C9	C12	1.498(3)
C4	C5	1.351(4)	C10	C11	1.339(3)
C4	C12	1.492(3)	C13	C14	1.373(4)
C5	C6	1.455(3)	C14	C15	1.395(5)
C6	C7	1.429(4)	C15	C16	1.376(4)

Table V. Bond Angles (°) for RB-2

Atom 1	Atom 2	Atom 3	Angle	Atom 1	Atom 2	Atom 3	Angle
=====	=====	=====	=====	=====	=====	=====	=====
O1	S	O2	116.1(1)	C6	C7	C8	124.0(2)
O1	S	C2	110.7(1)	C6	C7	C16	118.0(2)
O1	S	C11	109.9(1)	C8	C7	C16	117.6(2)
O2	S	C2	104.2(1)	C7	C8	C9	125.3(2)
O2	S	C11	105.2(1)	C8	C9	C10	120.3(2)
C2	S	C11	110.5(1)	C8	C9	C12	117.4(2)
S	C2	C3	132.1(2)	C10	C9	C12	121.6(2)
C2	C3	C4	129.4(3)	C9	C10	C11	130.4(2)
C3	C4	C5	120.8(2)	S	C11	C10	131.1(2)
C3	C4	C12	120.5(2)	C4	C12	C9	105.3(2)
C5	C4	C12	118.4(2)	C6	C13	C14	122.1(3)
C4	C5	C6	124.9(2)	C13	C14	C15	119.9(3)
C5	C6	C7	123.5(2)	C14	C15	C16	119.3(3)
C5	C6	C13	117.8(2)	C7	C16	C15	122.2(3)
C7	C6	C13	118.3(2)				

Standard deviations are in parentheses.



RB-3

1. X-ray sample T162 was submitted on December 22, 1995.
2. P. Main, S. Fiske, S. Hull, L. Lessinger, G. Germain, J. P. Declercq, M. Woolfson, (1982). MULTAN 11/82. University of York, England and University of Louvain, Belgium.

Table I. X-ray Data for RB-3 at 295 K

Formula	C ₁₆ H ₁₄
Formula weight	206.290
Crystal size (mm)	0.08 x 0.13 x 0.72
Crystal system	Monoclinic
Space group	<i>P</i> 2 ₁ / <i>c</i>
<i>a</i> (Å)	11.204(2)
<i>b</i> (Å)	17.085(2)
<i>c</i> (Å)	6.259(2)
β (°)	105.96(2)
<i>V</i> (Å ³)	1152.0(4)
<i>Z</i>	4
<i>d</i> _{calc} (g cm ⁻³)	1.189
μ (Cu <i>K</i> α) (cm ⁻¹)	4.71
Absorption correction	none
Maximum θ (°)	60
Unique reflections	1694
Observed reflections [<i>I</i> > 3.0σ(<i>I</i>)]	771
Number of variables	145
<i>R</i>	0.047
<i>R</i> _w	0.053
(Δρ) _{max} (e Å ⁻³)	0.13
(Δρ) _{min} (e Å ⁻³)	-0.11

Table II. Final Atomic Parameters for RB-3

320

Atom	x	y	z	B(Å ²)
----	-	-	-	-----
C1	0.6556(3)	0.0778(2)	0.2829(6)	4.3(1)
C2	0.7655(4)	0.0807(2)	0.2030(6)	5.4(1)
C3	0.8833(4)	0.0885(3)	0.3217(7)	6.0(1)
C4	0.9395(4)	0.0934(3)	0.5713(7)	6.6(1)
C5	0.9027(4)	0.1640(3)	0.6830(6)	5.8(1)
C6	0.7910(4)	0.1856(2)	0.7028(6)	5.1(1)
C7	0.6740(3)	0.1467(2)	0.6135(5)	4.12(9)
C8	0.5640(3)	0.1846(2)	0.5788(6)	4.39(9)
C9	0.4466(3)	0.1571(2)	0.4378(6)	4.3(1)
C10	0.4357(3)	0.1167(2)	0.2344(6)	4.5(1)
C11	0.5424(4)	0.0968(2)	0.1520(6)	4.8(1)
C12	0.6688(3)	0.0652(2)	0.5236(6)	4.34(9)
C13	0.3372(4)	0.1804(3)	0.4863(7)	5.8(1)
C14	0.2207(4)	0.1639(3)	0.3499(7)	6.7(1)
C15	0.2112(4)	0.1254(3)	0.1499(7)	6.6(1)
C16	0.3160(4)	0.1031(2)	0.0926(7)	5.7(1)
H2	0.751	0.076	0.039	6.4
H3	0.944	0.092	0.232	7.2
H4A	1.032	0.094	0.601	7.9
H4B	0.914	0.046	0.639	7.9
H5	0.972	0.200	0.753	7.0
H6	0.789	0.234	0.790	6.1
H8	0.564	0.236	0.657	5.3
H11	0.530	0.097	-0.012	5.7
H12A	0.747	0.036	0.595	5.2
H12B	0.596	0.036	0.546	5.2
H13	0.344	0.210	0.626	6.9
H14	0.145	0.179	0.394	8.0
H15	0.127	0.114	0.047	7.9
H16	0.307	0.076	-0.053	6.8

 The parameters of the hydrogen atoms were not refined.

Standard deviations are in parentheses.

Anisotropically refined atoms are given in the form of the isotropic equivalent displacement parameter defined as:
 $(4/3) * [a^2*B(1,1) + b^2*B(2,2) + c^2*B(3,3) + ab(\cos\gamma)*B(1,2) + ac(\cos\beta)*B(1,3) + bc(\cos\alpha)*B(2,3)]$.

Table III. Final Anisotropic Thermal Parameters (U's) for RB-3

321

Atom	U(1,1)	U(2,2)	U(3,3)	U(1,2)	U(1,3)	U(2,3)
C1	0.070(2)	0.043(2)	0.049(2)	0.000(2)	0.015(2)	-0.004(2)
C2	0.076(3)	0.067(3)	0.065(2)	0.007(2)	0.026(2)	-0.007(2)
C3	0.071(3)	0.083(3)	0.079(3)	0.012(3)	0.030(2)	0.003(3)
C4	0.056(2)	0.096(3)	0.096(3)	0.008(3)	0.017(2)	0.015(3)
C5	0.074(3)	0.076(3)	0.063(3)	-0.005(3)	0.007(2)	0.007(2)
C6	0.072(3)	0.069(3)	0.046(2)	-0.006(2)	0.004(2)	-0.002(2)
C7	0.065(2)	0.058(2)	0.032(2)	-0.007(2)	0.010(2)	0.003(2)
C8	0.070(2)	0.057(2)	0.040(2)	0.001(2)	0.015(2)	-0.001(2)
C9	0.063(2)	0.053(2)	0.048(2)	-0.006(2)	0.015(2)	0.001(2)
C10	0.060(2)	0.049(2)	0.055(2)	-0.007(2)	0.007(2)	0.005(2)
C11	0.075(3)	0.056(2)	0.048(2)	-0.005(2)	0.014(2)	-0.009(2)
C12	0.067(2)	0.045(2)	0.052(2)	-0.005(2)	0.015(2)	0.004(2)
C13	0.067(2)	0.076(3)	0.079(3)	0.004(3)	0.025(2)	0.009(3)
C14	0.068(3)	0.097(4)	0.091(3)	0.001(3)	0.027(2)	0.013(3)
C15	0.058(3)	0.092(3)	0.092(3)	-0.006(3)	0.006(2)	0.021(3)
C16	0.074(3)	0.061(3)	0.070(3)	-0.010(2)	0.004(2)	0.007(2)

 The form of the anisotropic displacement parameter is:

$\exp\{-2\pi^2[h^2a^{*2}U(1,1) + k^2b^{*2}U(2,2) + l^2c^{*2}U(3,3) + 2hka^*b^*U(1,2) + 2hla^*c^*U(1,3) + 2klb^*c^*U(2,3)]\}$, where a^* , b^* , and c^* are reciprocal lattice constants.

Table IV. Bond Distances (Å) for RB-3

322

Atom 1 =====	Atom 2 =====	Distance =====	Atom 1 =====	Atom 2 =====	Distance =====
C1	C2	1.451(6)	C7	C12	1.497(5)
C1	C11	1.347(5)	C8	C9	1.446(5)
C1	C12	1.489(5)	C9	C10	1.423(5)
C2	C3	1.331(5)	C9	C13	1.399(6)
C3	C4	1.518(6)	C10	C11	1.466(6)
C4	C5	1.507(6)	C10	C16	1.409(5)
C5	C6	1.342(6)	C13	C14	1.379(5)
C6	C7	1.439(5)	C14	C15	1.392(7)
C7	C8	1.356(5)	C15	C16	1.373(7)

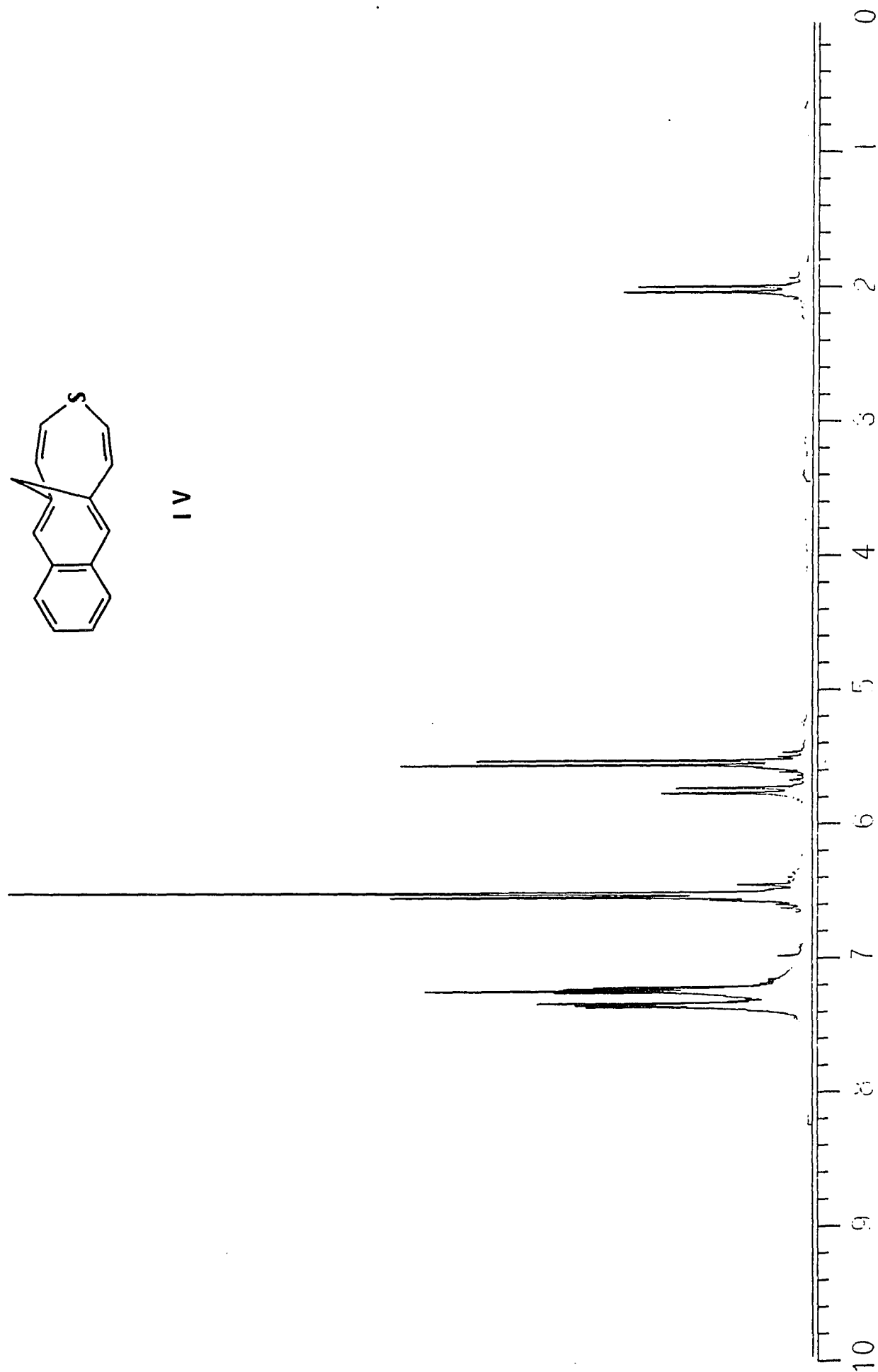
Table V. Bond Angles in (°) for RB-3

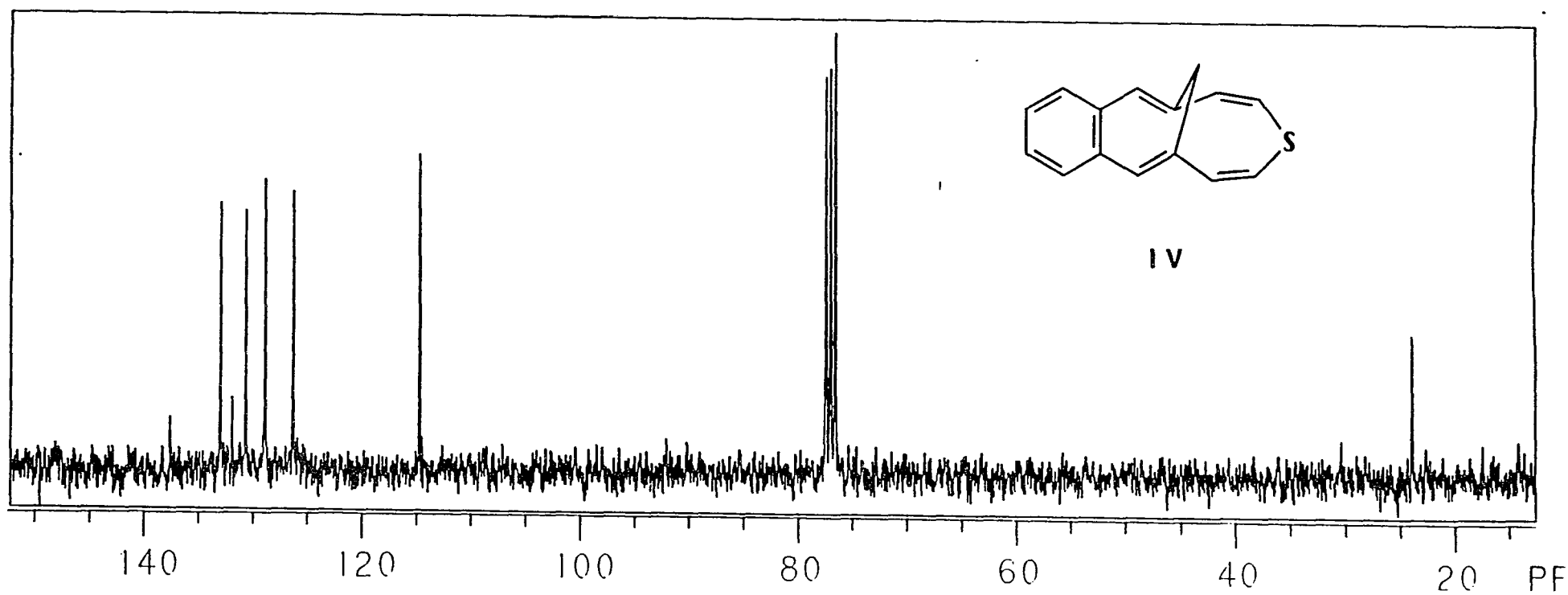
Atom 1 =====	Atom 2 =====	Atom 3 =====	Angle =====	Atom 1 =====	Atom 2 =====	Atom 3 =====	Angle =====
C2	C1	C11	121.9(3)	C8	C9	C10	122.9(4)
C2	C1	C12	119.7(3)	C8	C9	C13	118.6(3)
C11	C1	C12	117.7(4)	C10	C9	C13	117.9(3)
C1	C2	C3	128.0(4)	C9	C10	C11	123.3(3)
C2	C3	C4	130.3(4)	C9	C10	C16	118.5(4)
C3	C4	C5	115.6(3)	C11	C10	C16	117.8(3)
C4	C5	C6	130.1(4)	C1	C11	C10	124.4(3)
C5	C6	C7	127.5(4)	C1	C12	C7	103.2(3)
C6	C7	C8	122.2(3)	C9	C13	C14	123.0(4)
C6	C7	C12	120.9(3)	C13	C14	C15	118.6(4)
C8	C7	C12	116.3(3)	C14	C15	C16	120.5(4)
C7	C8	C9	125.3(3)	C10	C16	C15	121.6(4)

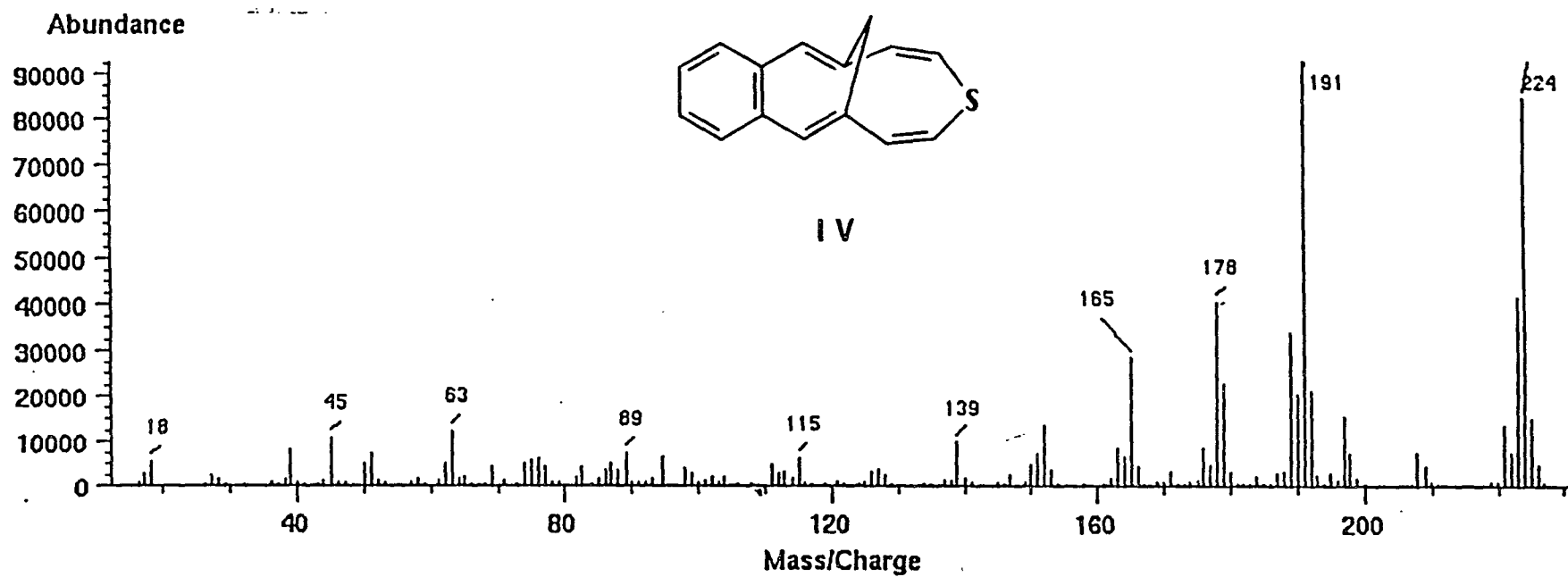
Standard deviations are in parentheses.

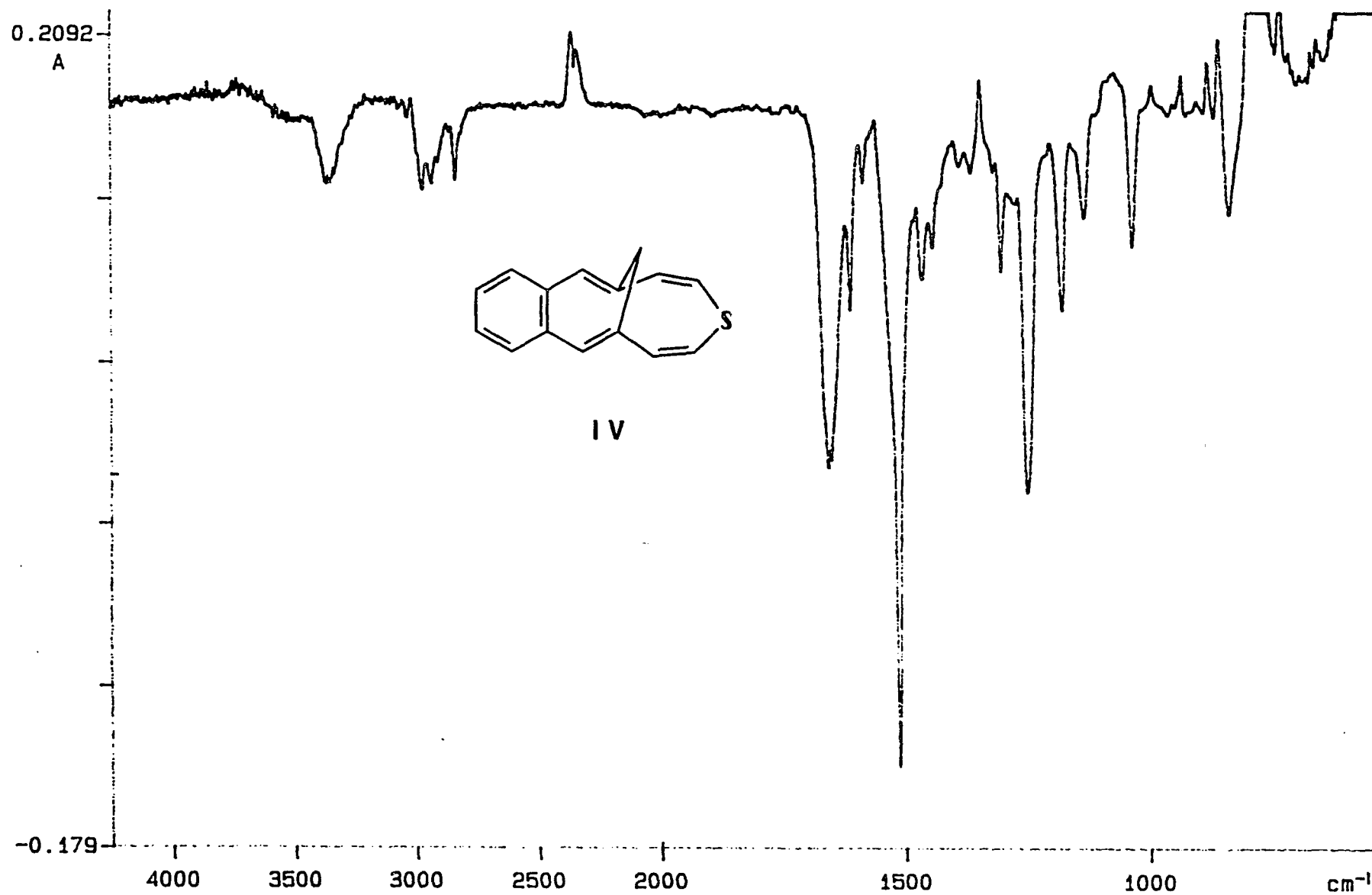


IV









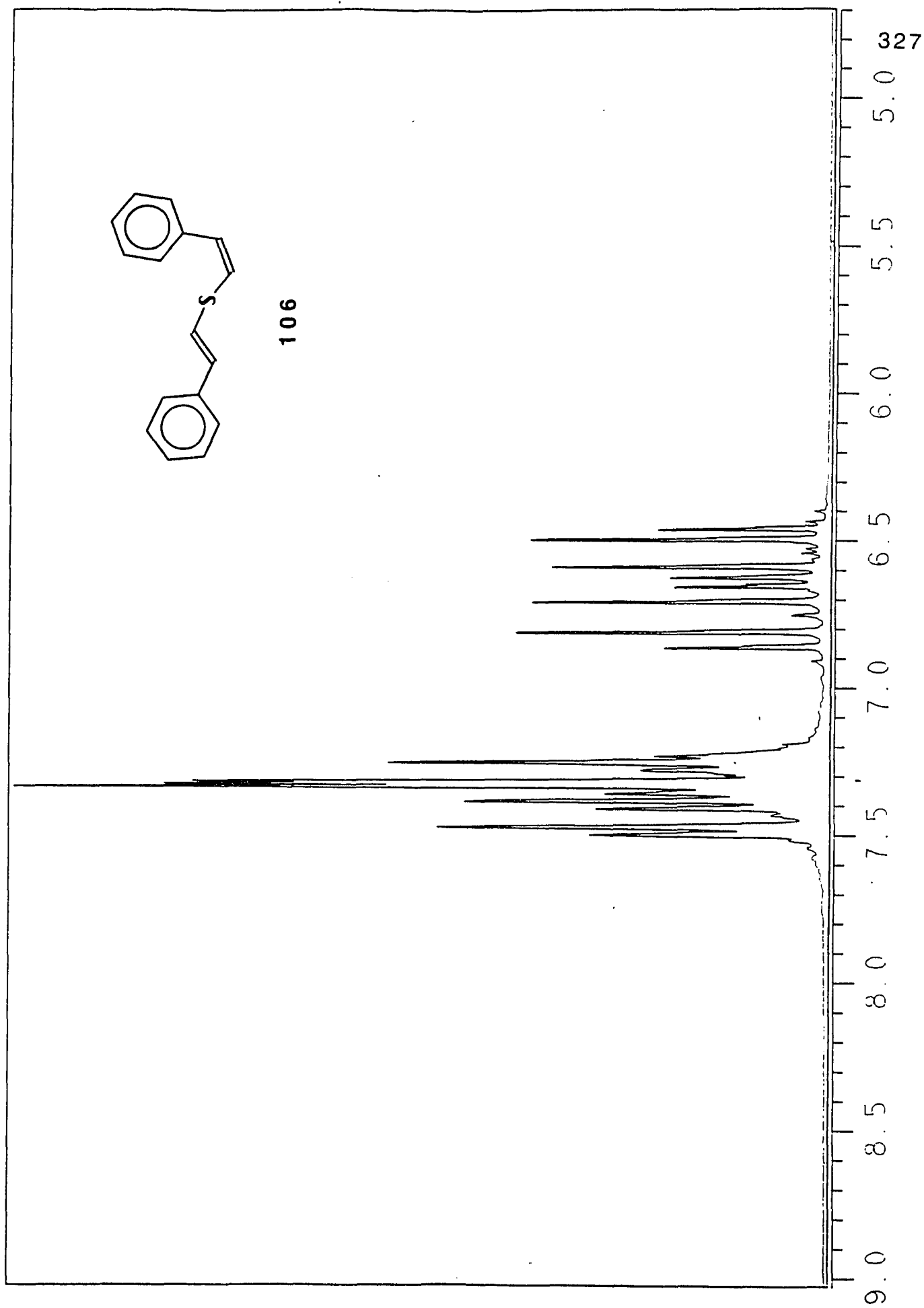
95/07/05 19:46

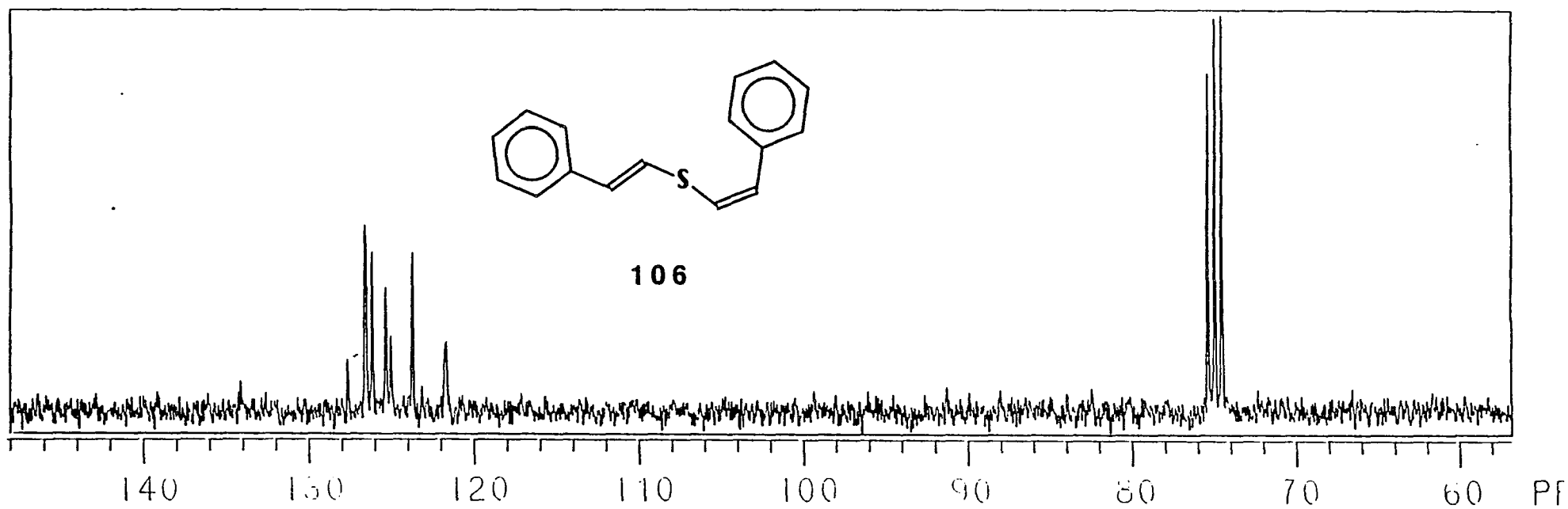
X: 1 scan, 4.0cm⁻¹, flat

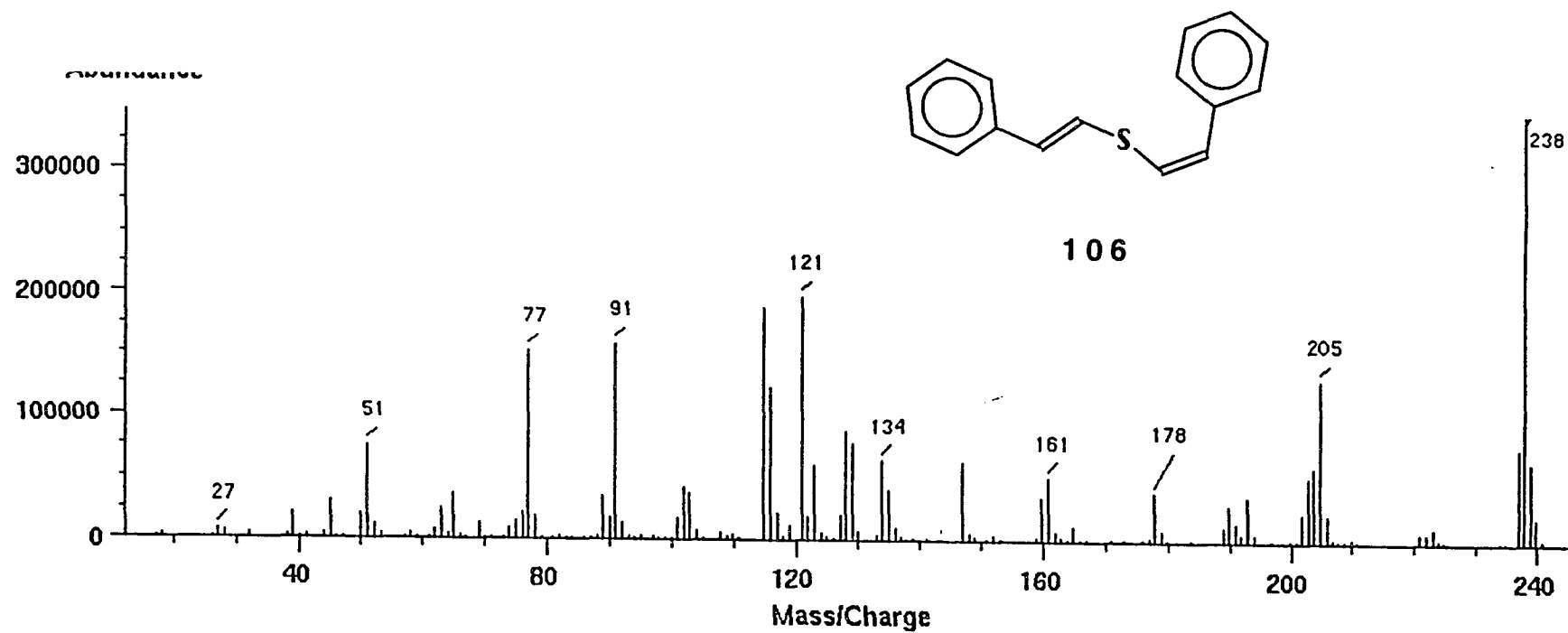
326

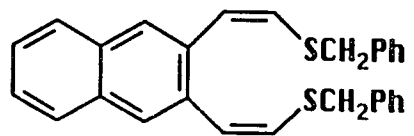


106

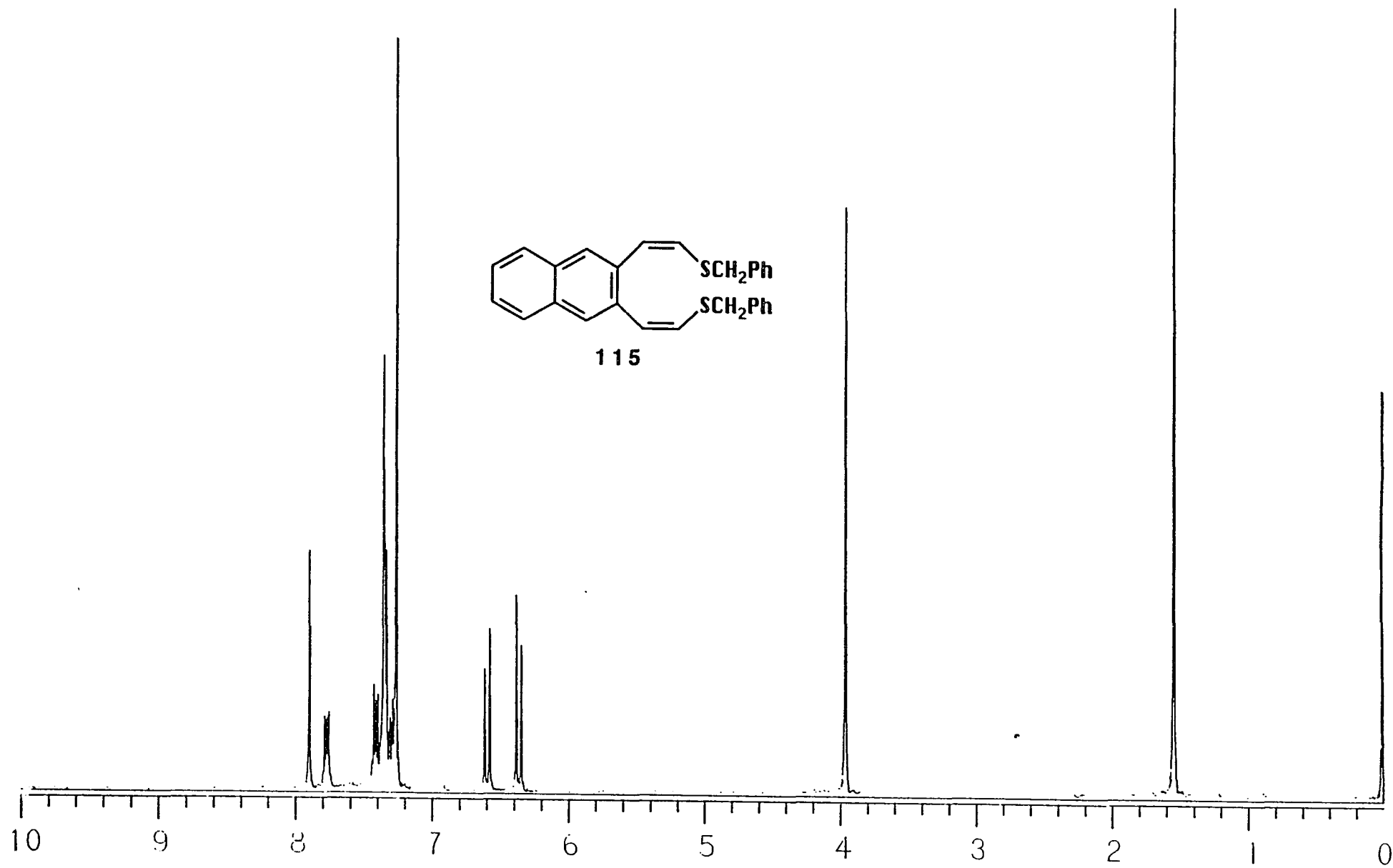


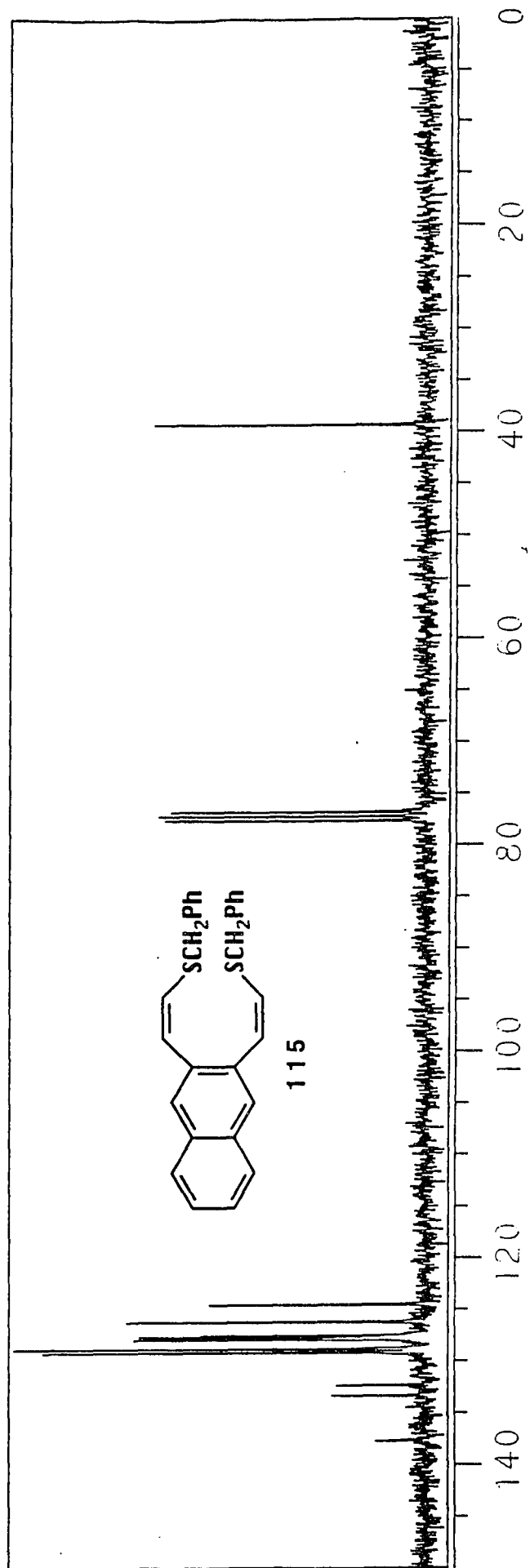


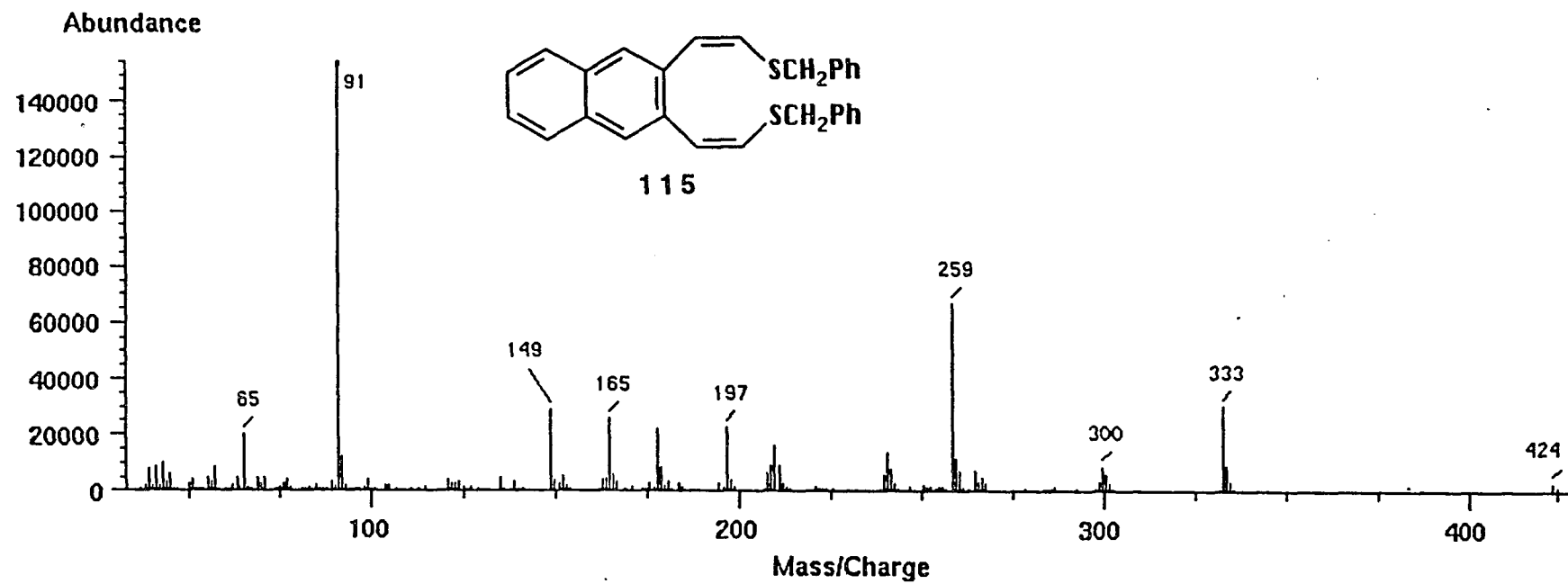


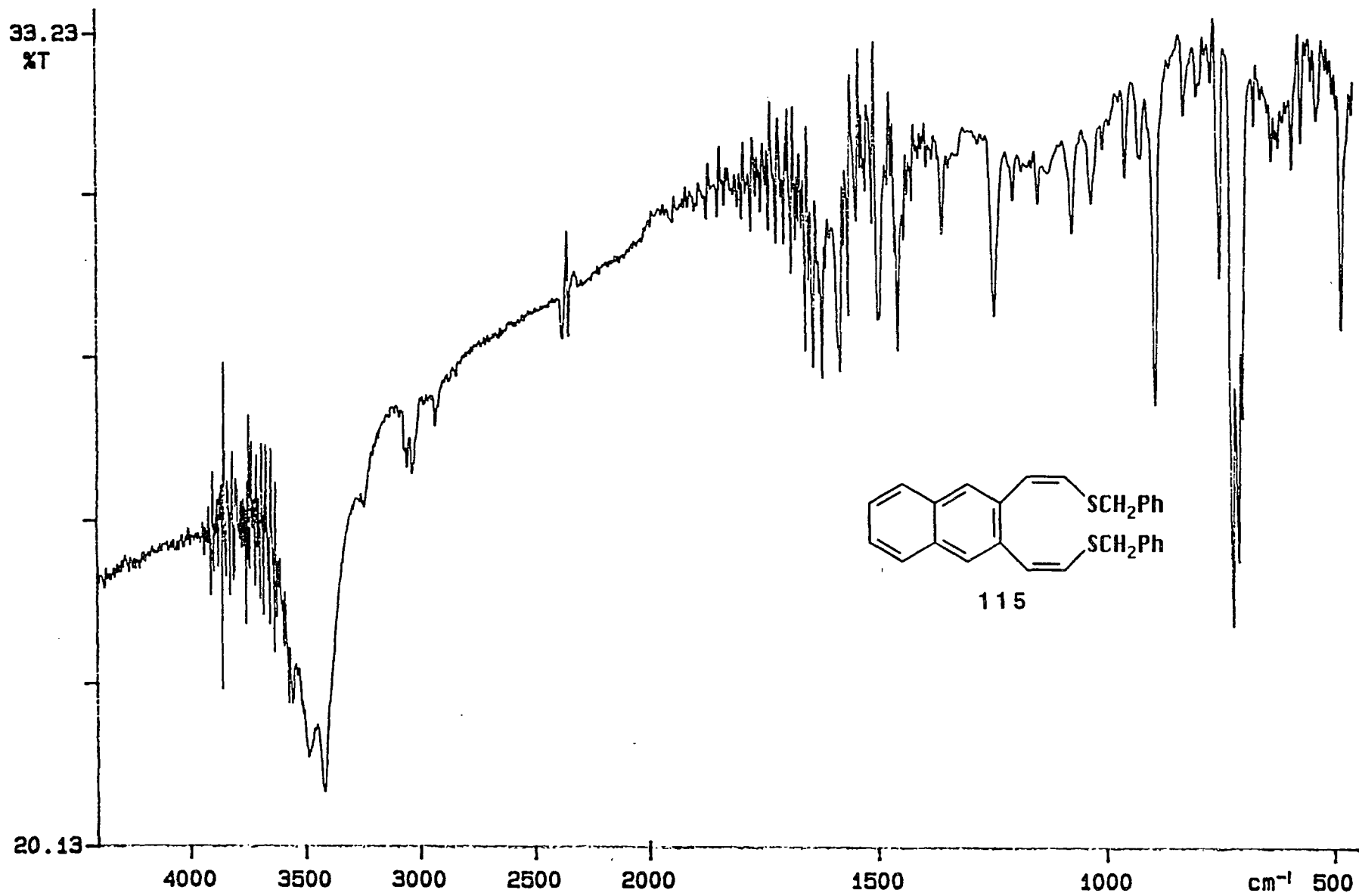


115

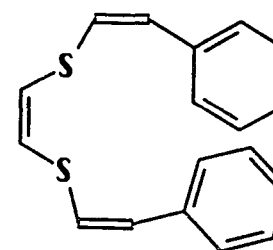




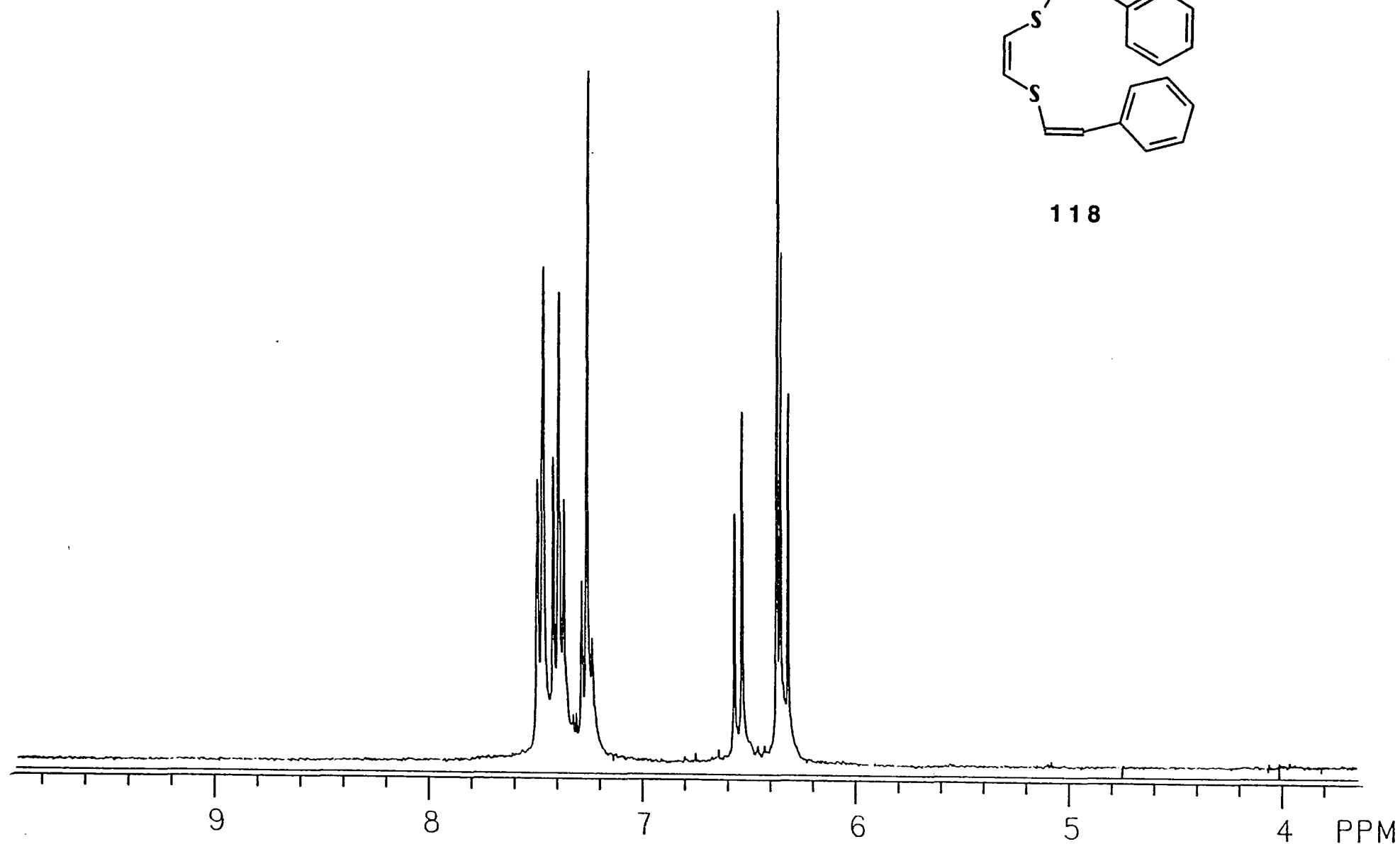


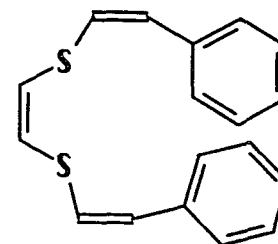


94/06/03 15:21
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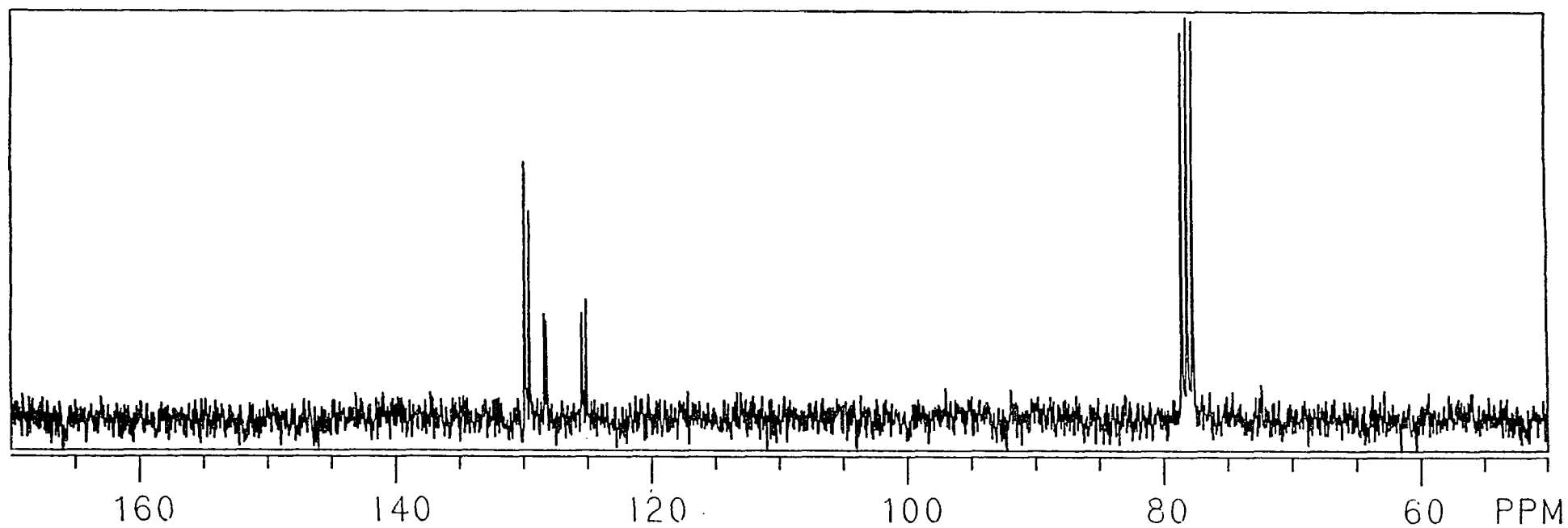


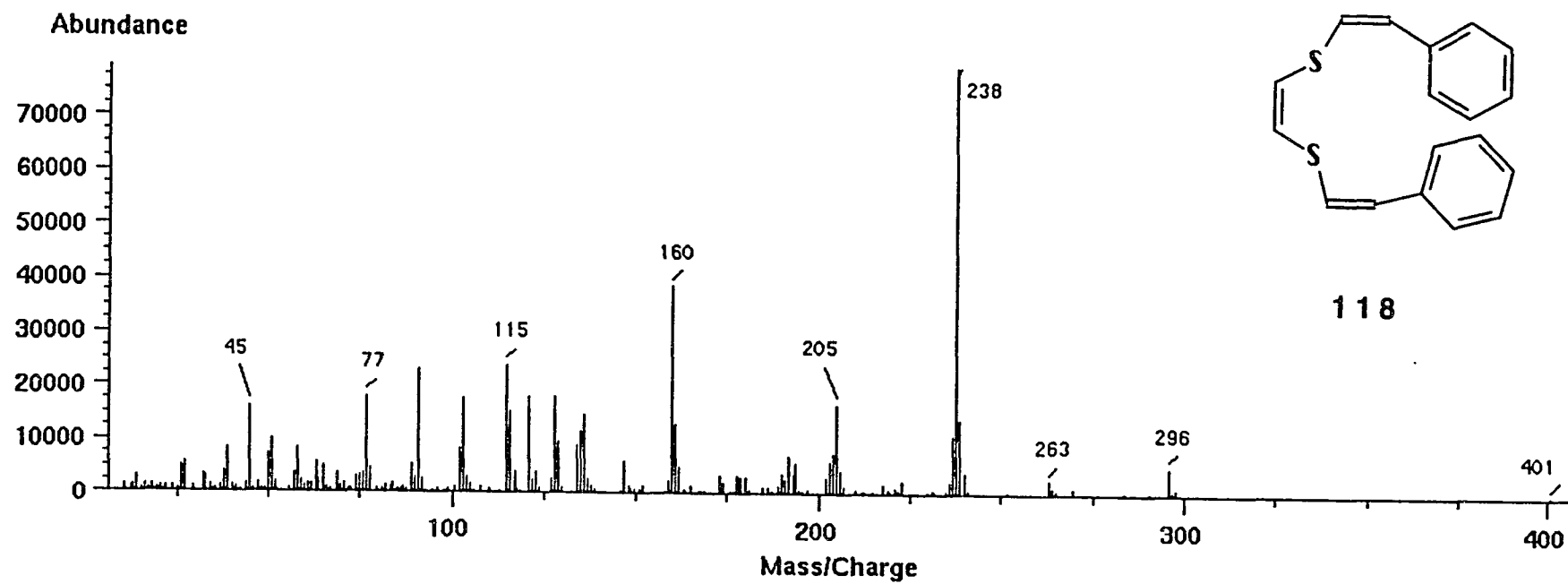
118

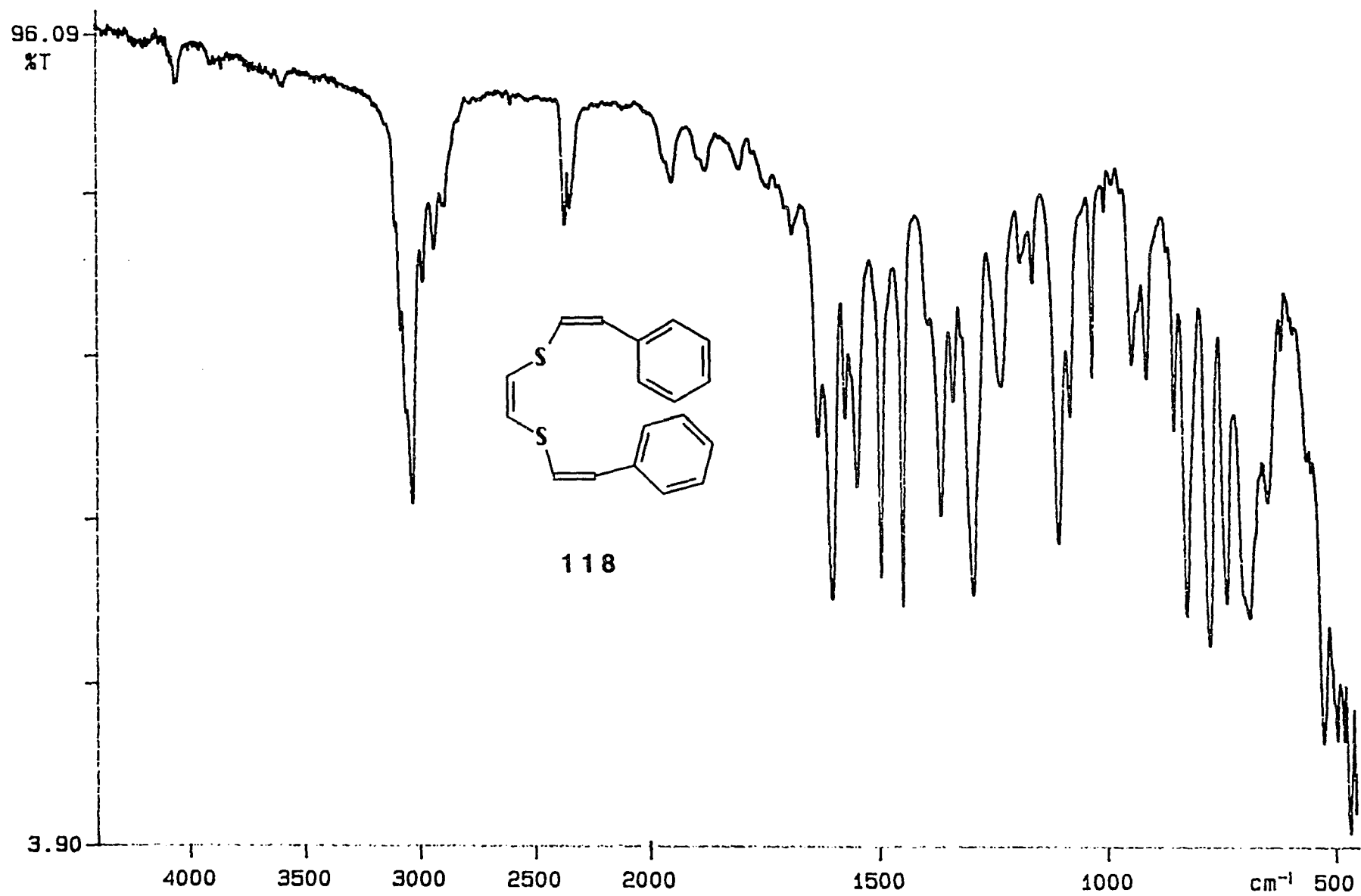




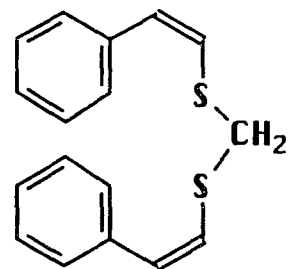
118



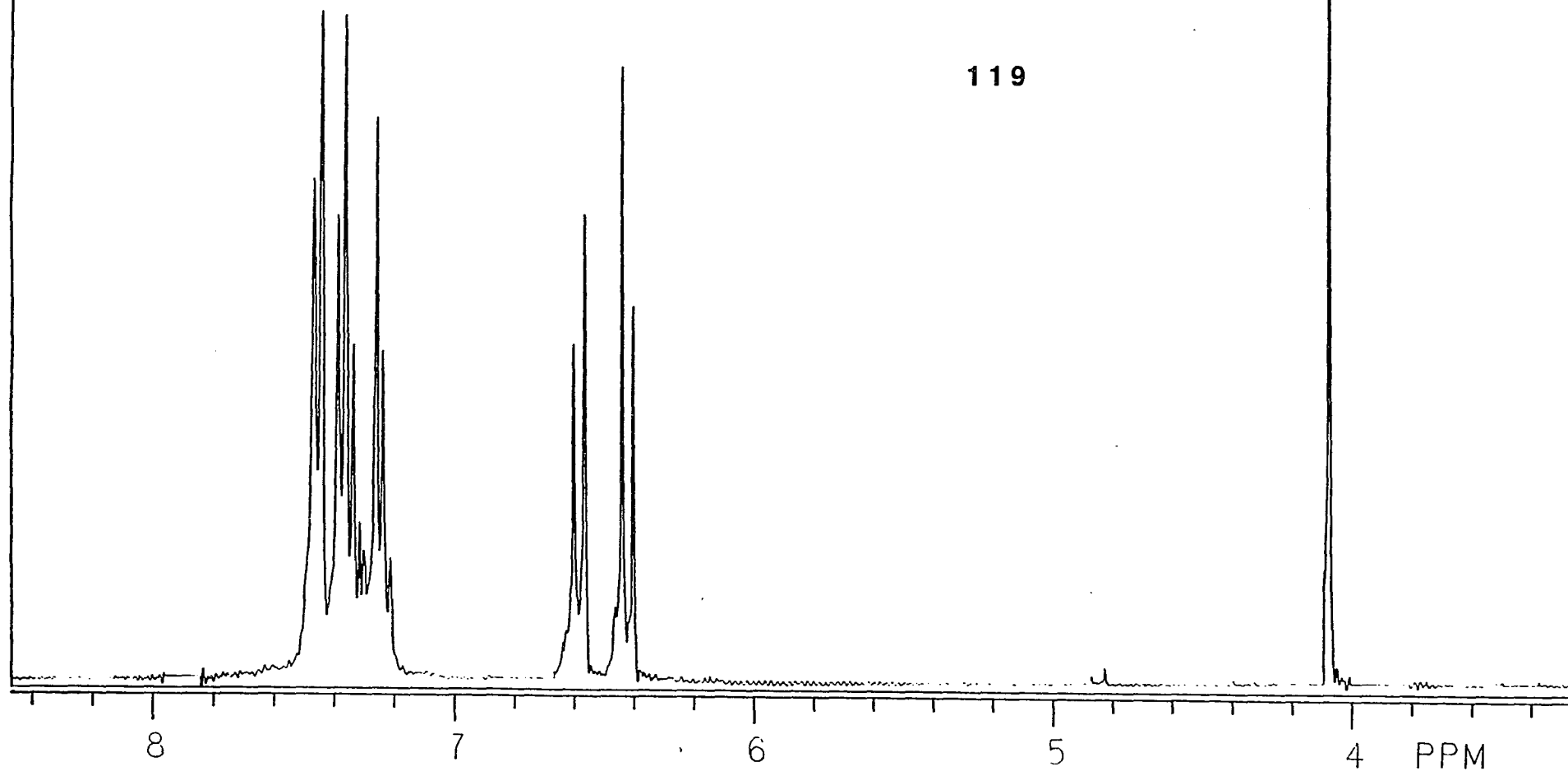


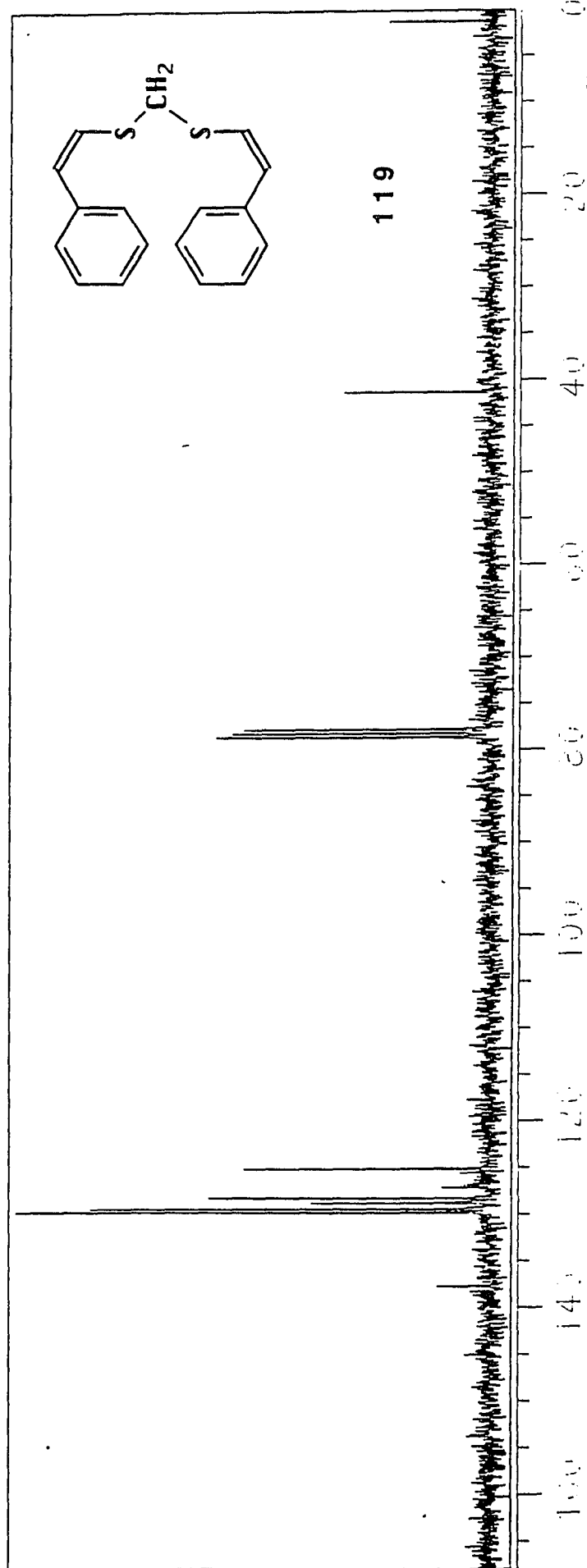


94/12/12 19:33
X: 1 scan, 4.0 cm^{-1}

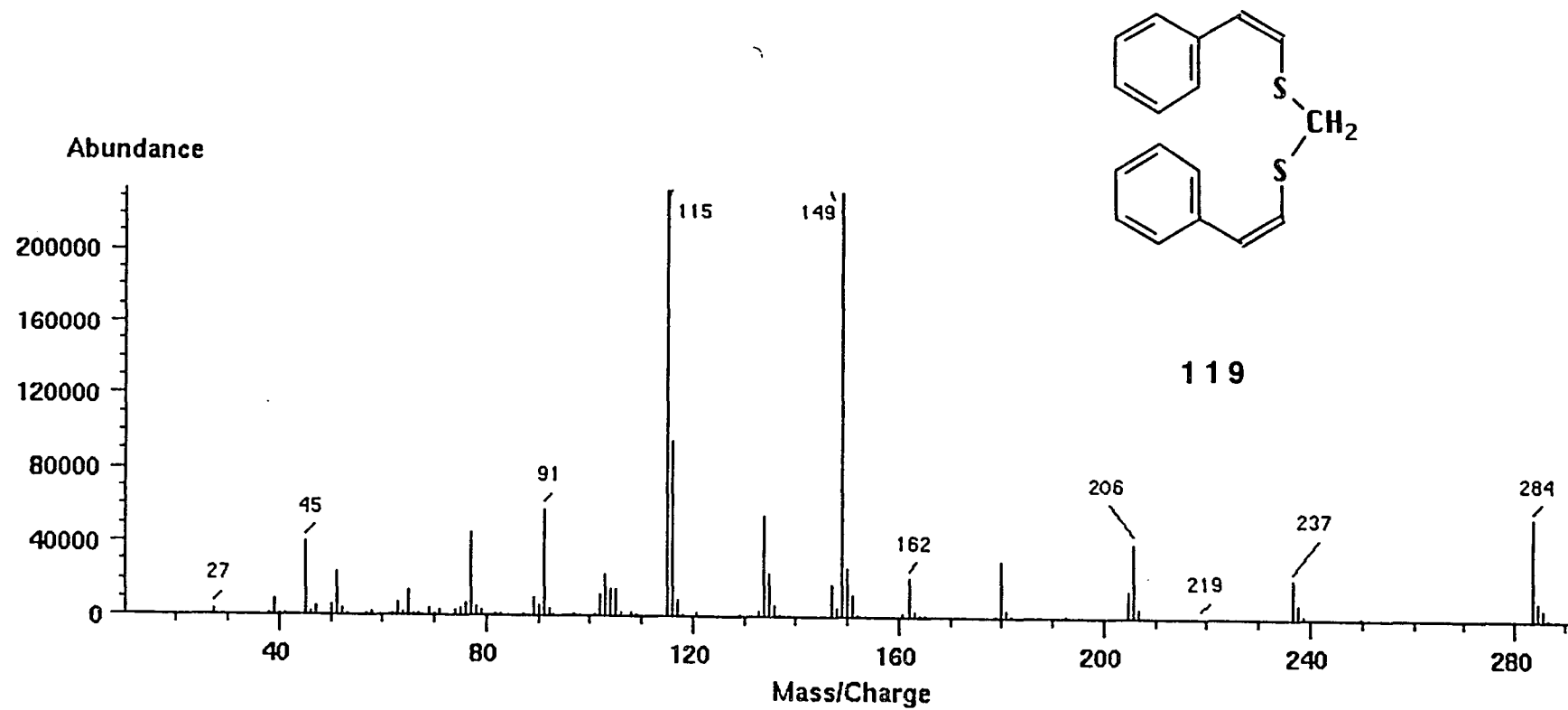


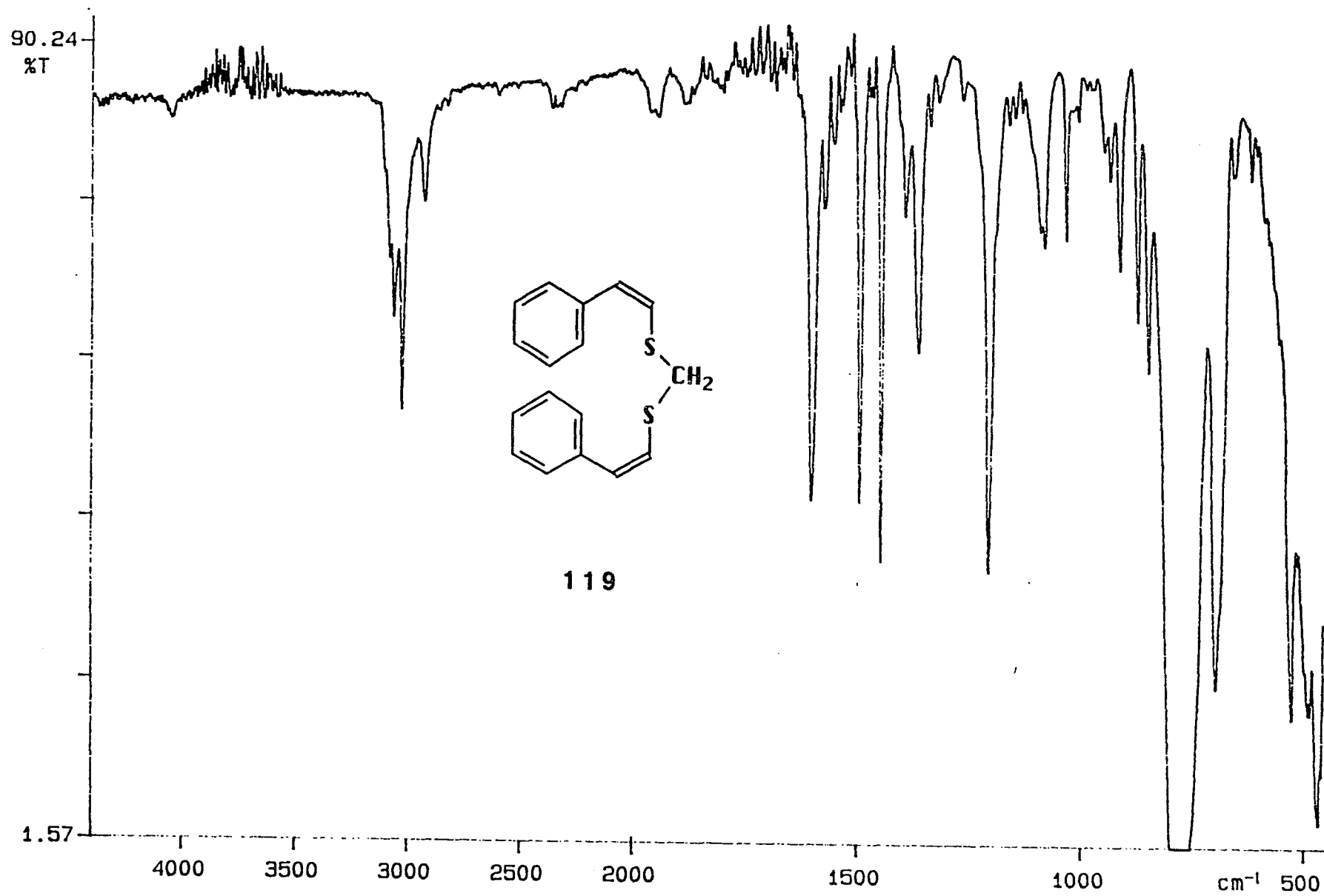
119



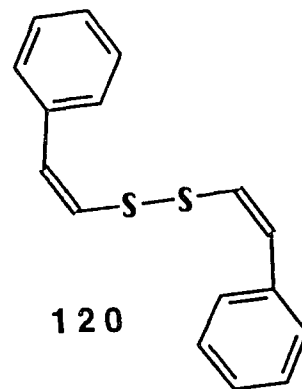


339

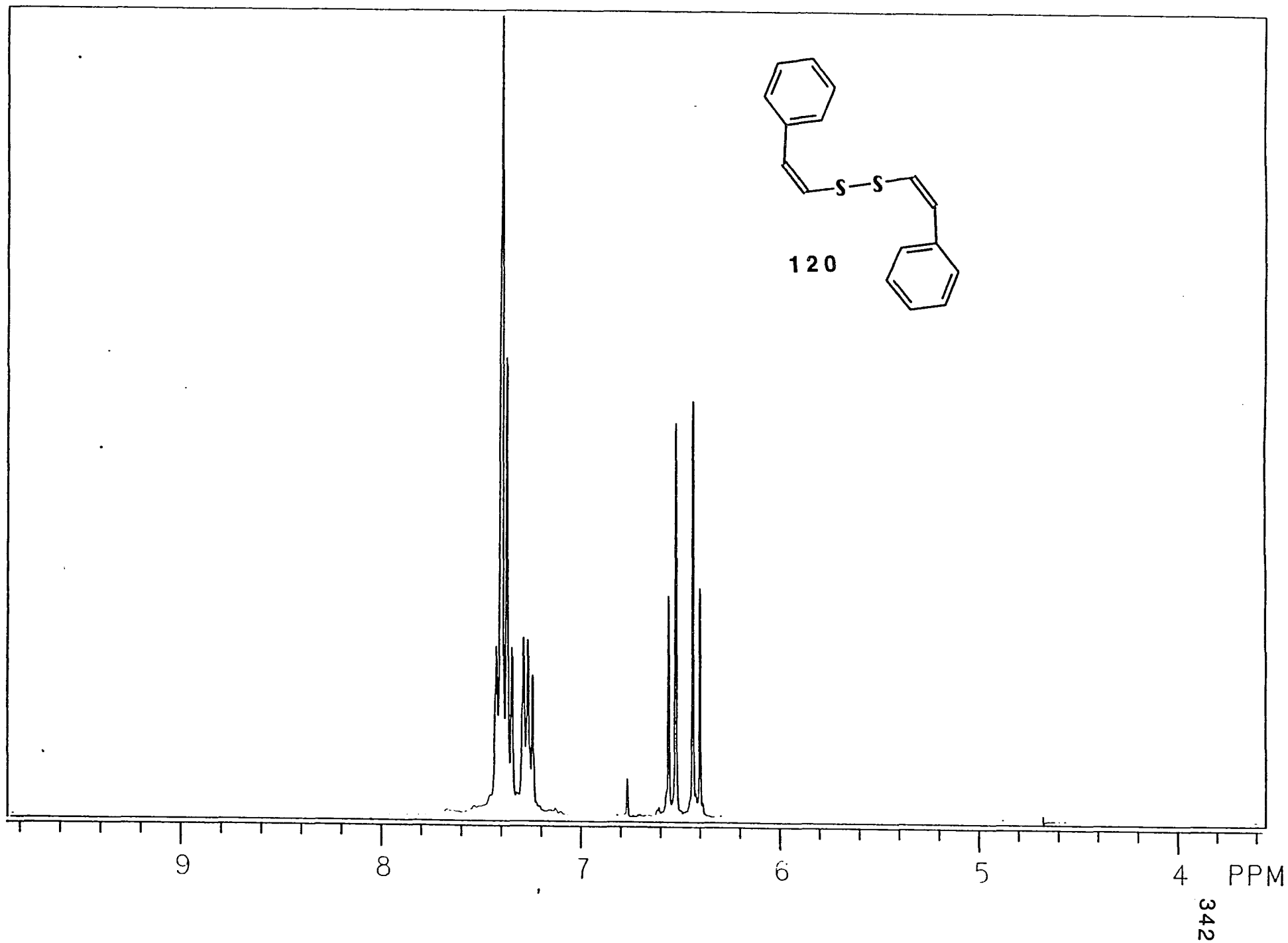


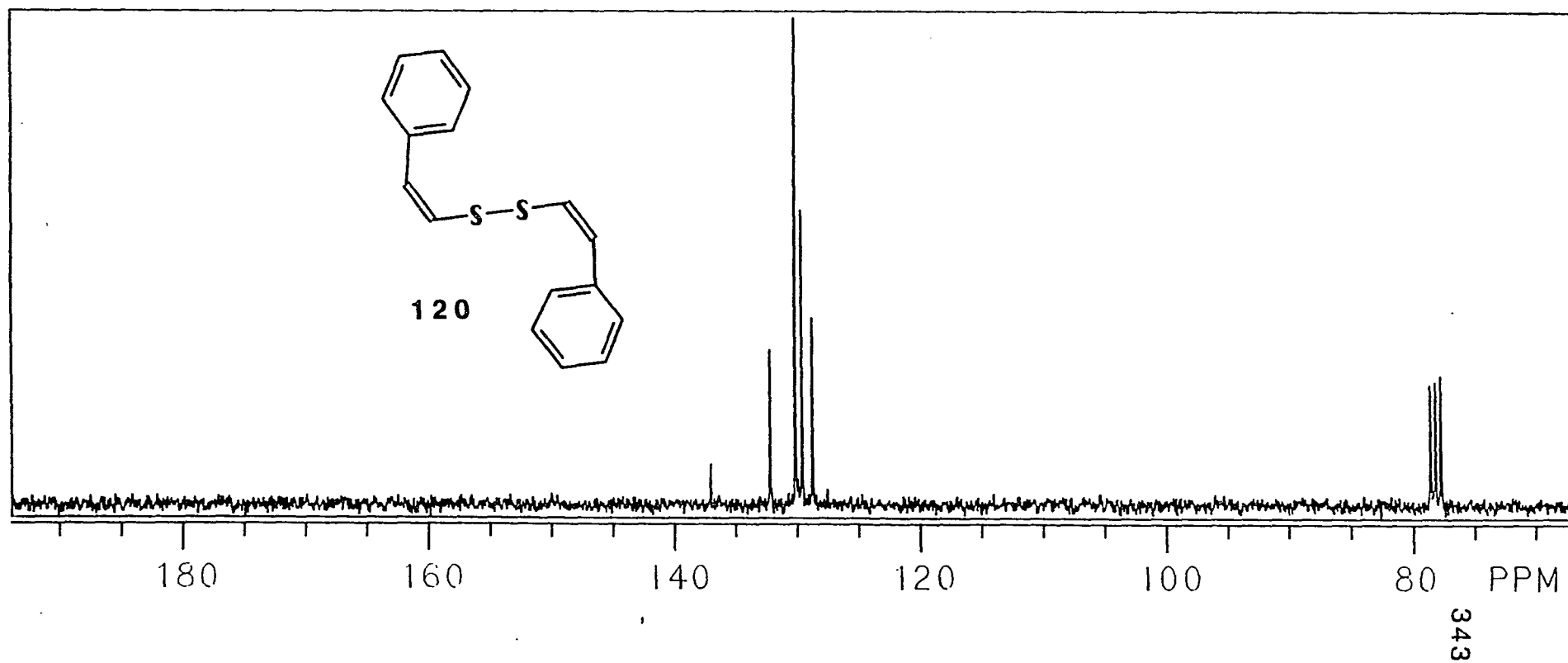


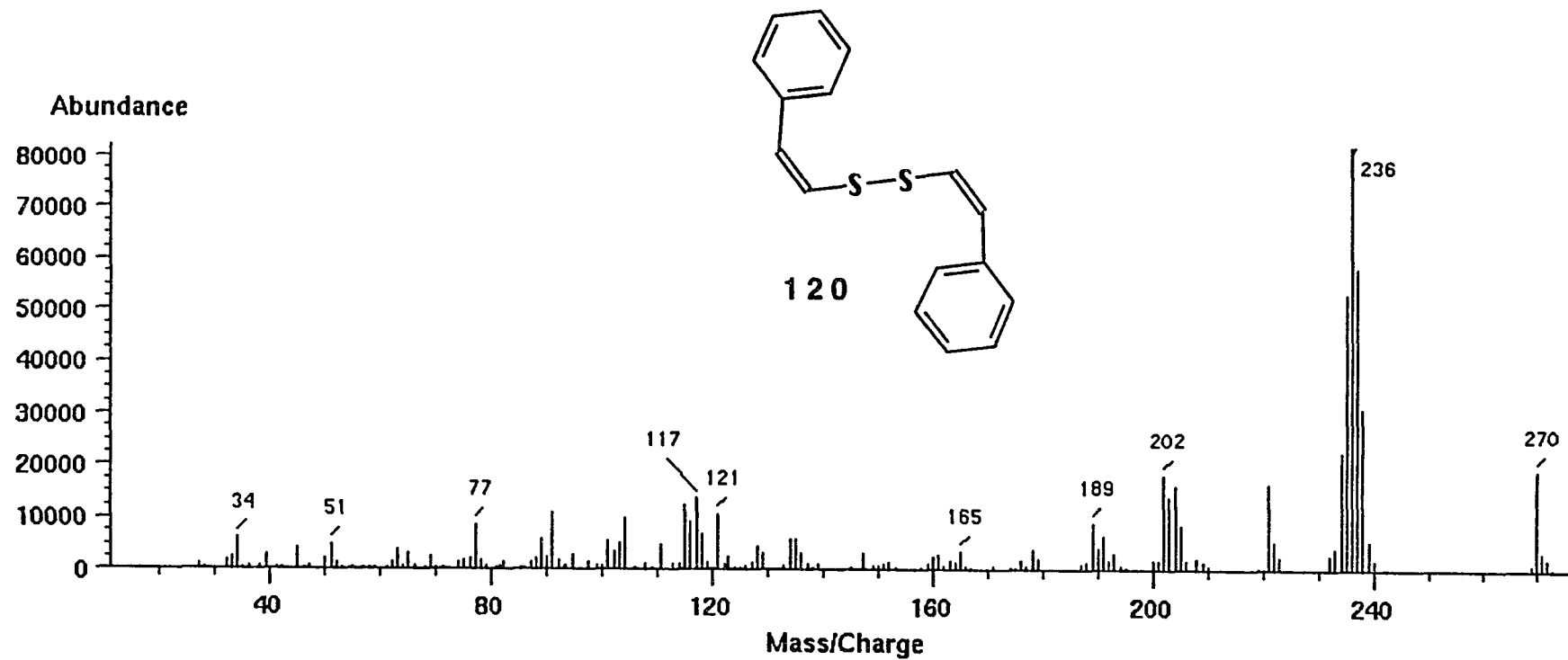
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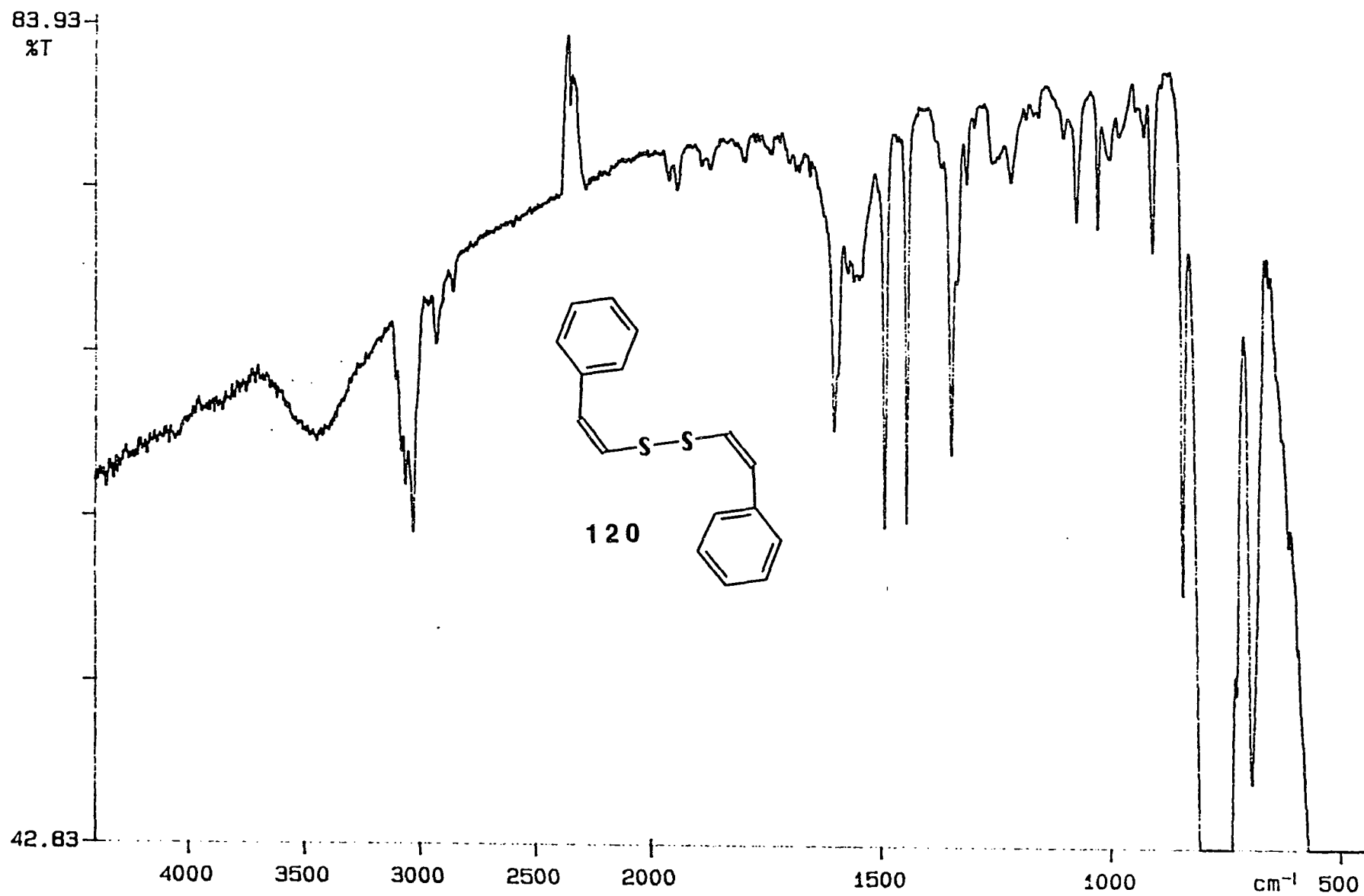


120

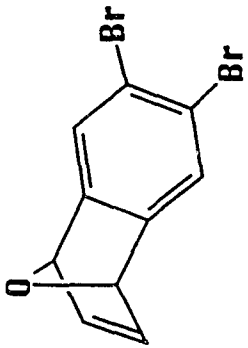




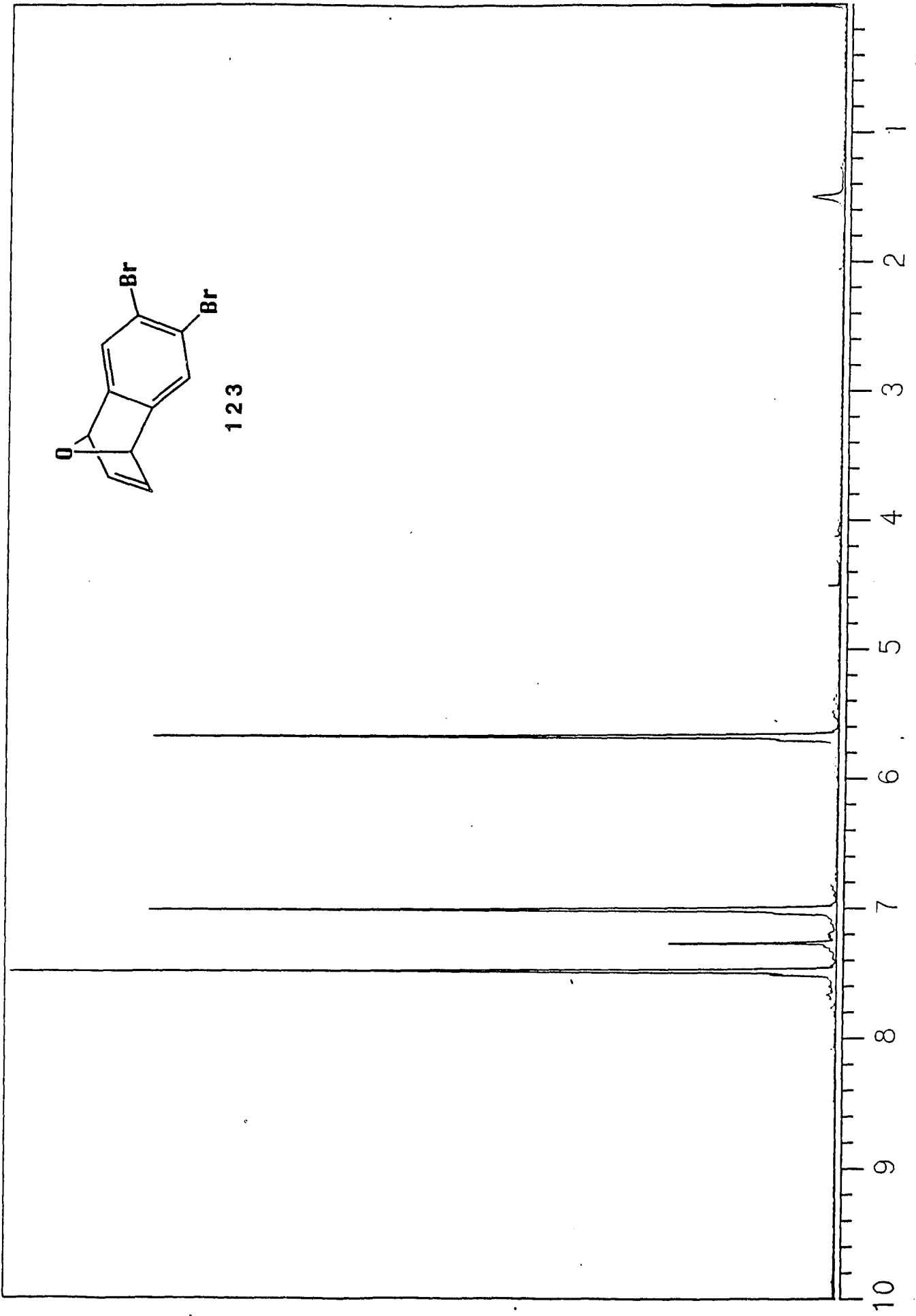


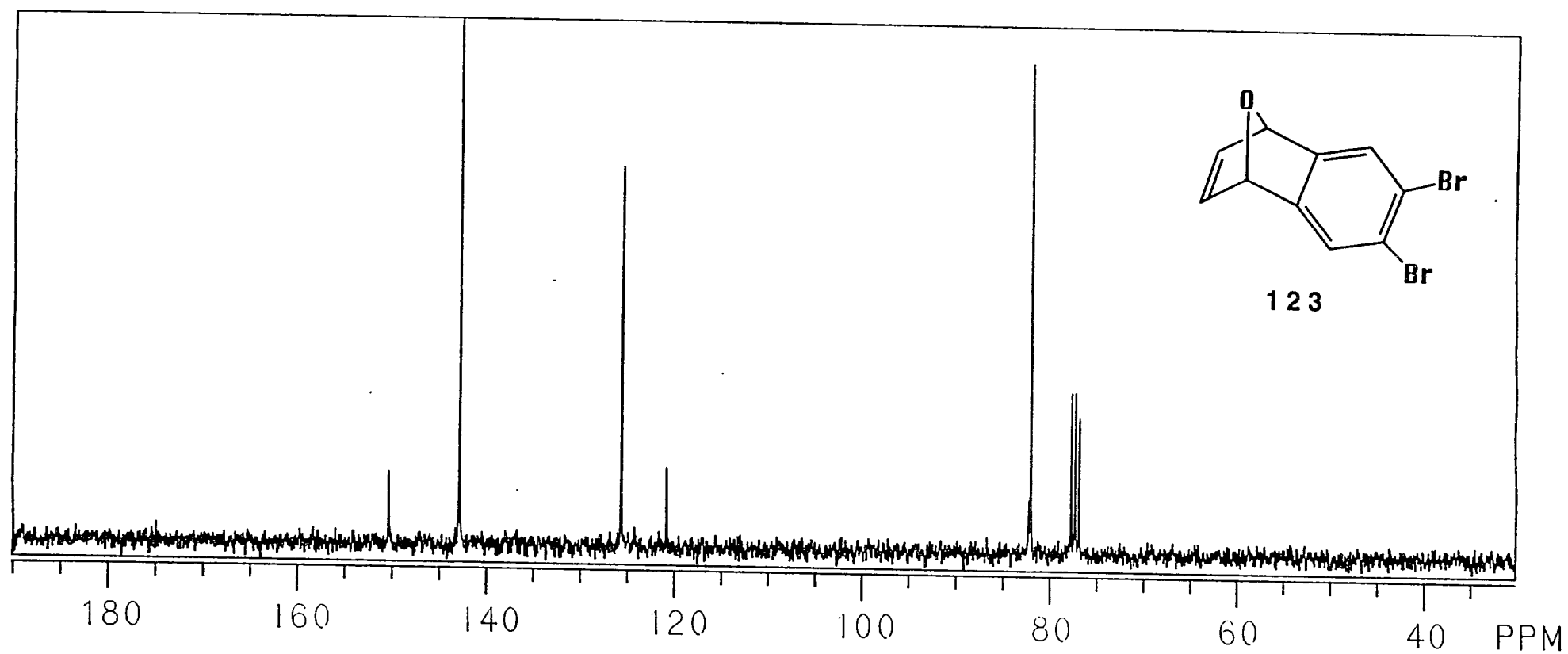


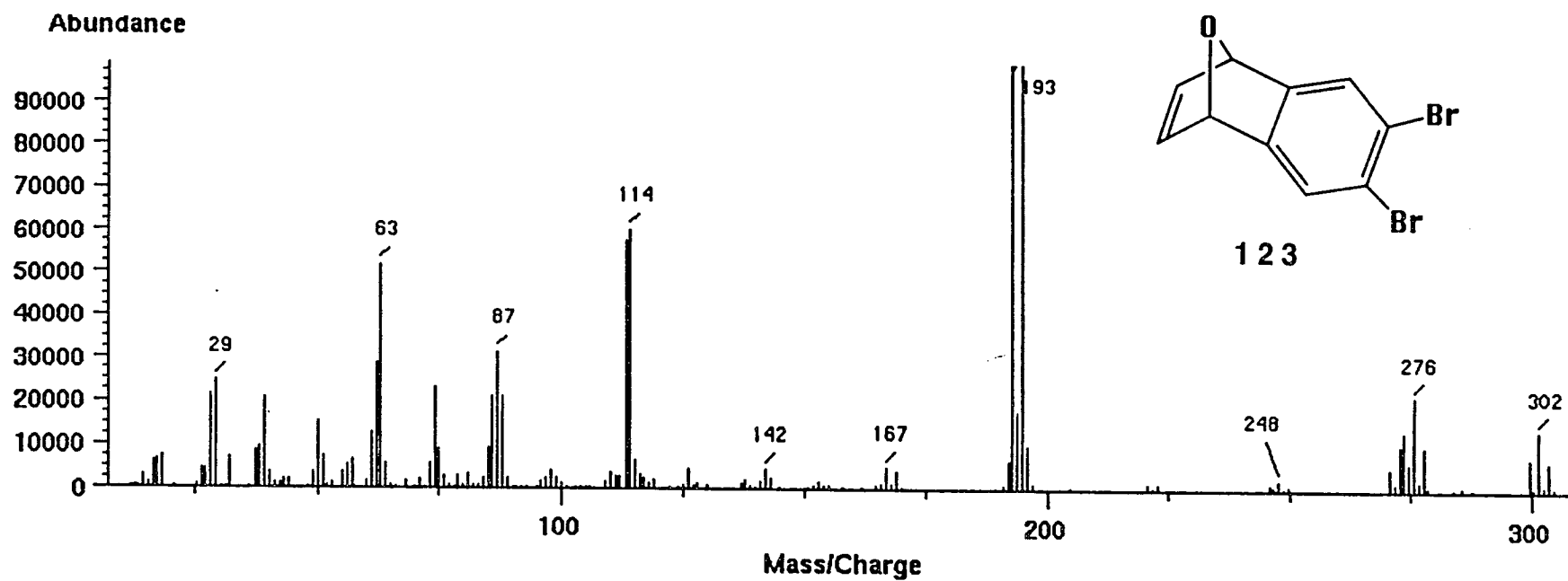
94/10/24 10:03
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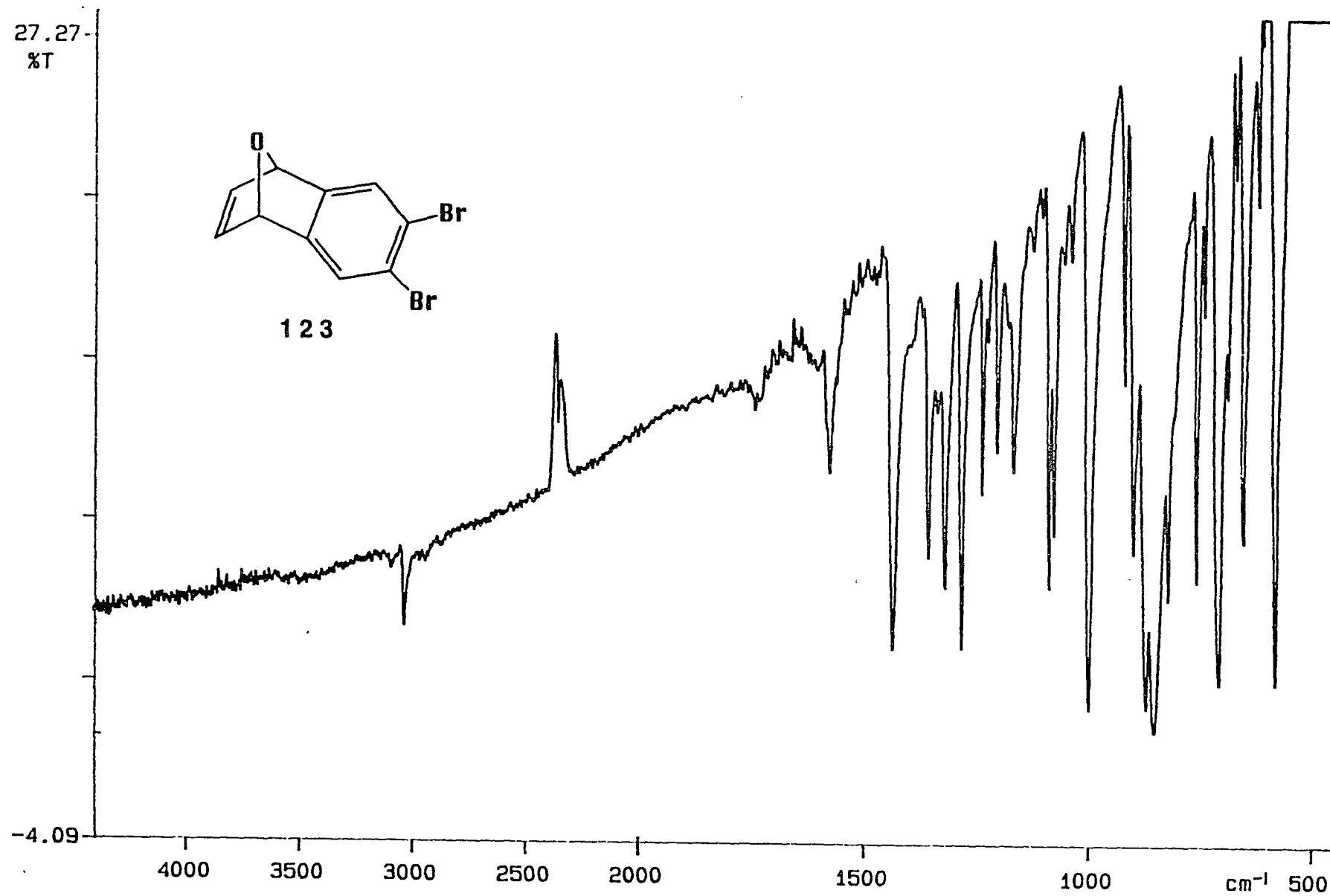


123



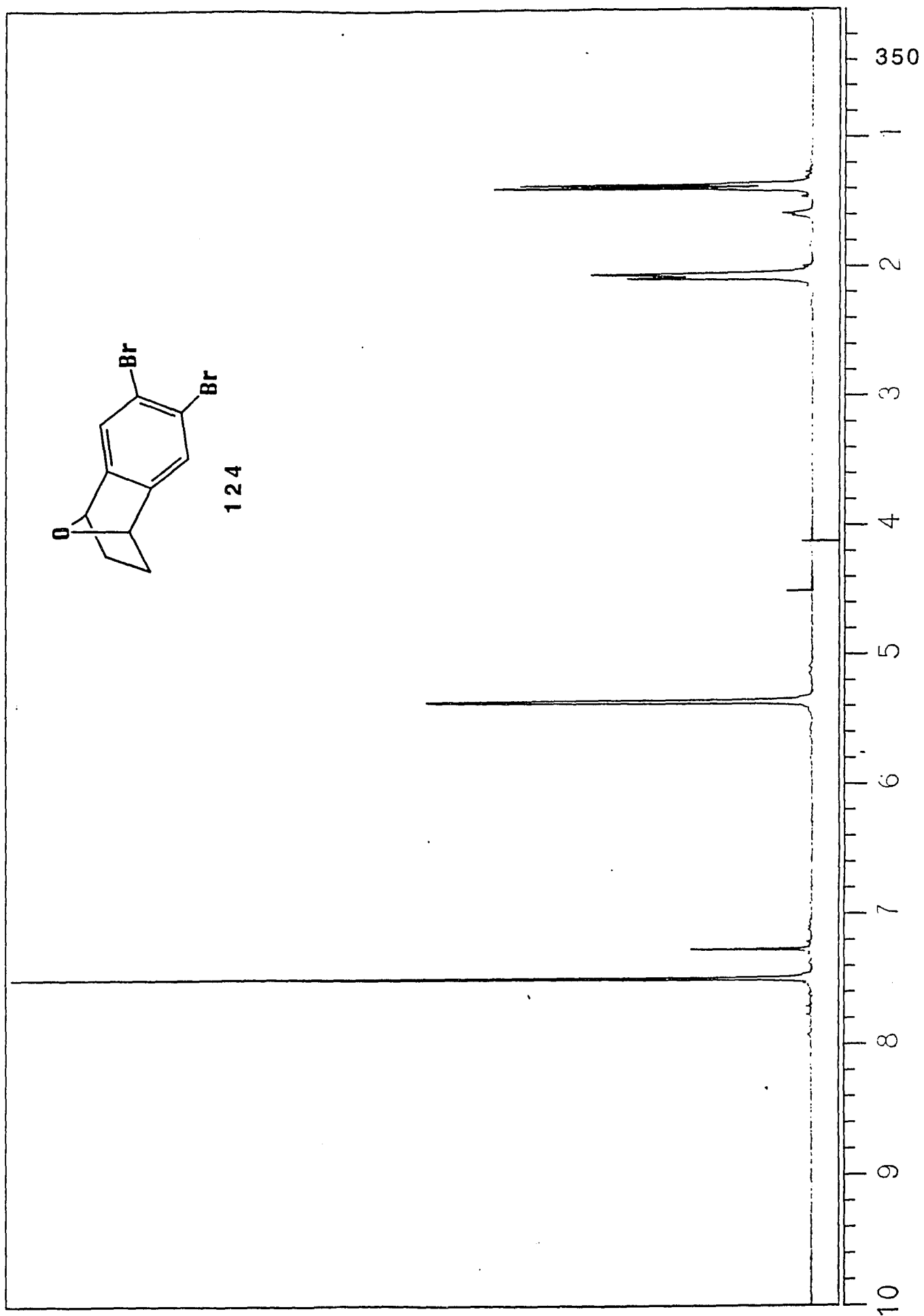


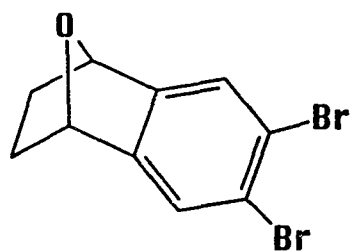




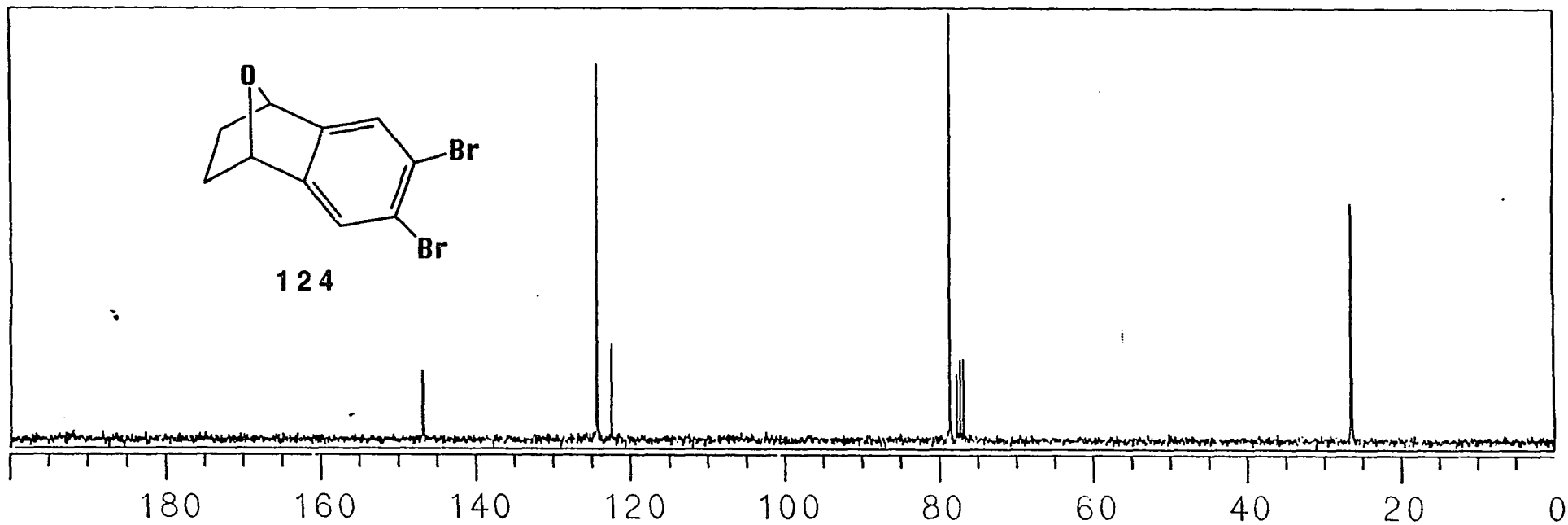
94/02/04 14:33
X: 1 scan, 4.0cm⁻¹

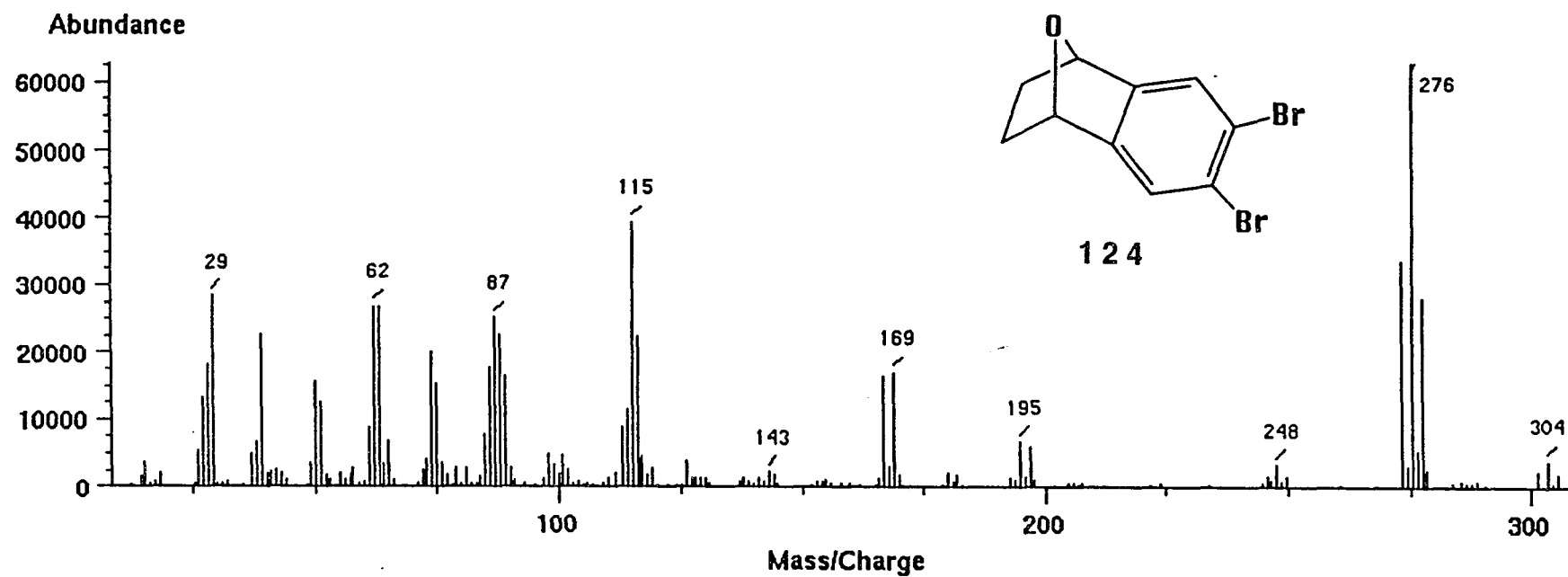
349

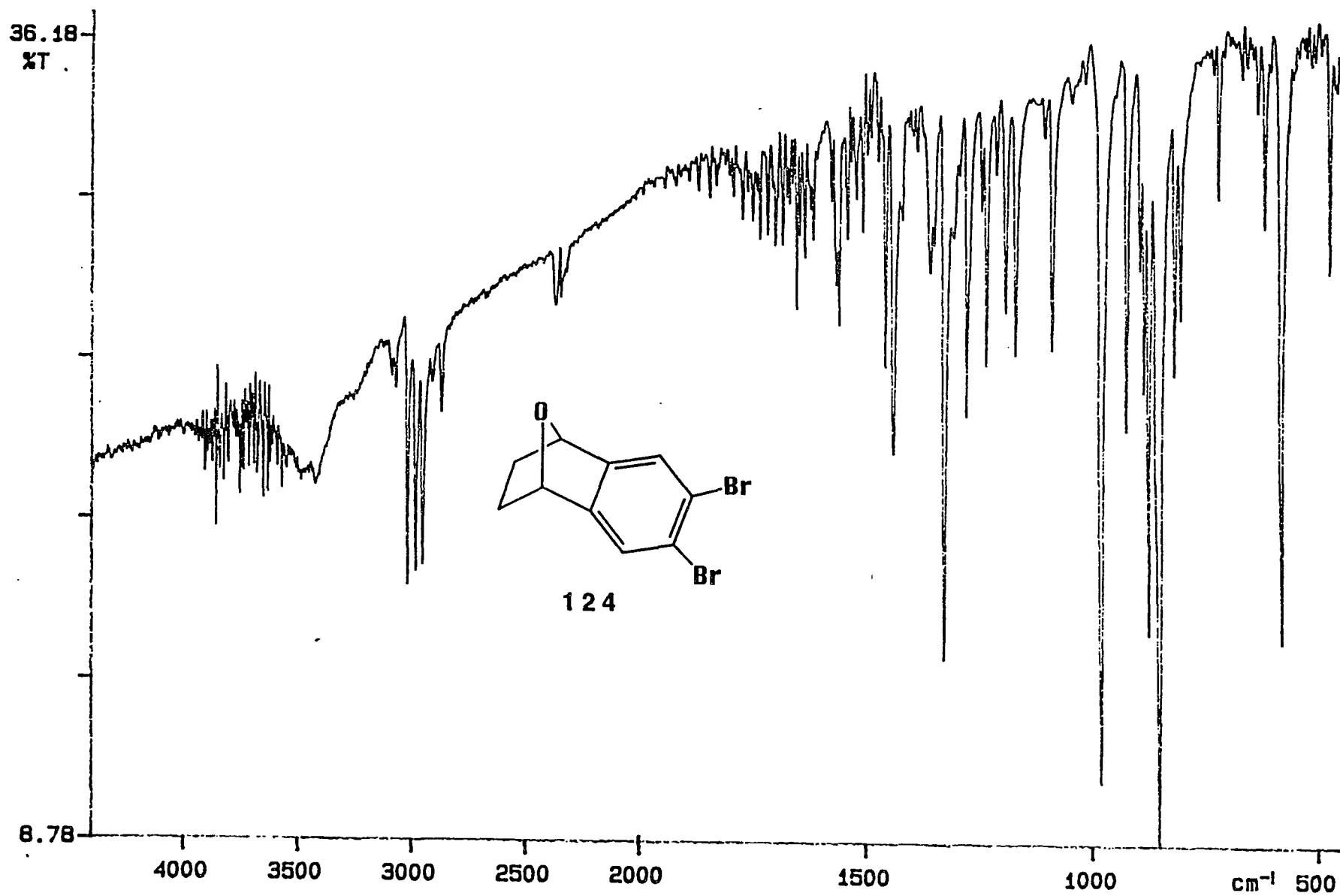




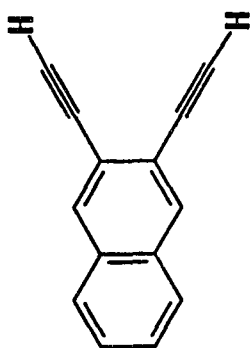
124



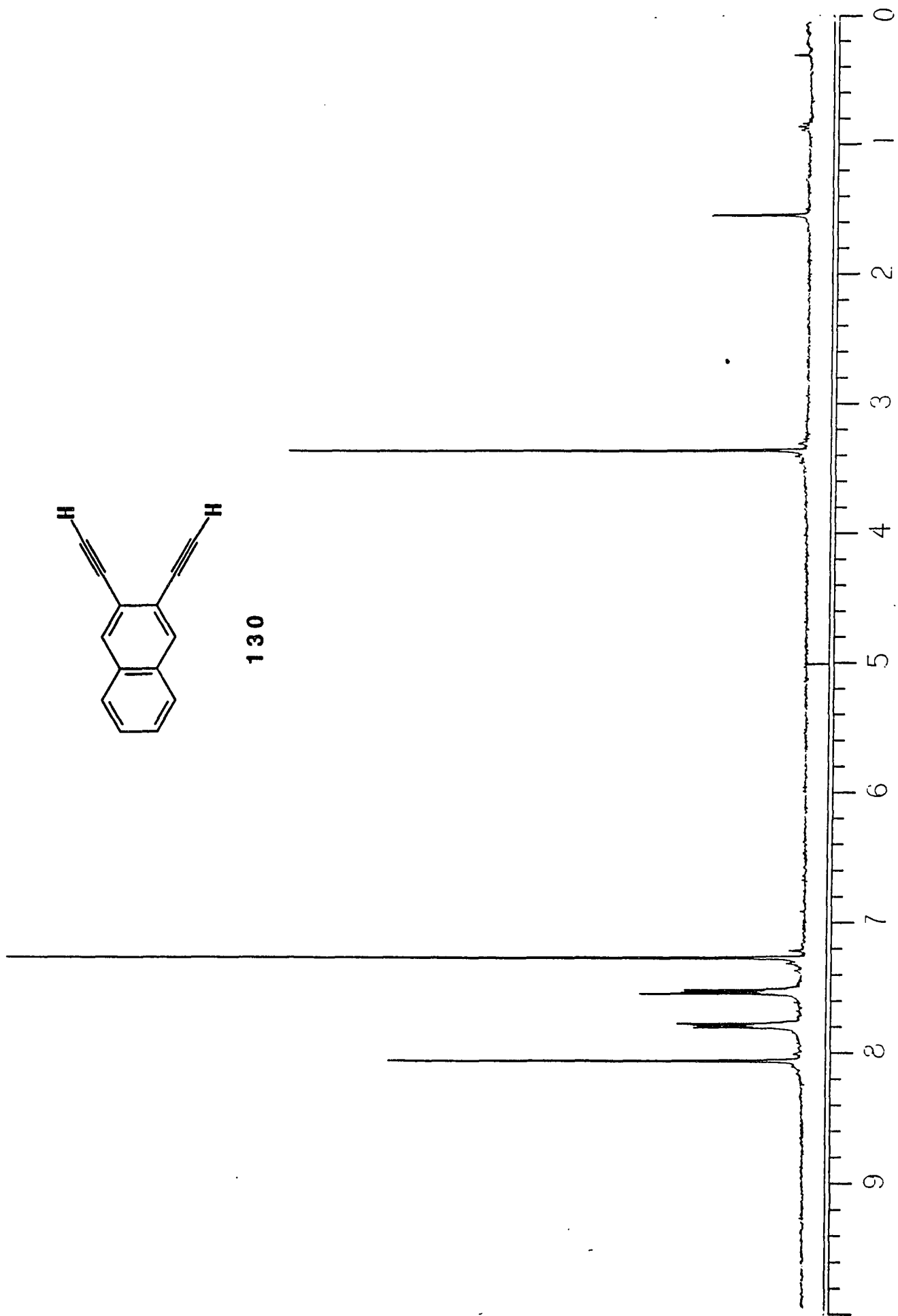


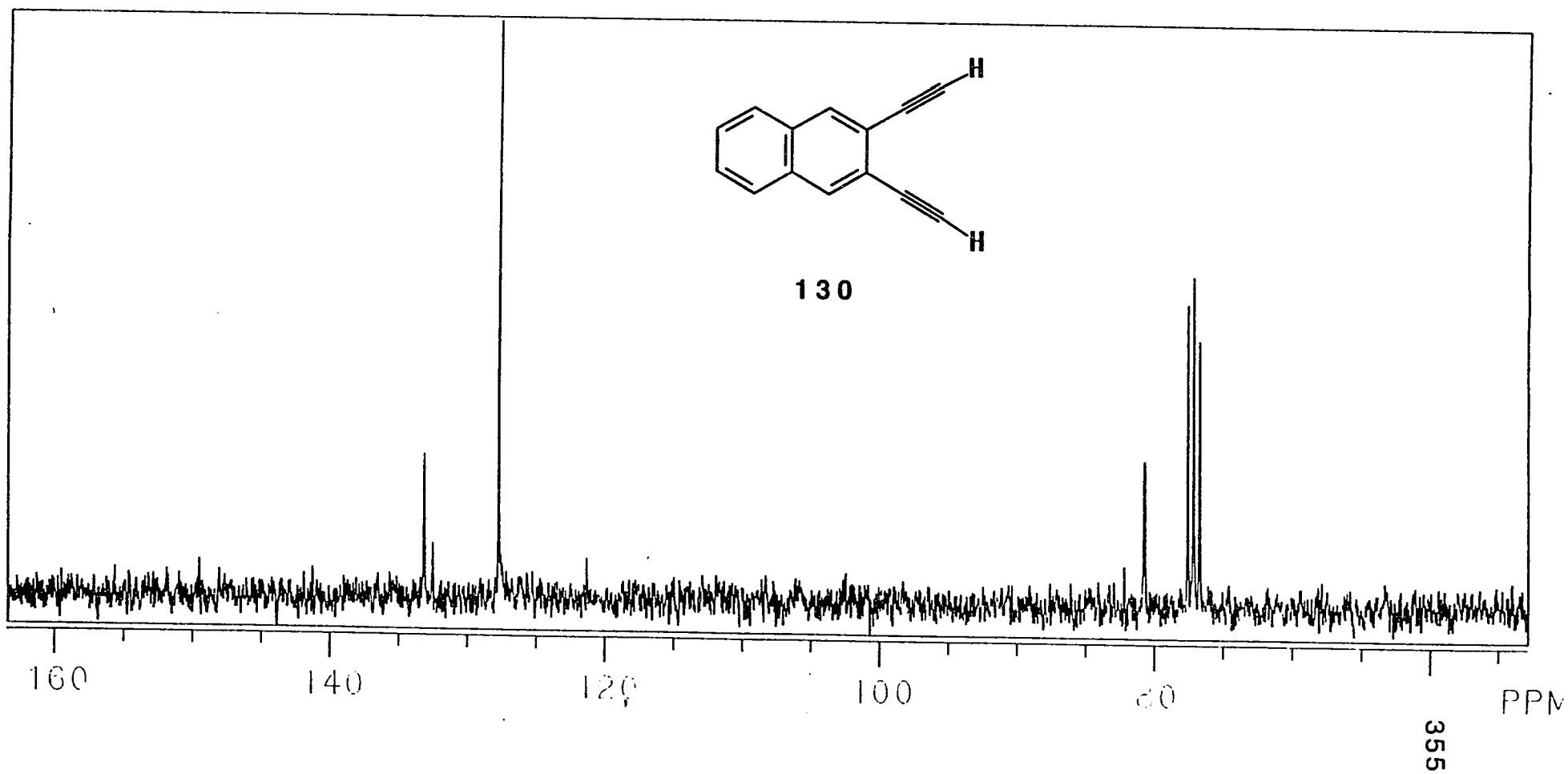


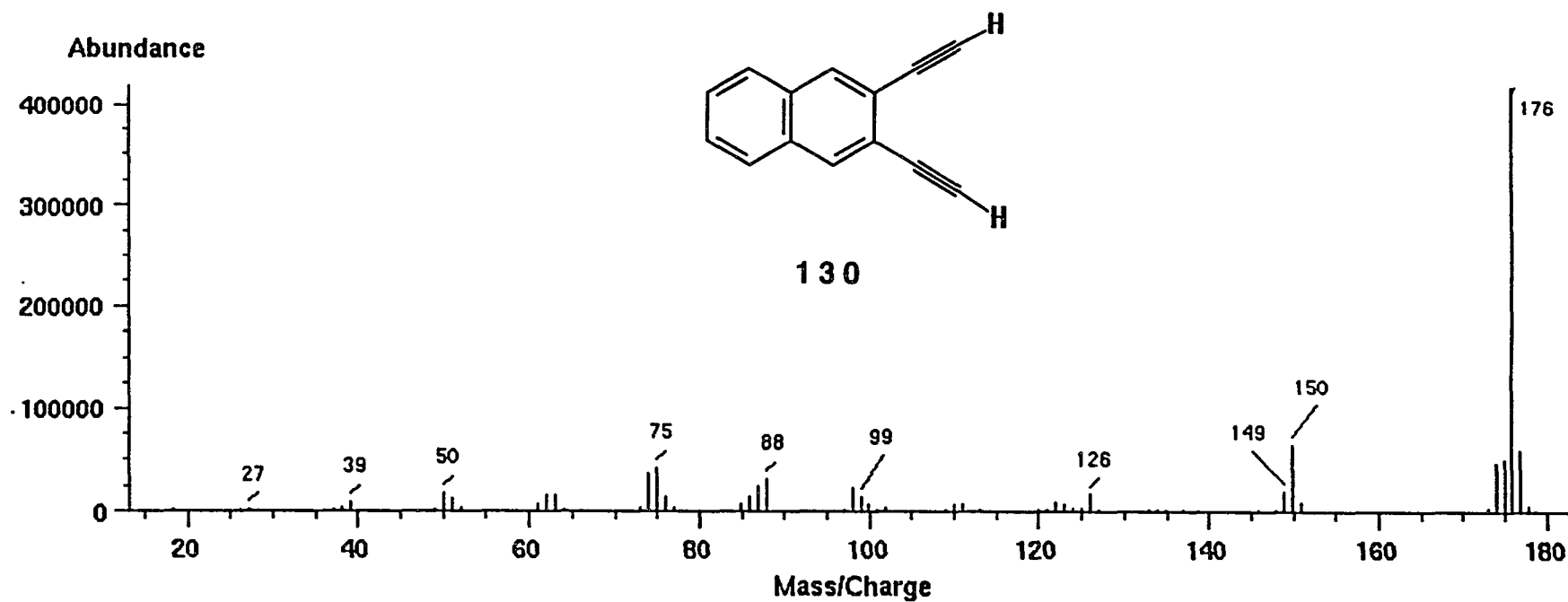
94/06/08 09:59
X: 1 scan, 4.0cm⁻¹

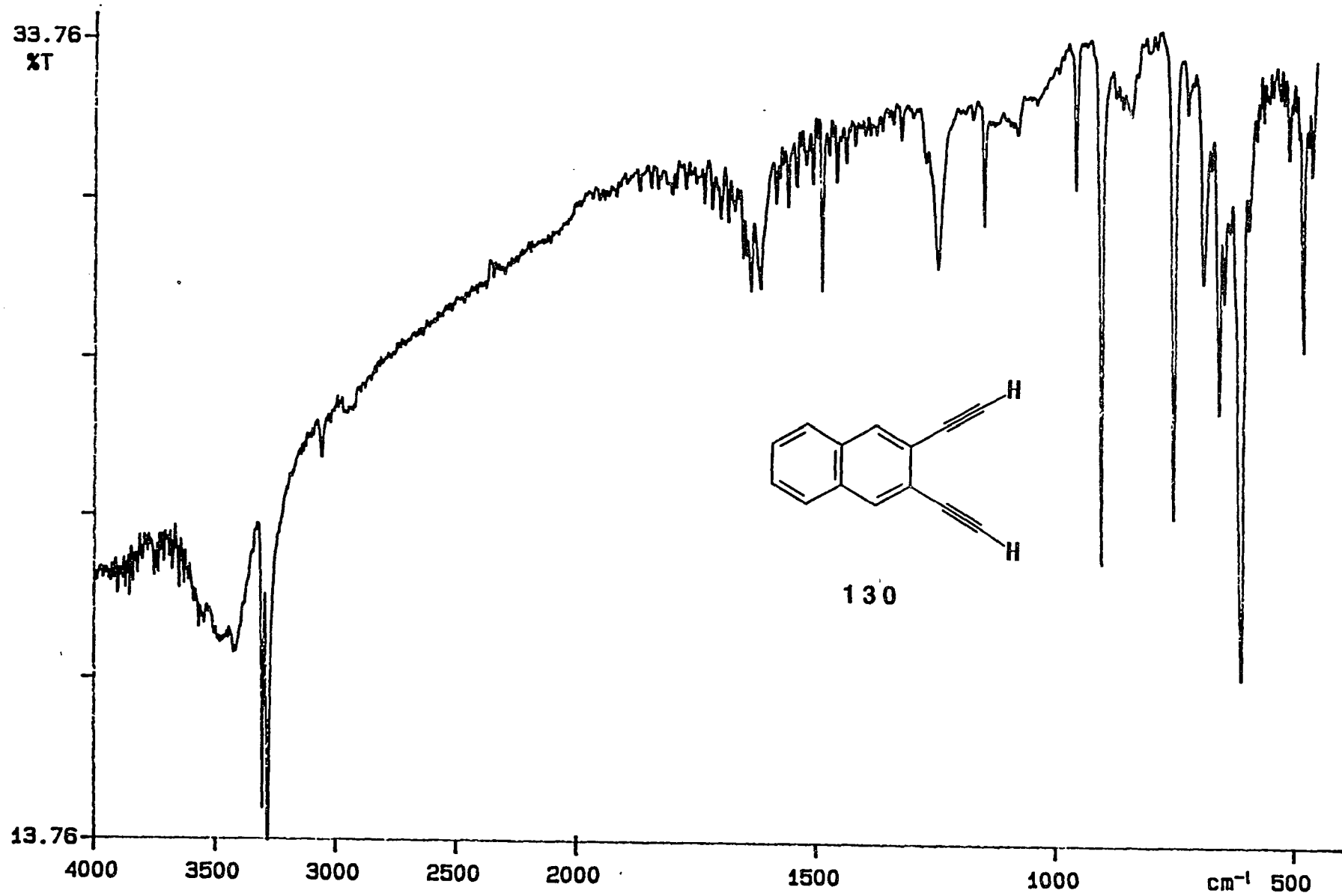


130

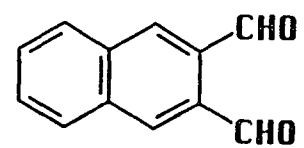




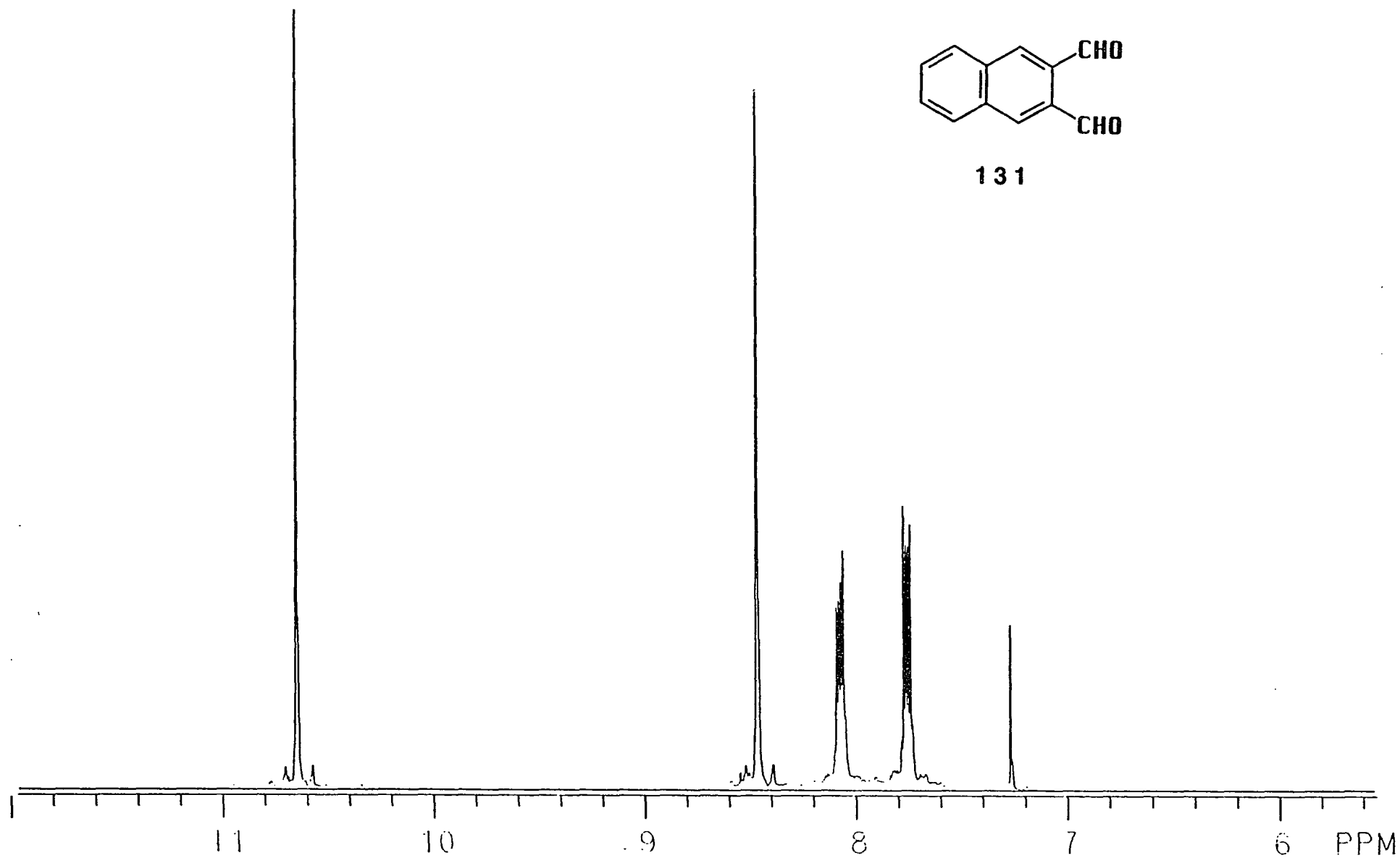


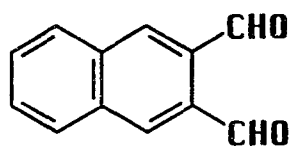


94/05/23 17:34
X: 1 scan, 4.0cm⁻¹

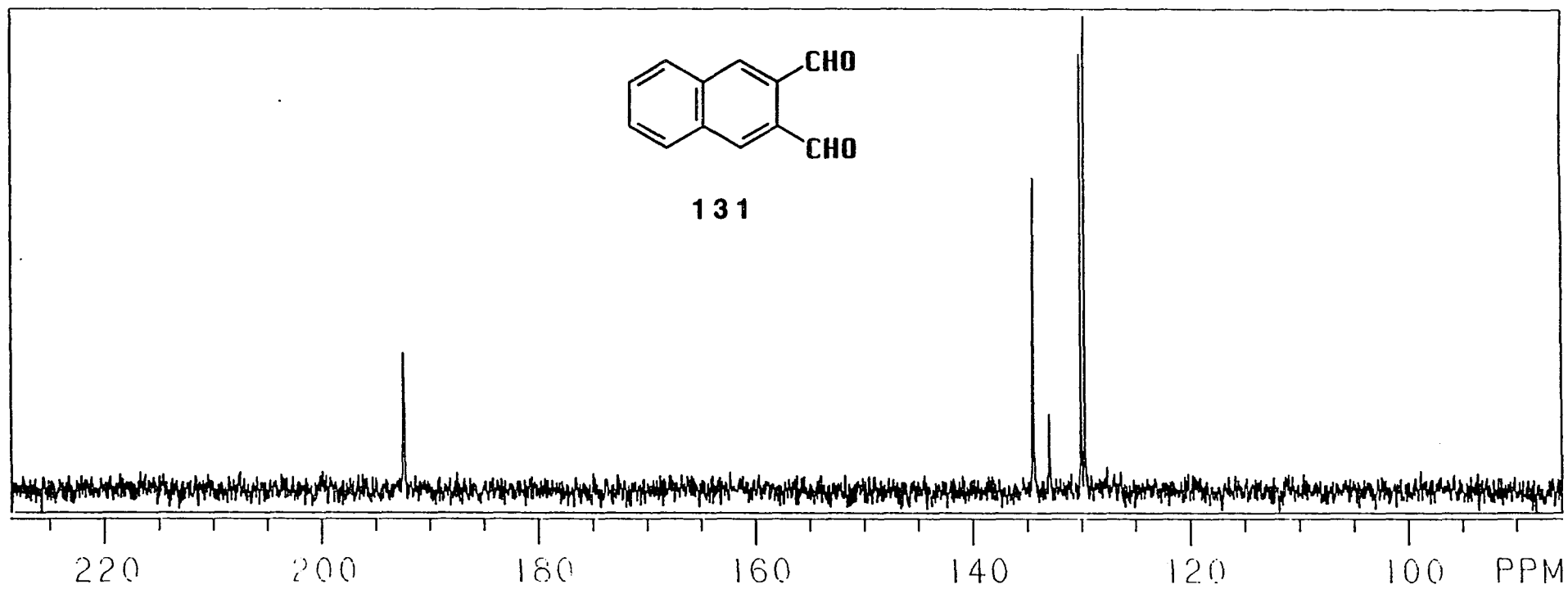


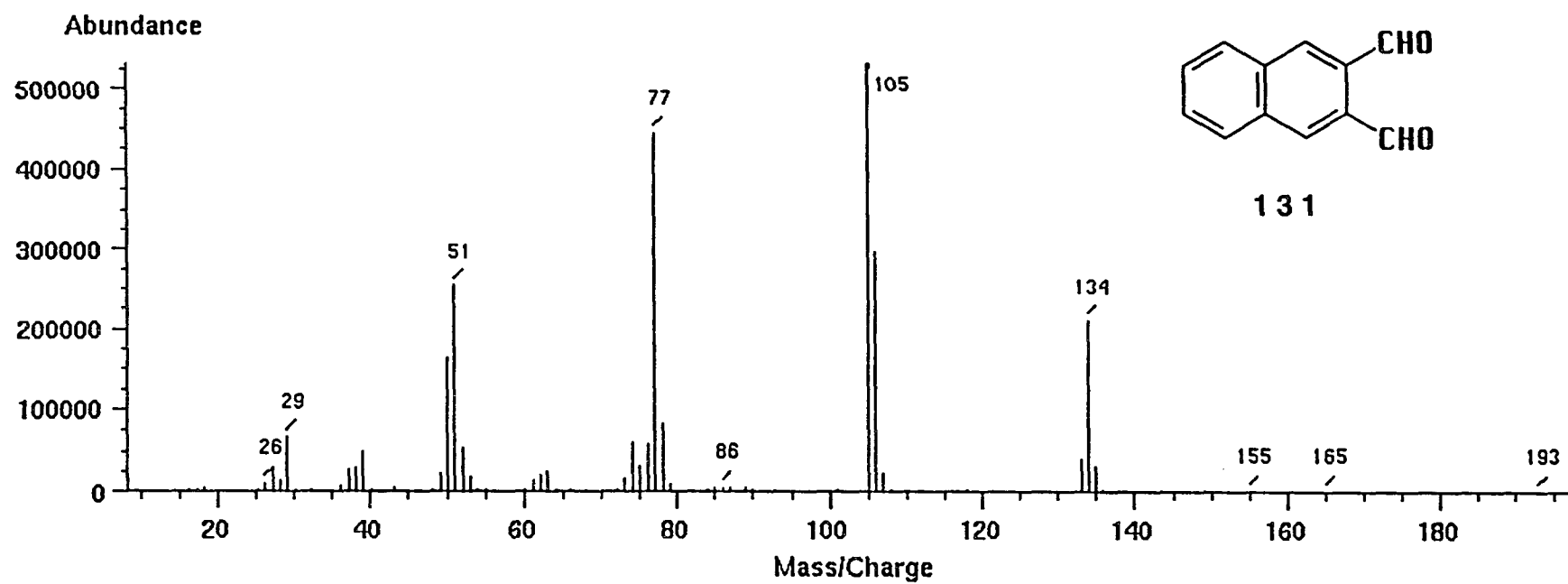
131

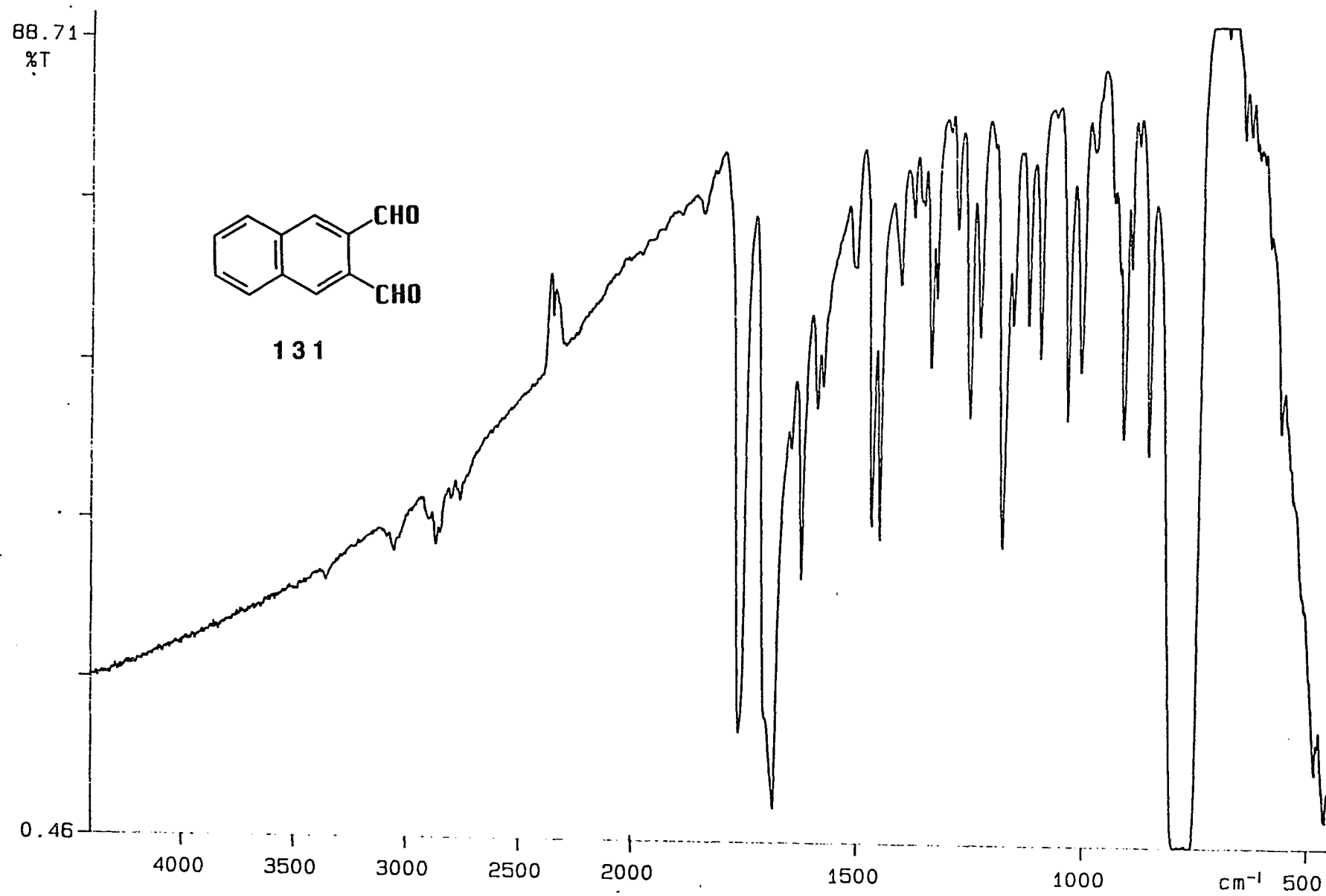




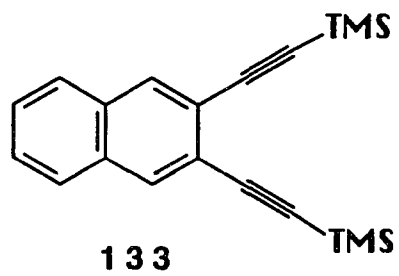
131





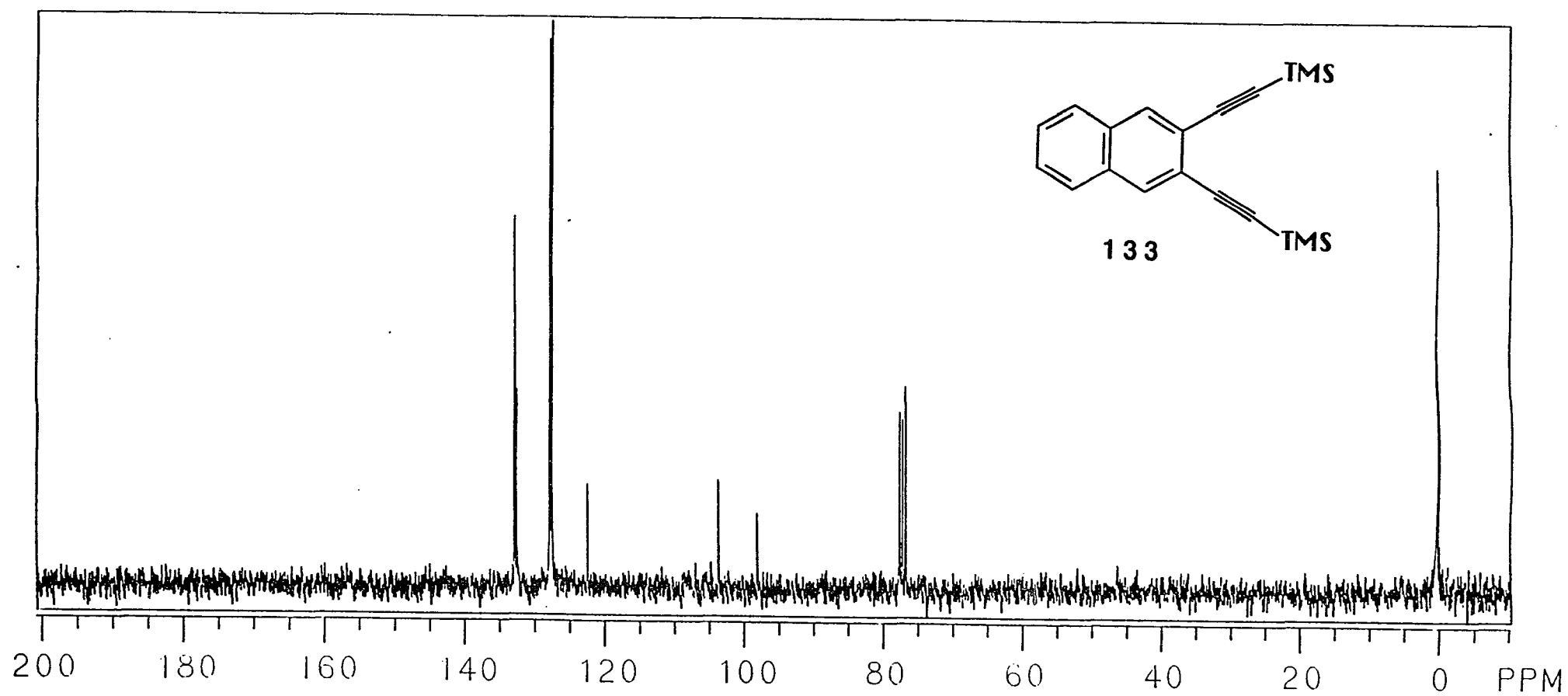


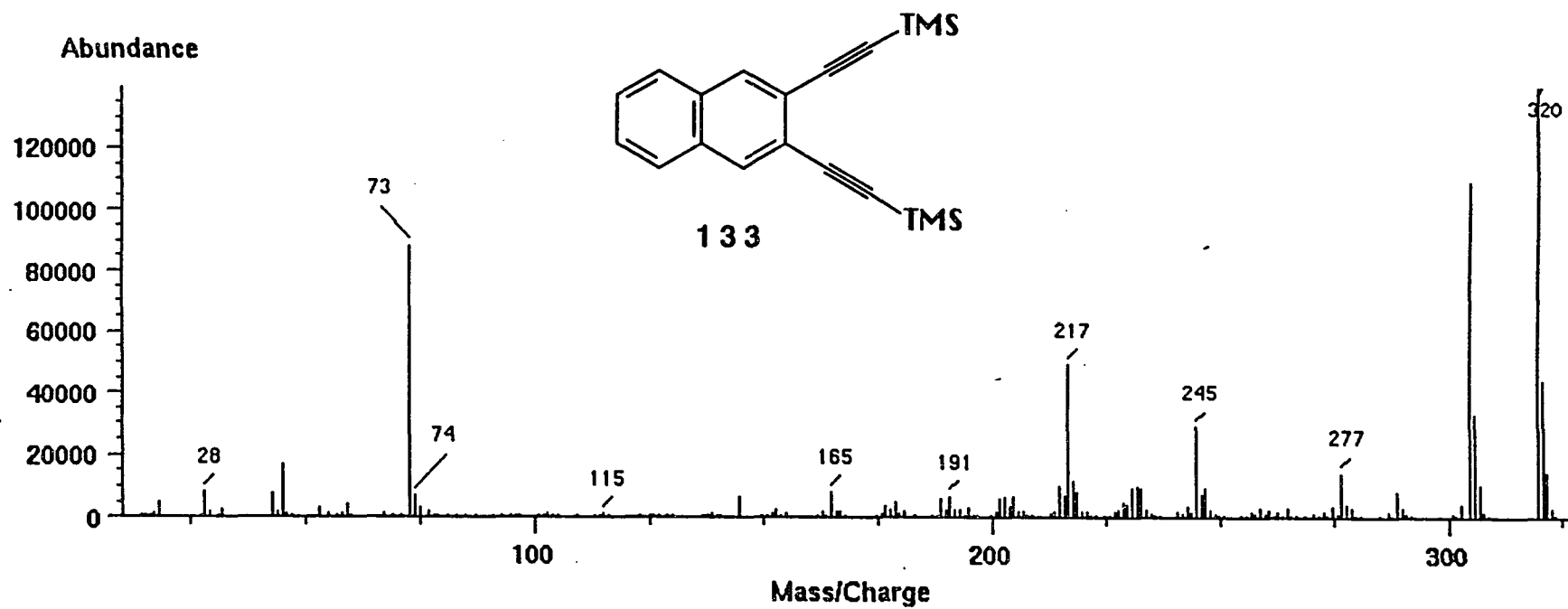
95/06/13 20:20
X: 1 scan, 4.0cm⁻¹

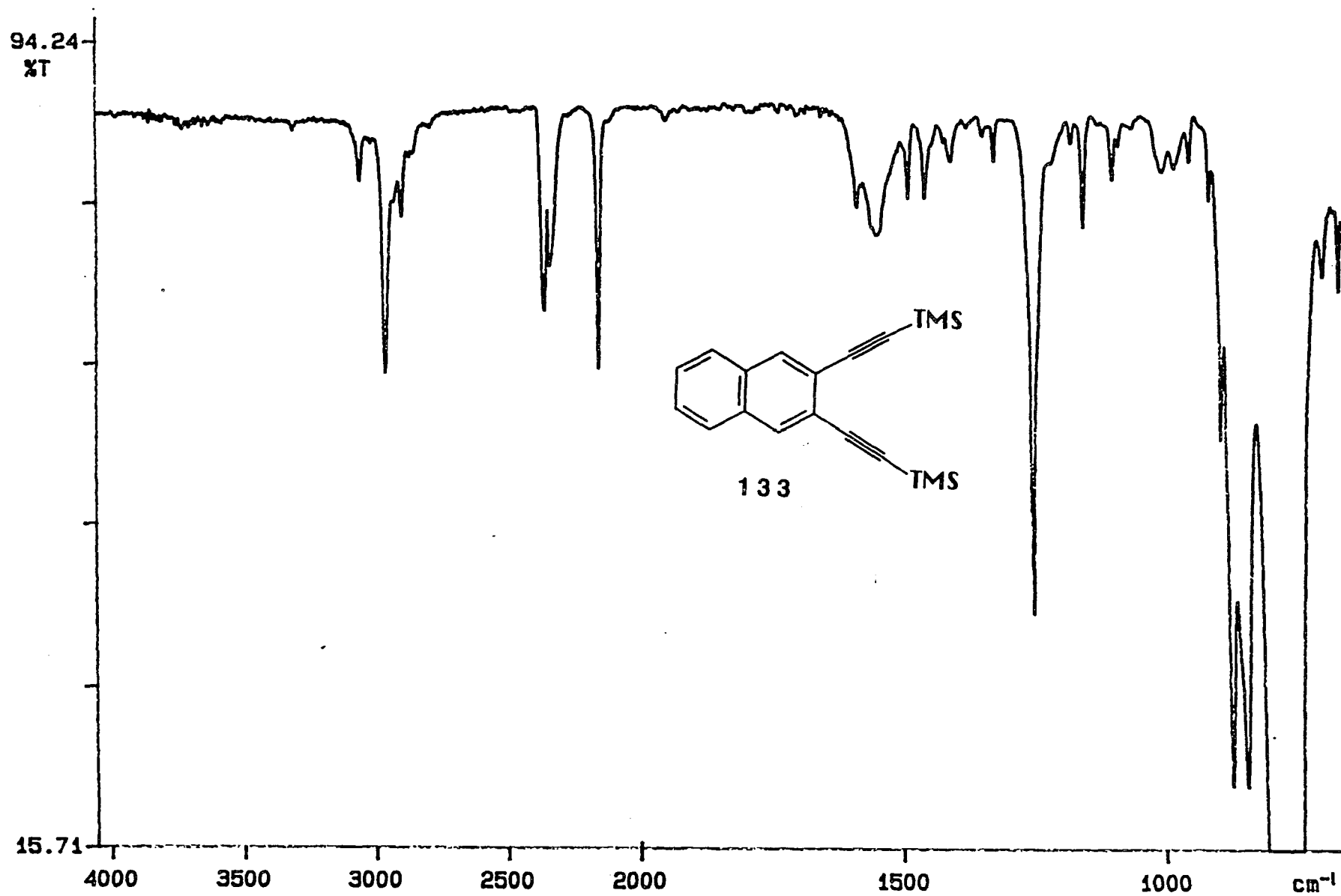


10 8 6 4 2 0

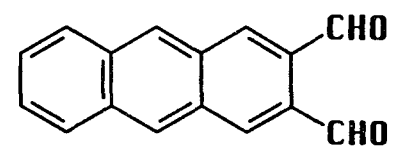
362



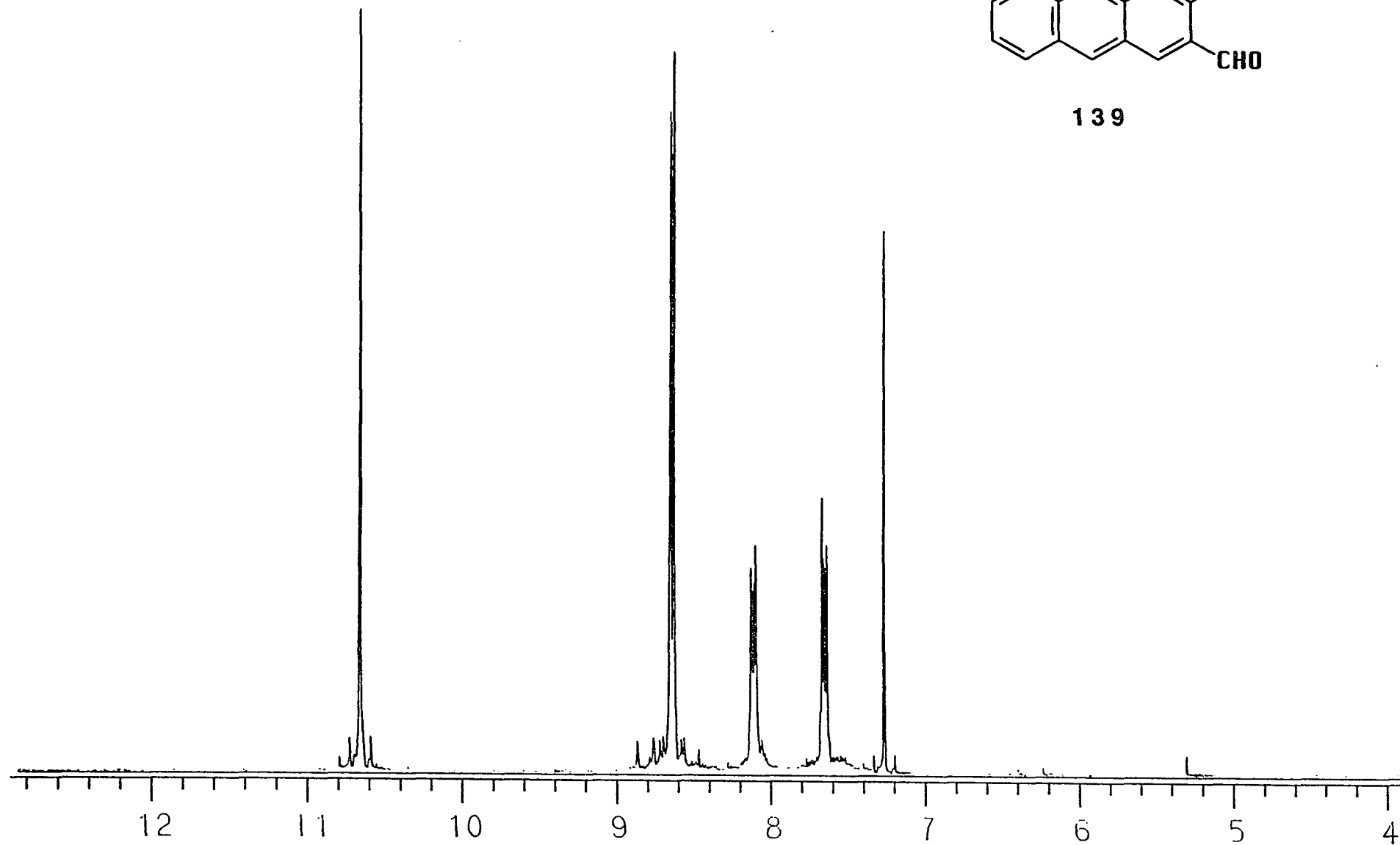


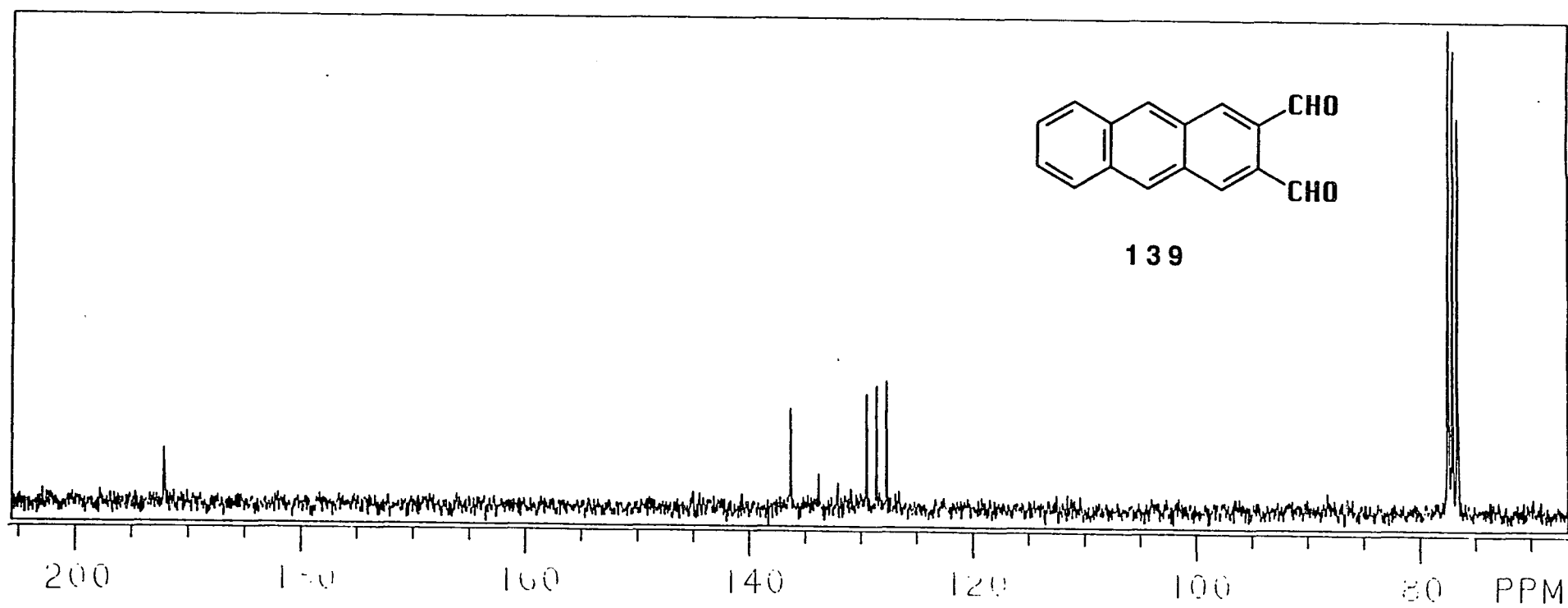


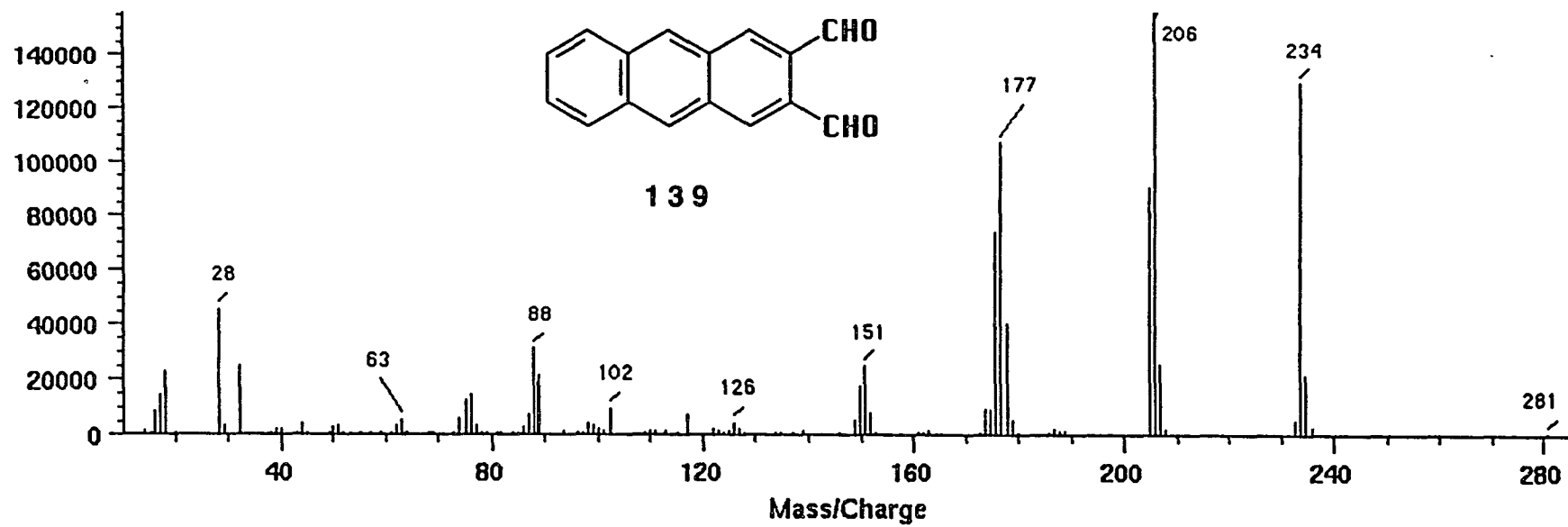
94/05/30 09:50
X: 1 scan, 4.0cm⁻¹

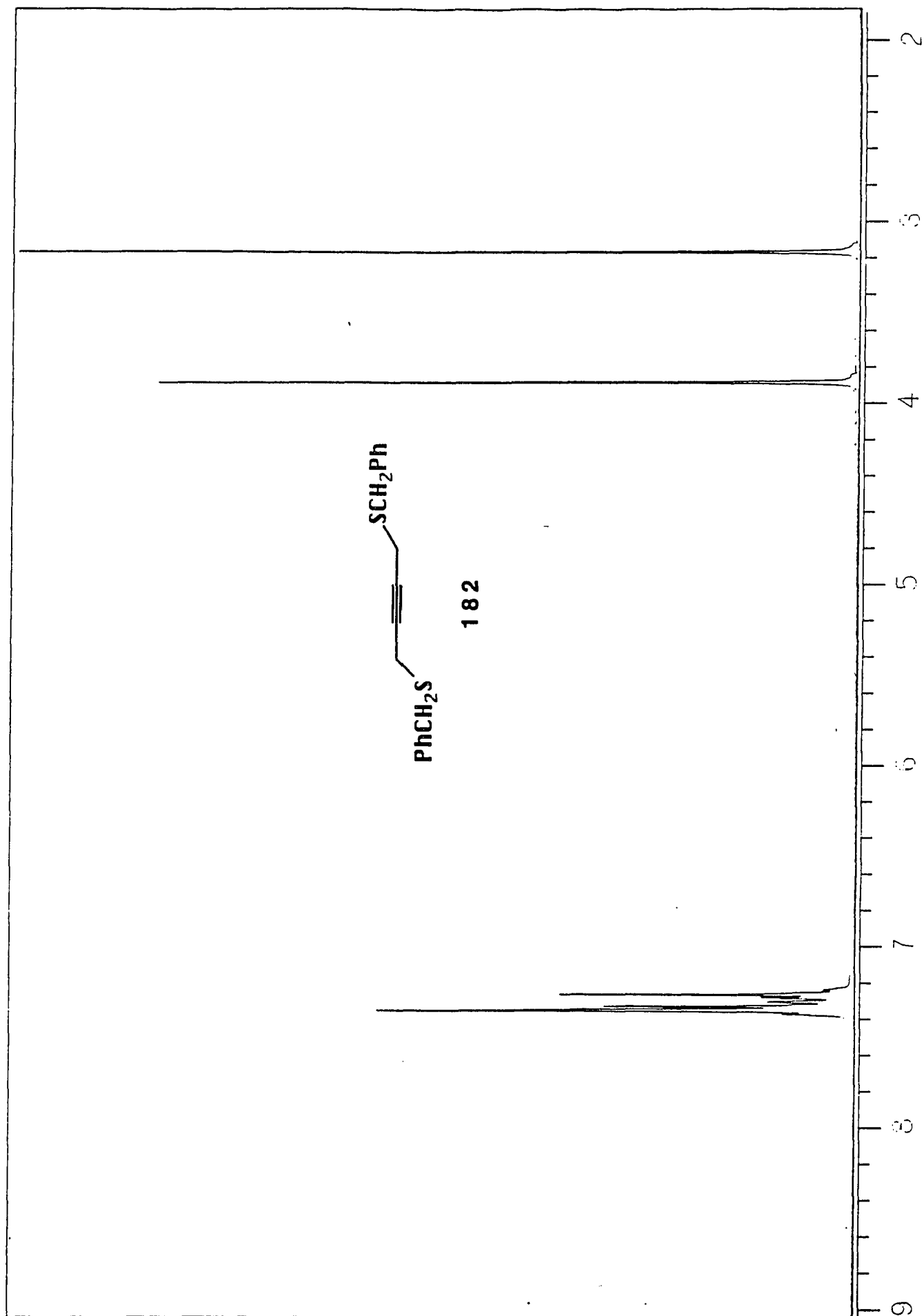


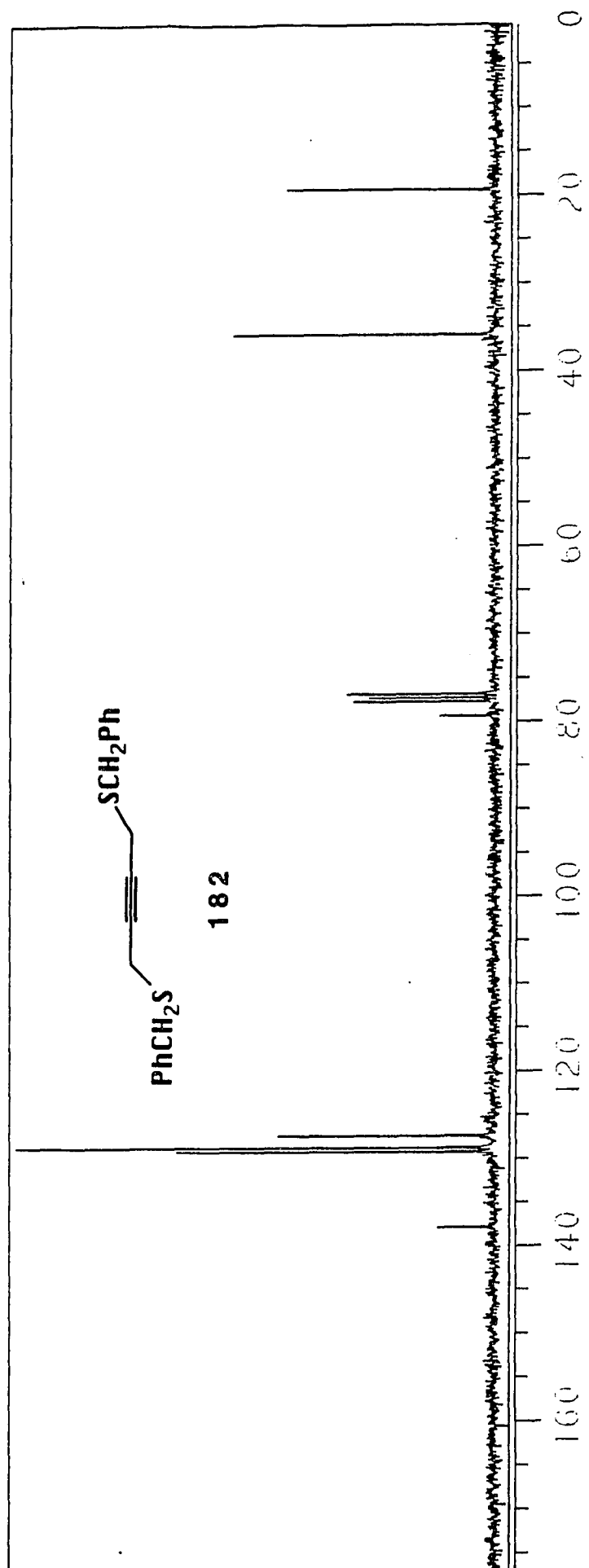
139

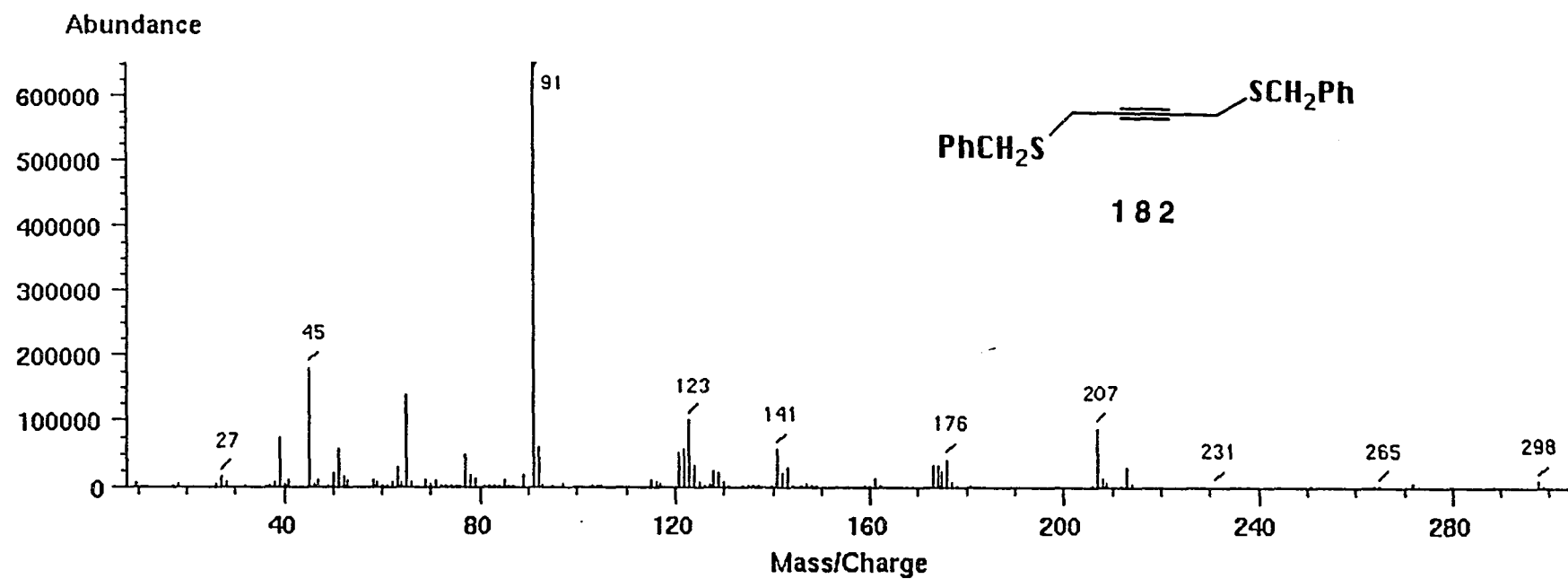


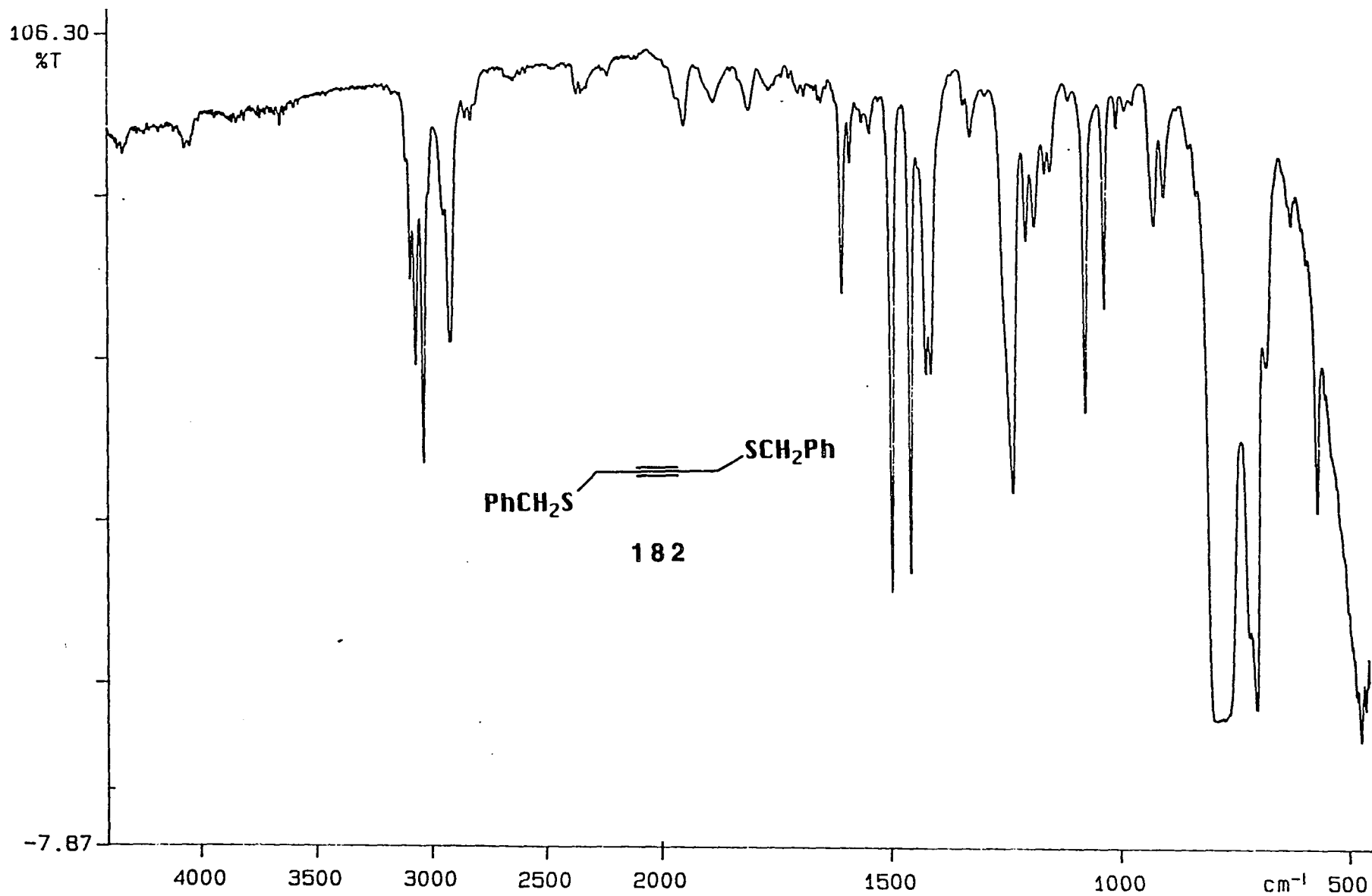








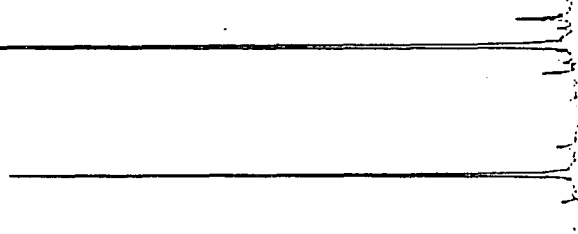


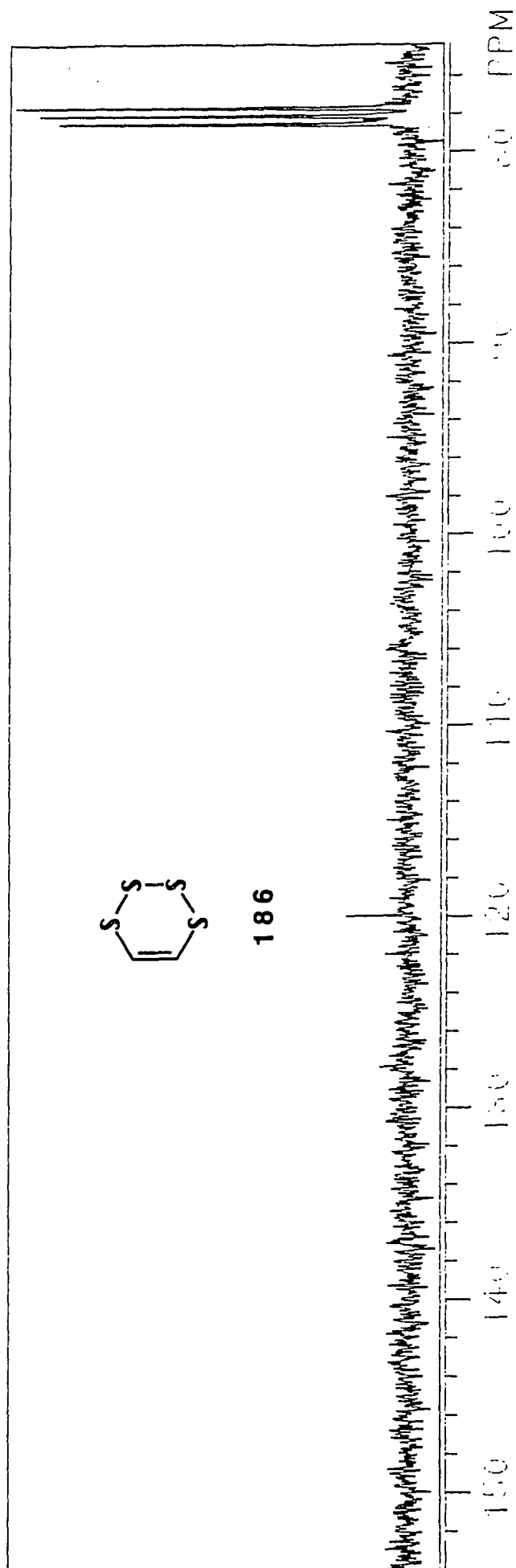


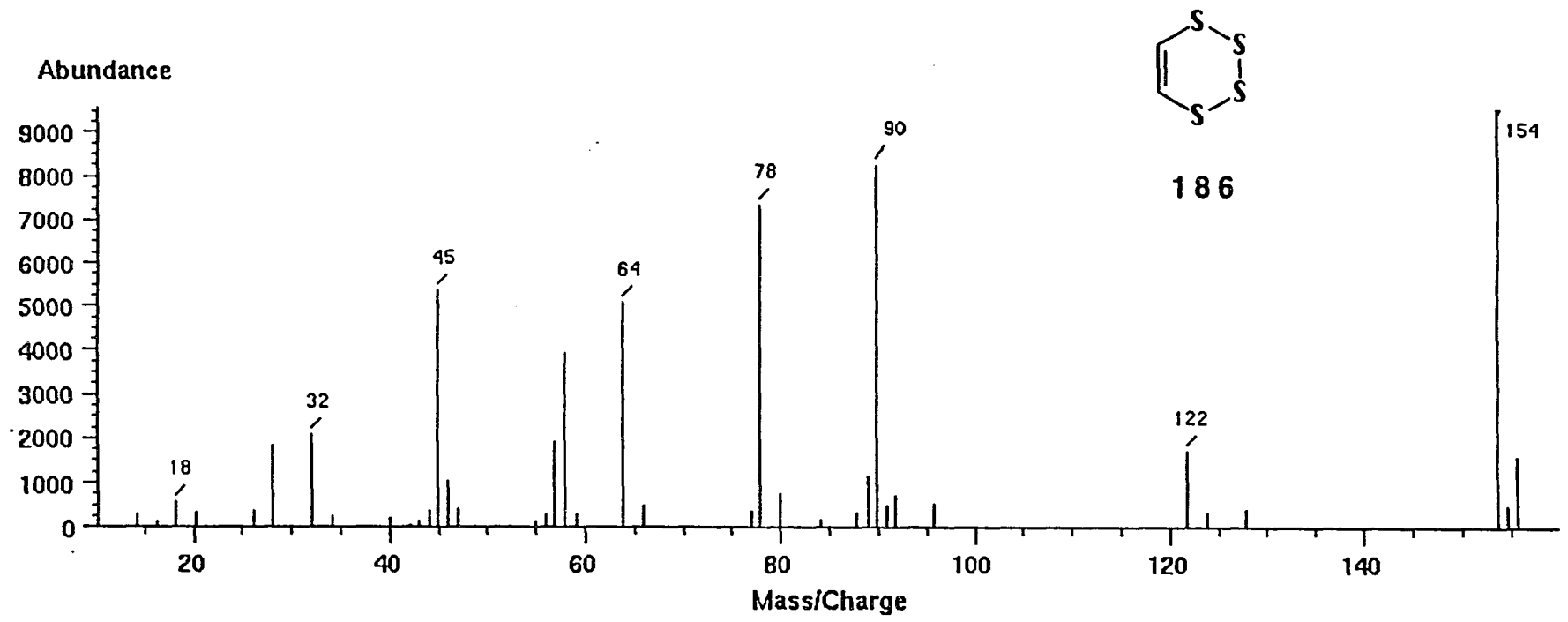
94/09/01 12:40
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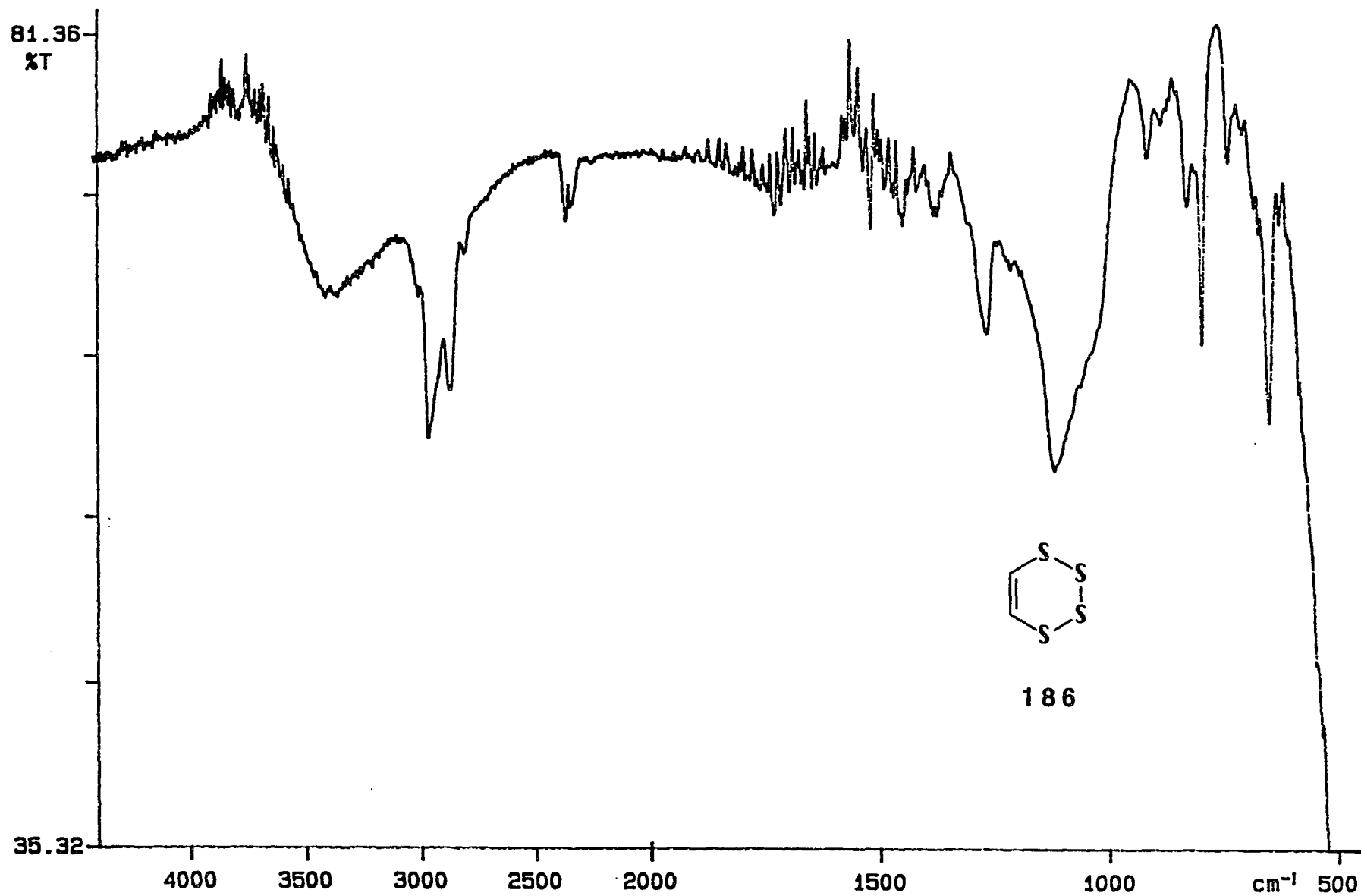


186

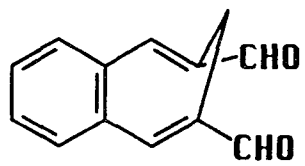




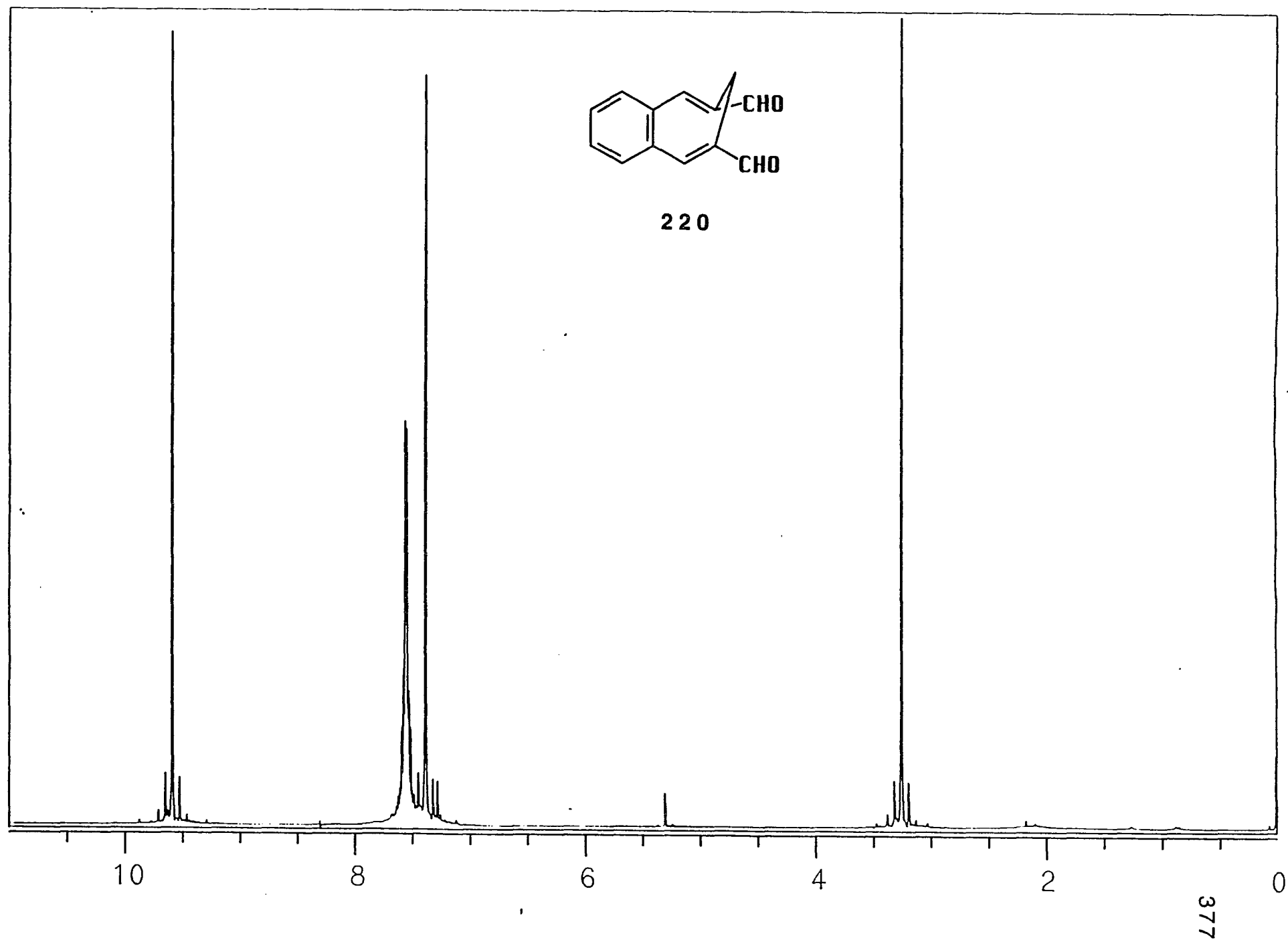


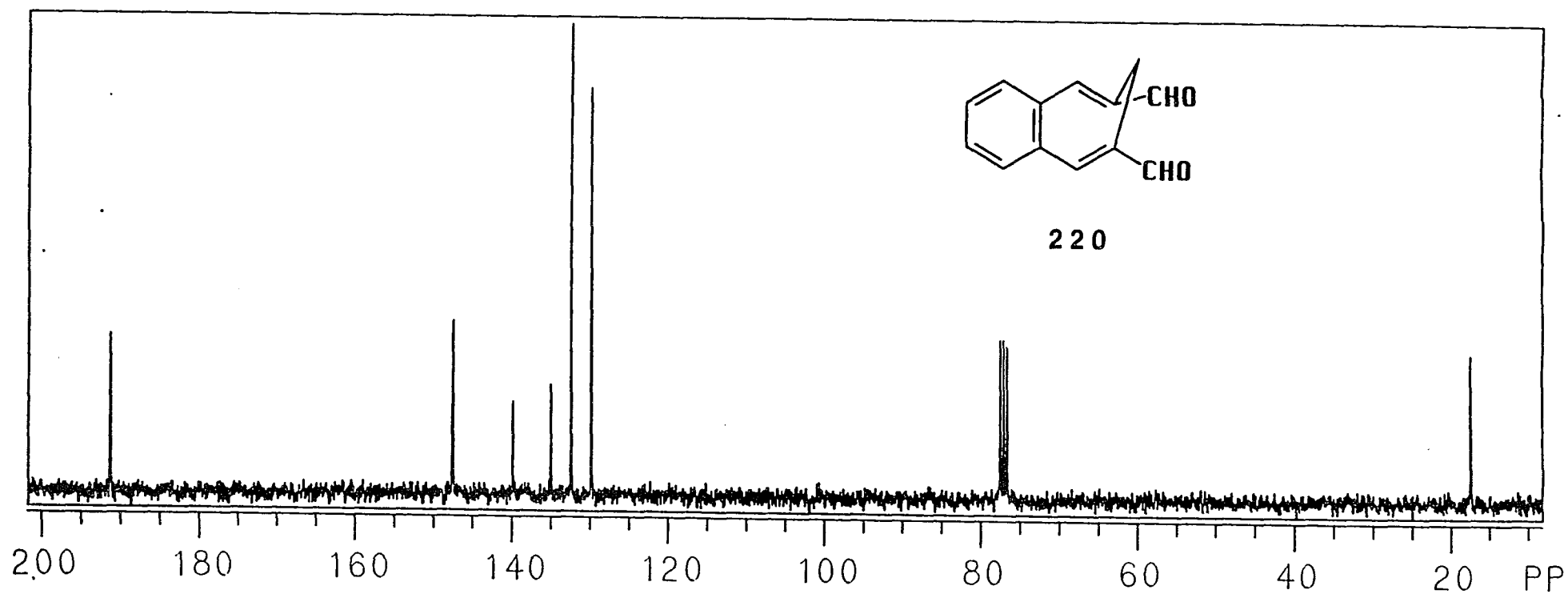


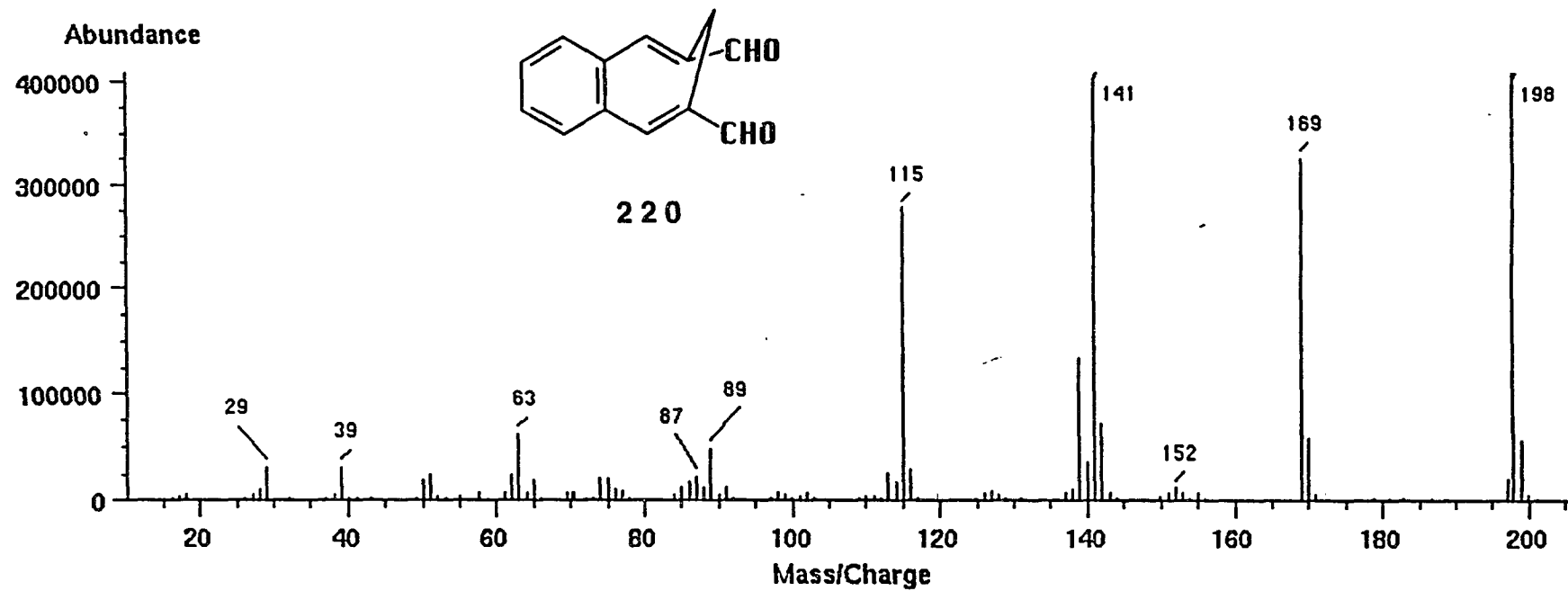
95/04/14 10:42
X: 1 scan, 4.0cm⁻¹

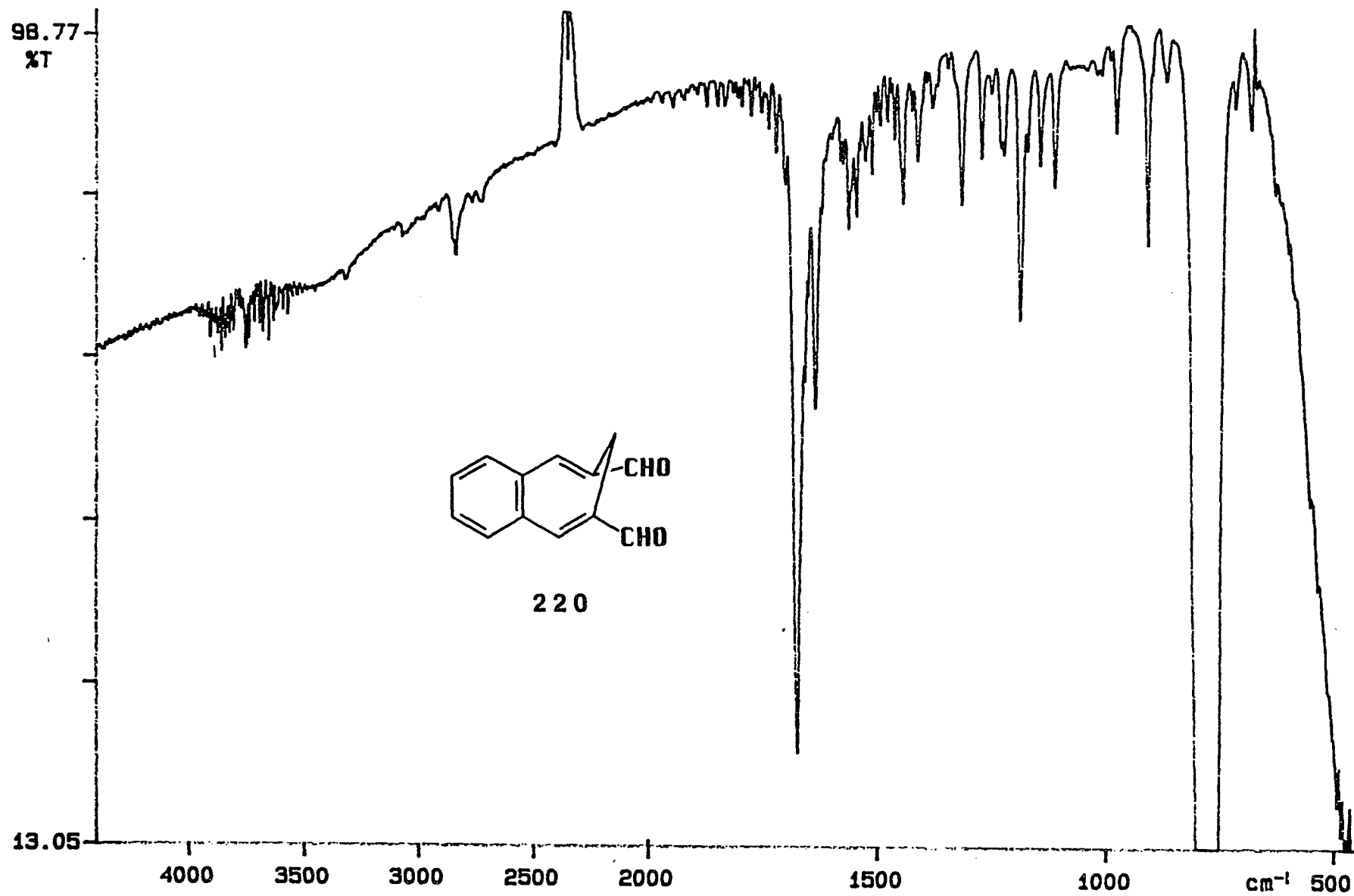


220

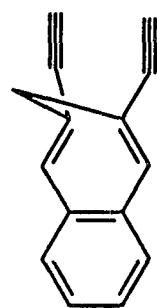




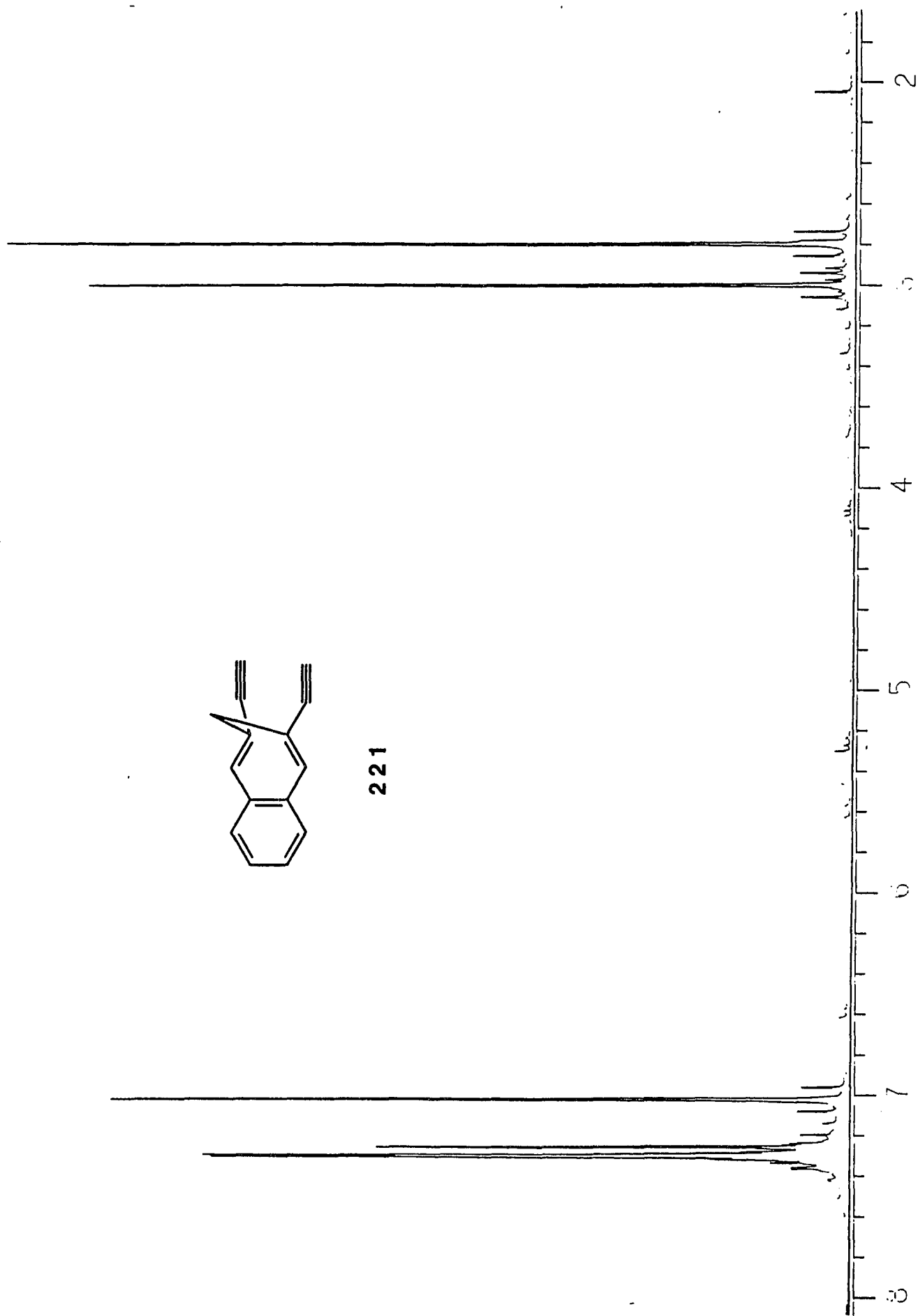


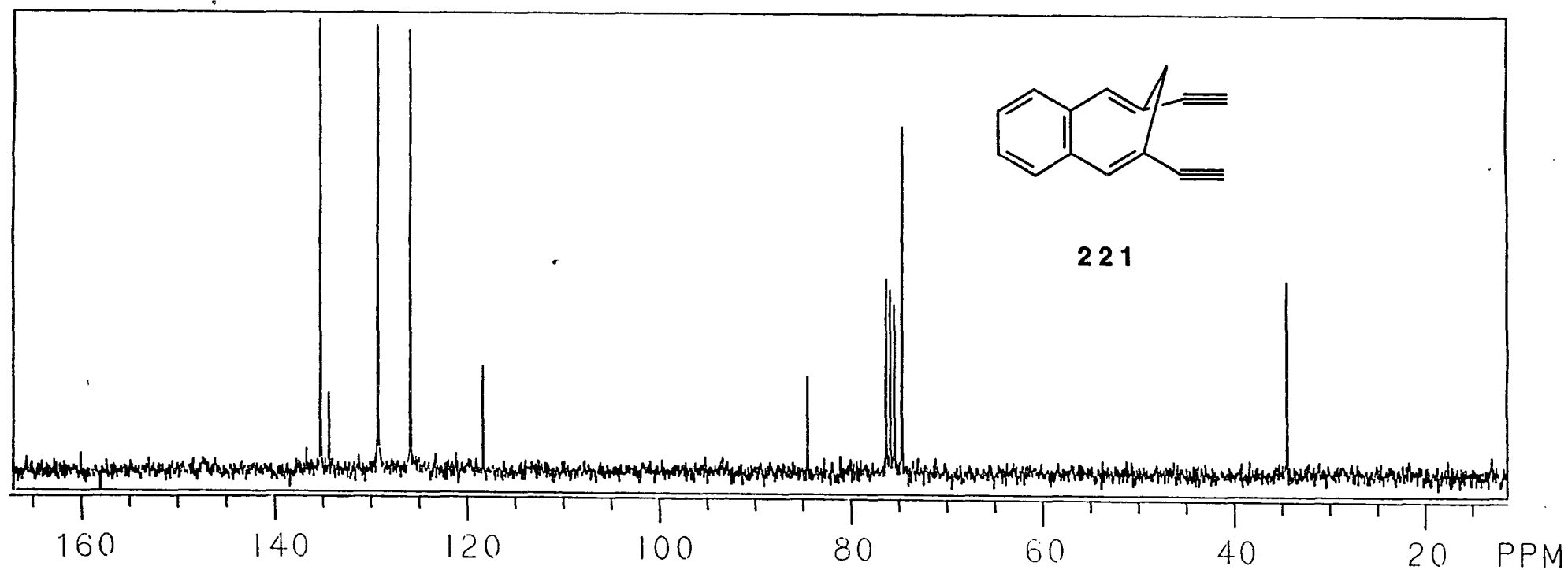


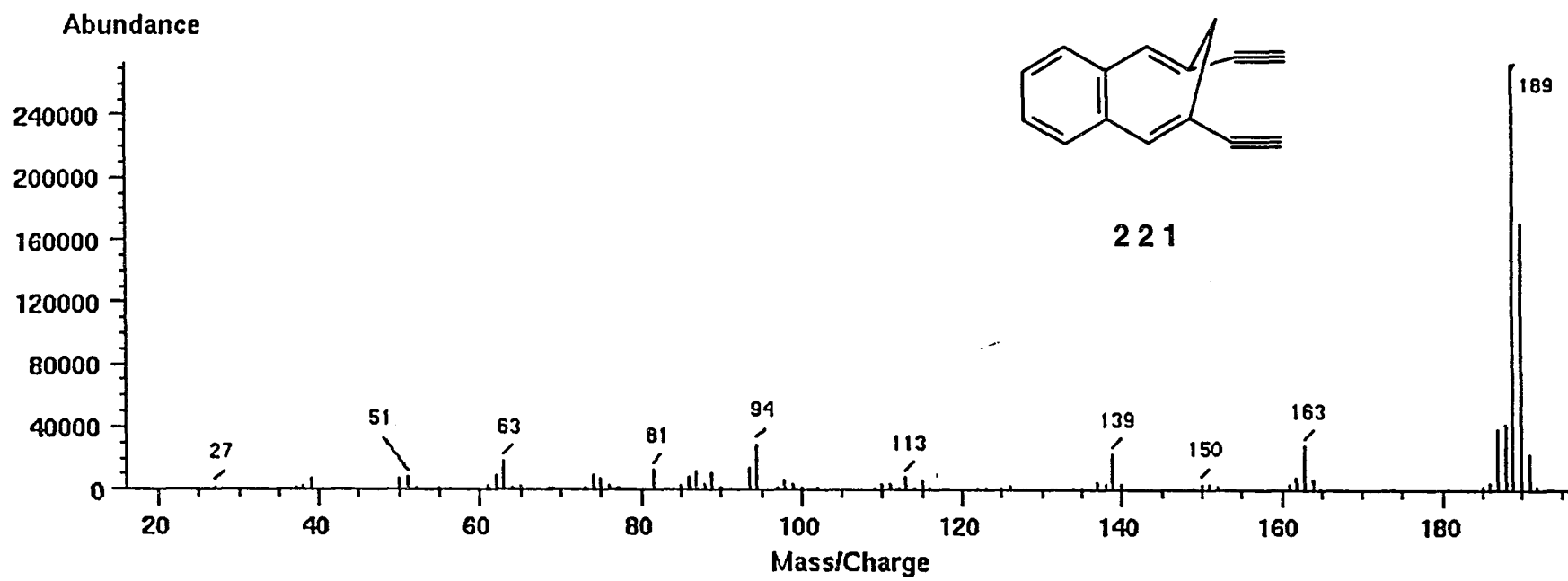
95/06/07 11:43
X: 1 scan, 4.0cm⁻¹

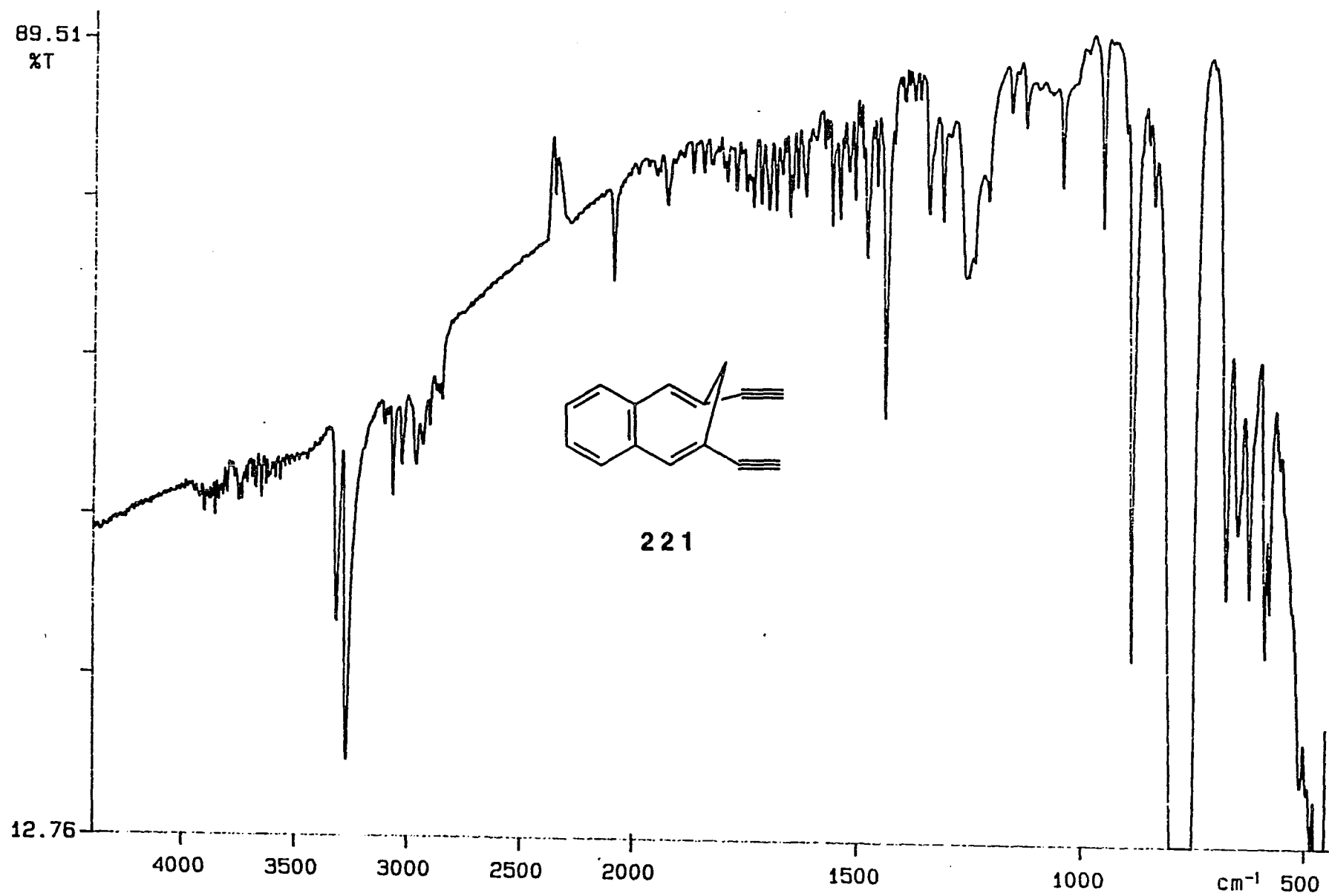


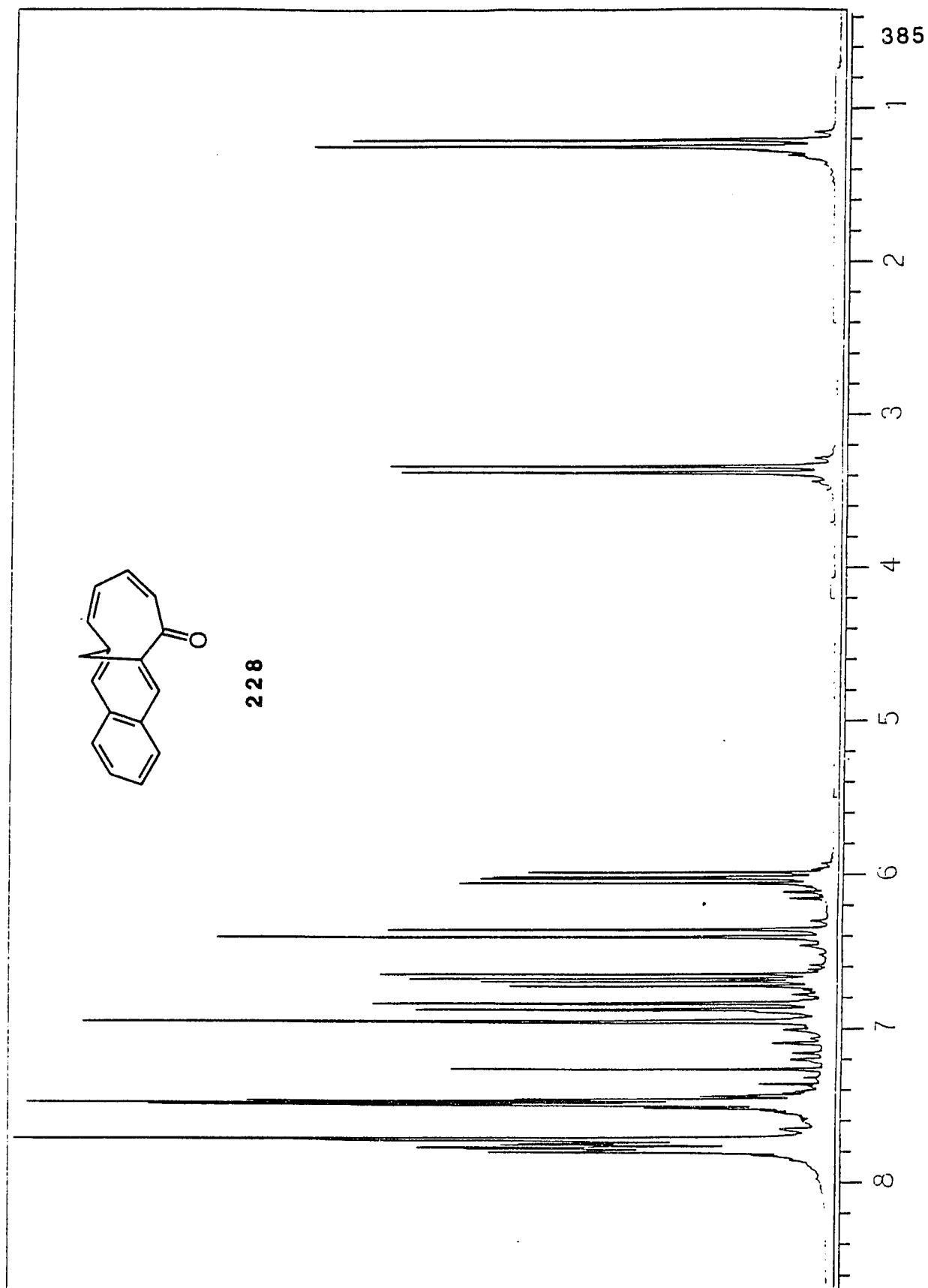
221

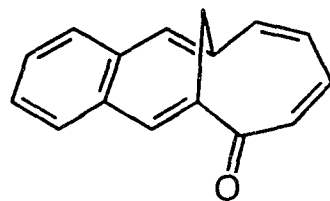




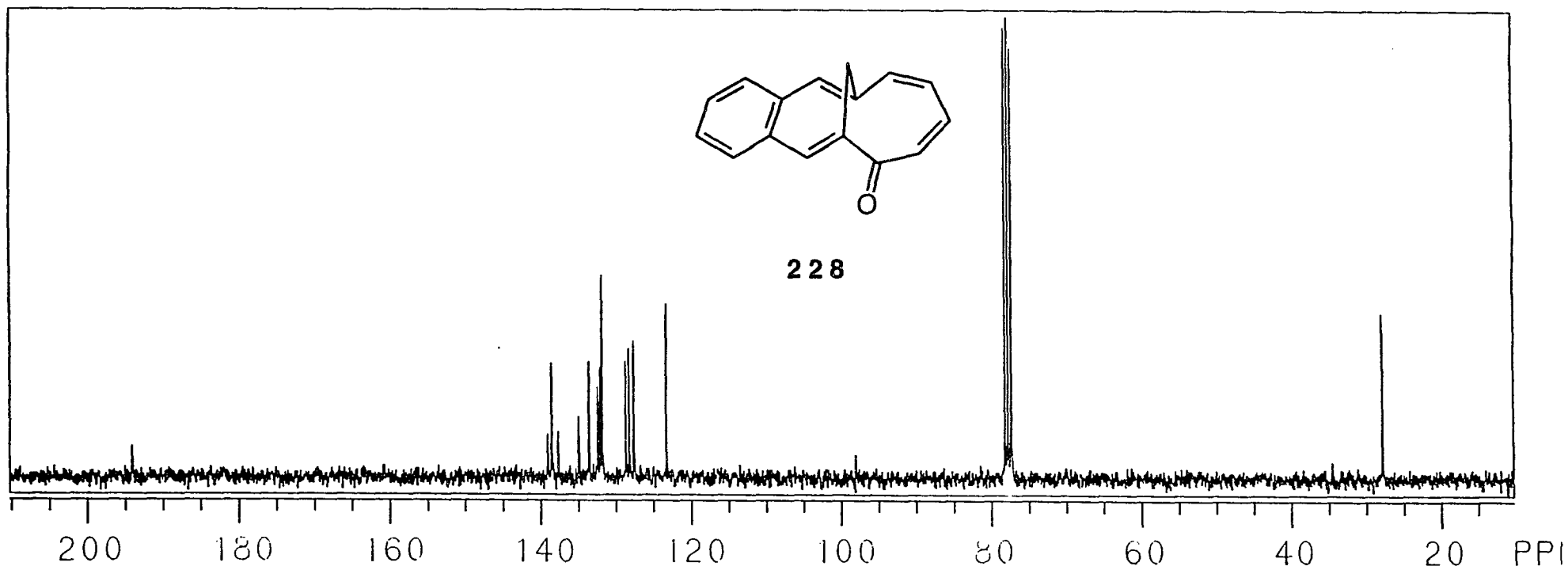




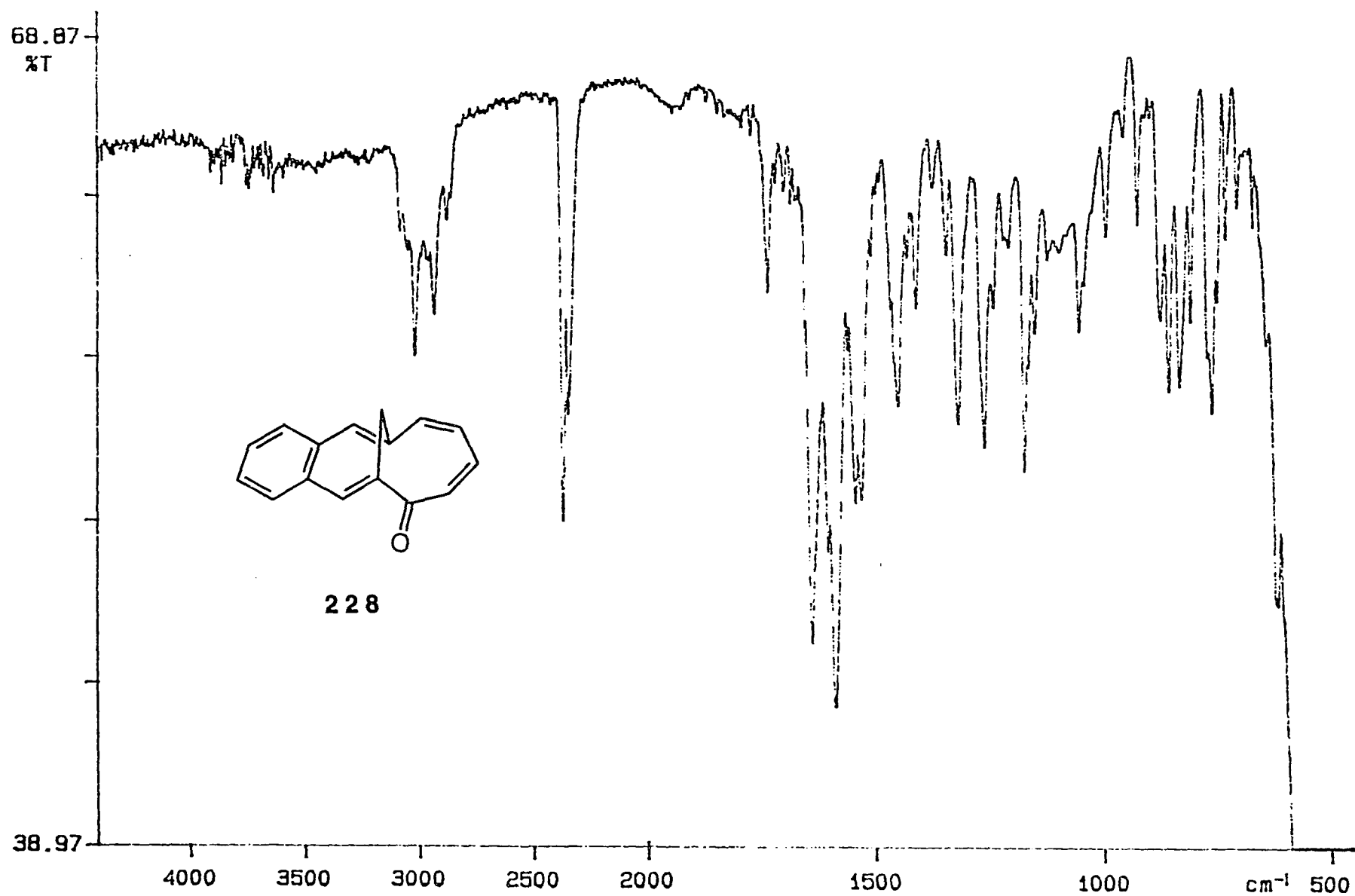




228



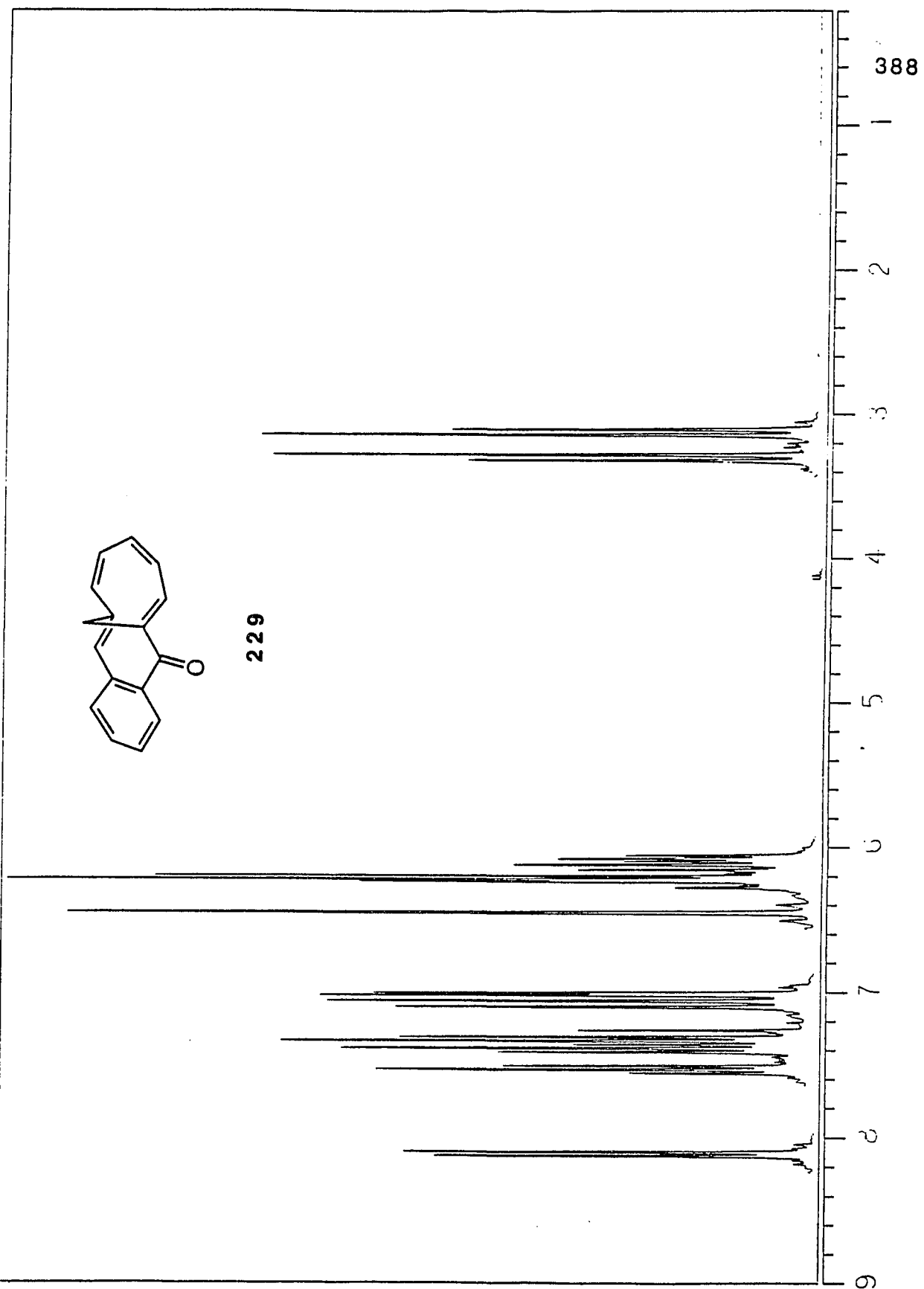
PERKIN ELMER



96/03/28 05:30

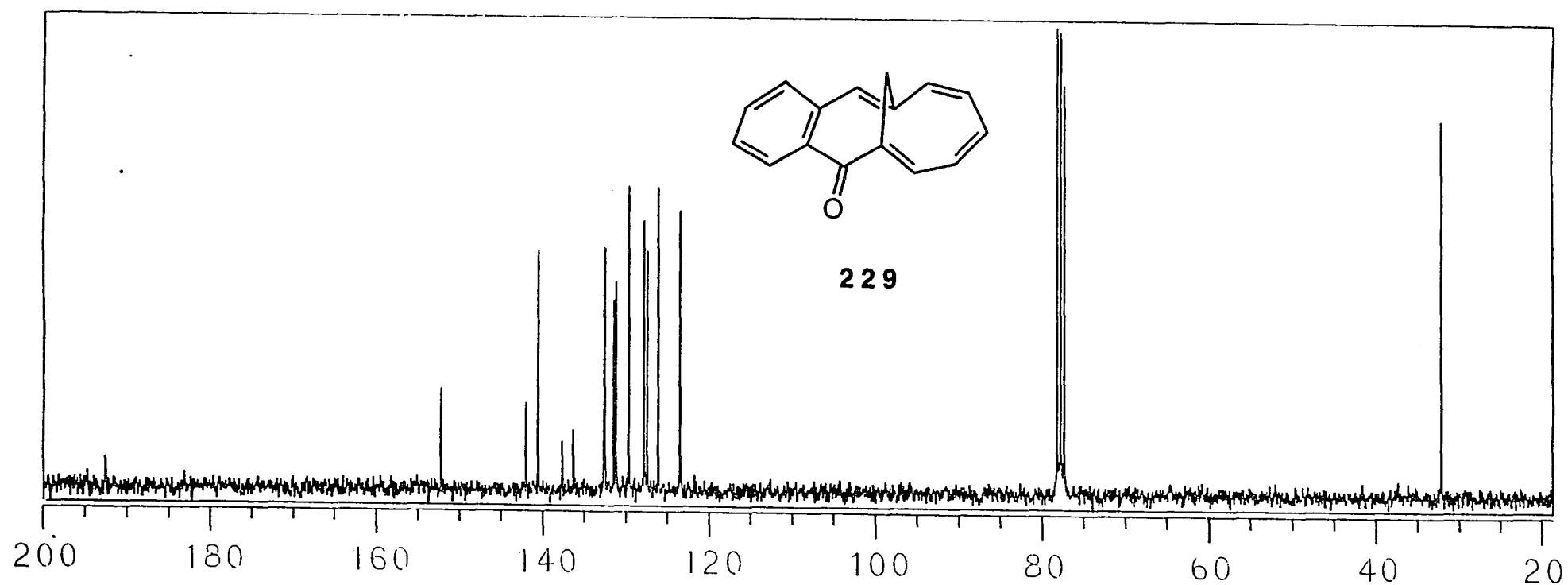
X: 1 scan, 4.0cm-1, flat

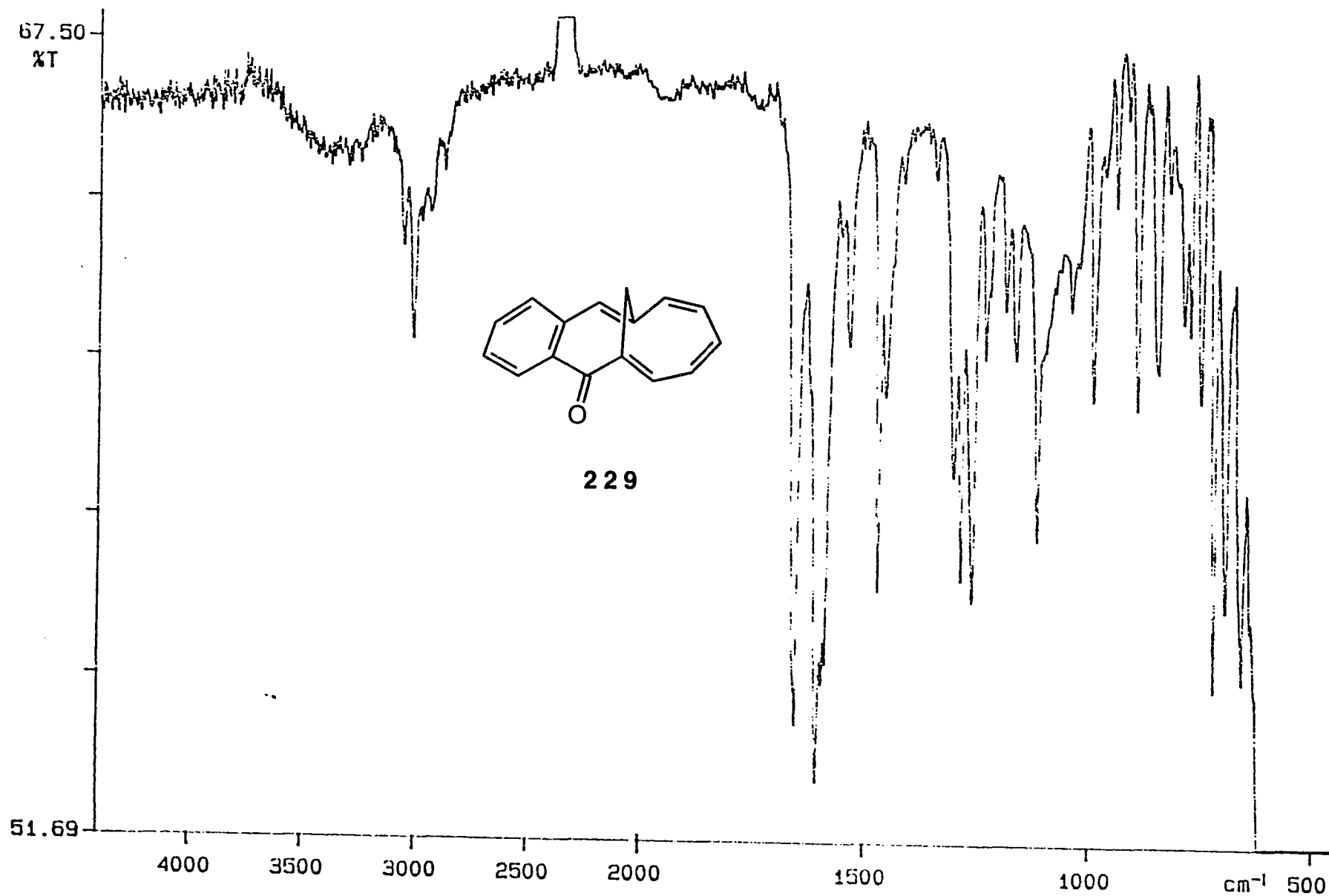
387



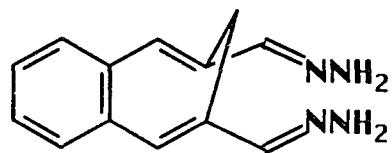
229

388

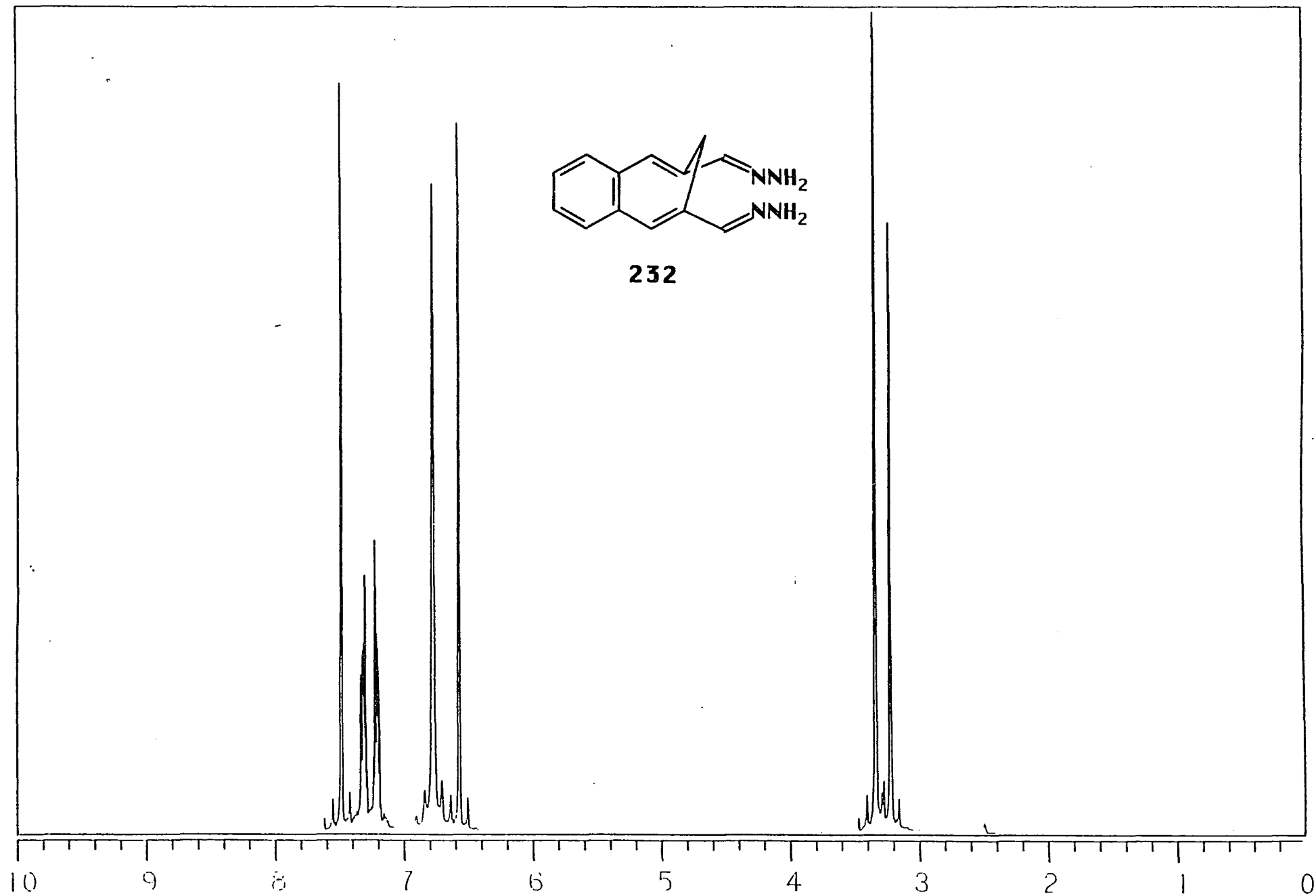


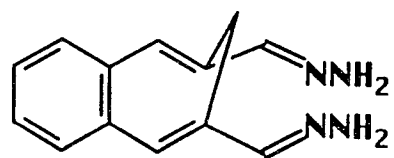


96/03/28 05:40
X: 1 scan, 4.0cm⁻¹, flat

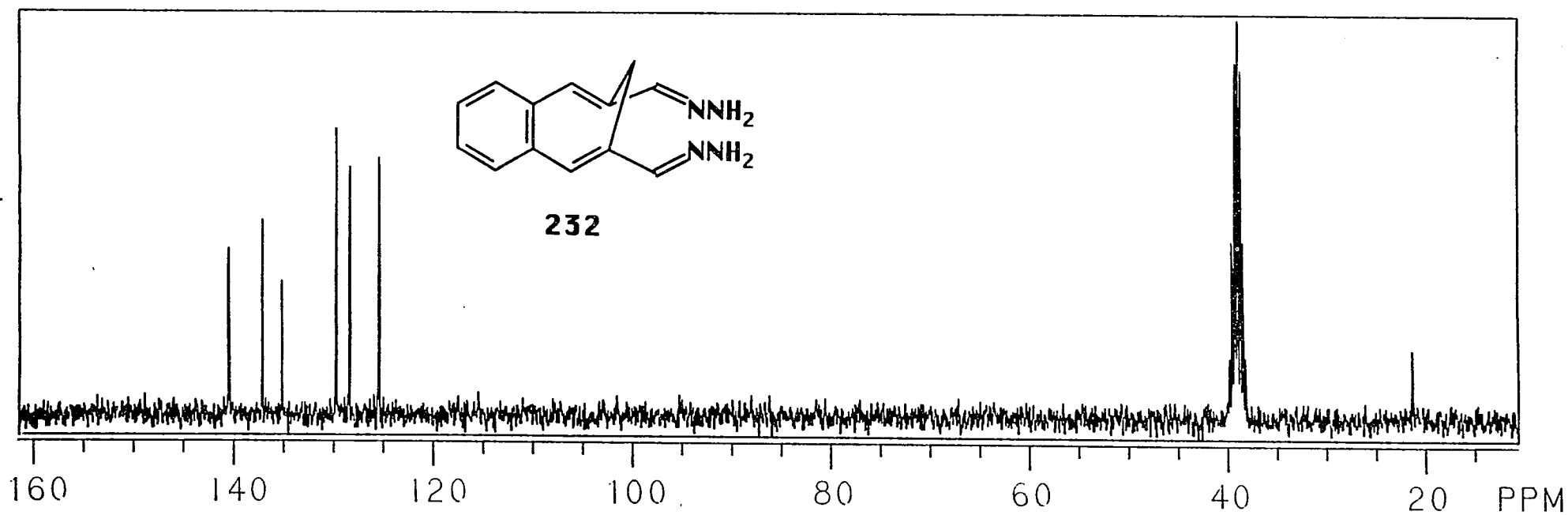


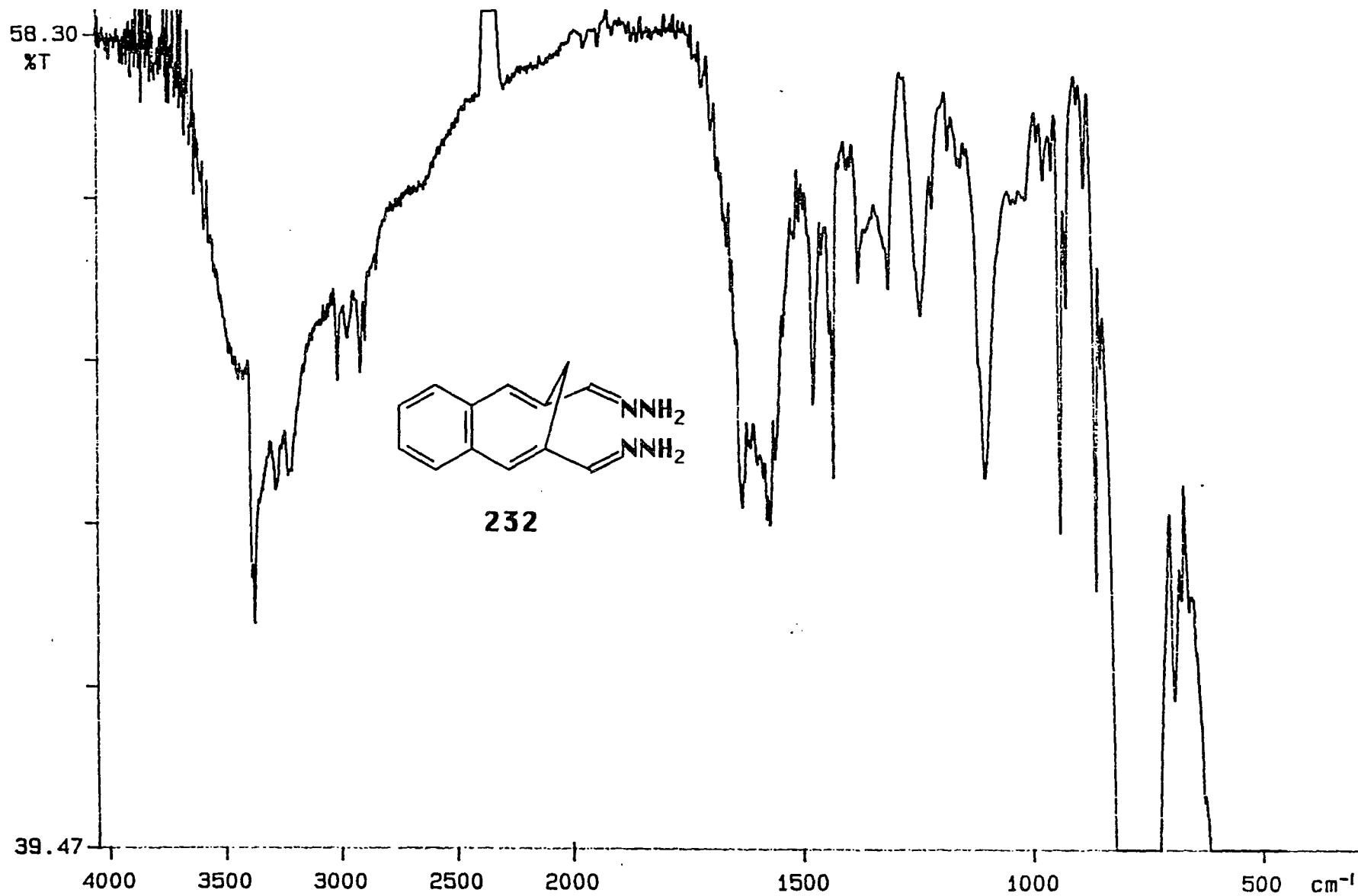
232





232

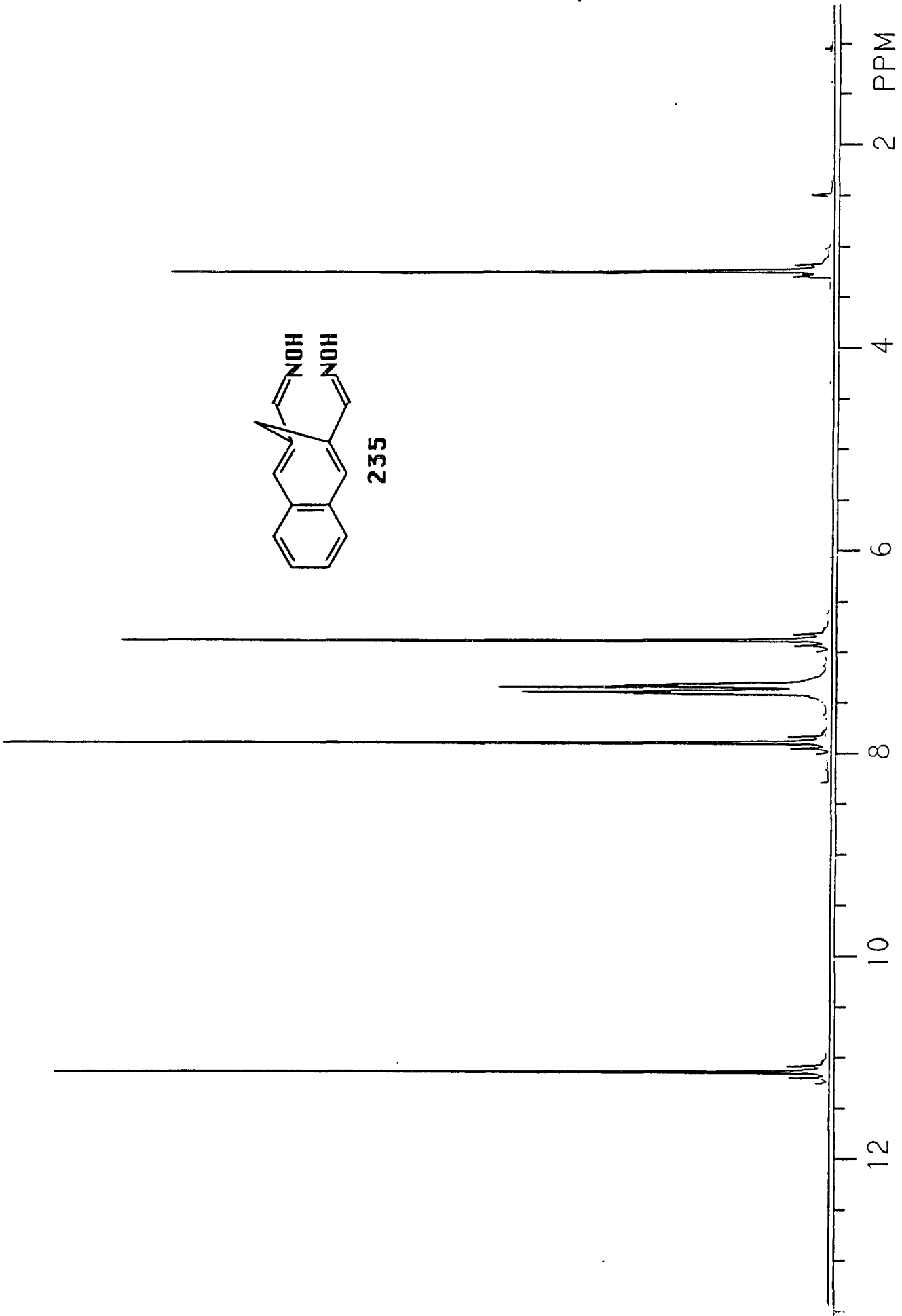


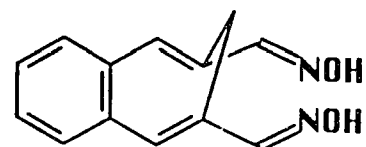


95/06/22 17:36

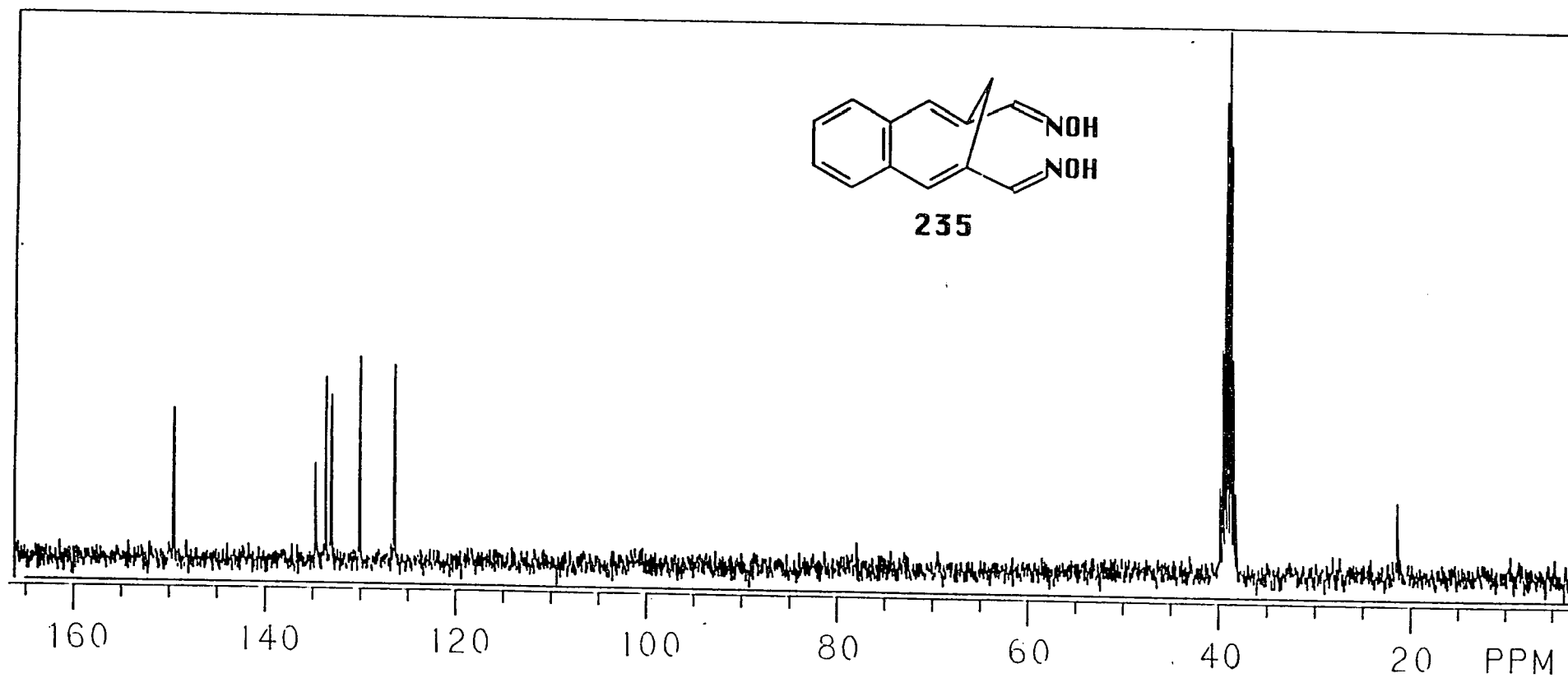
X: 1 scan, 4.0cm⁻¹, flat

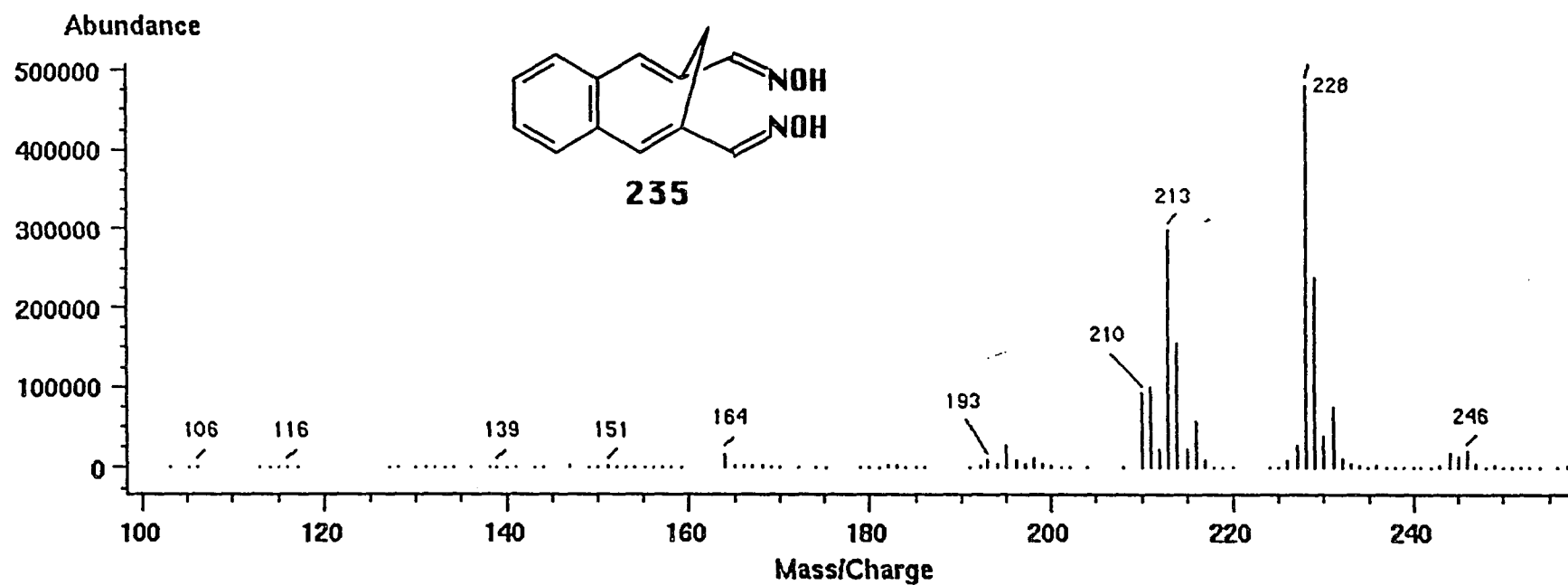
393

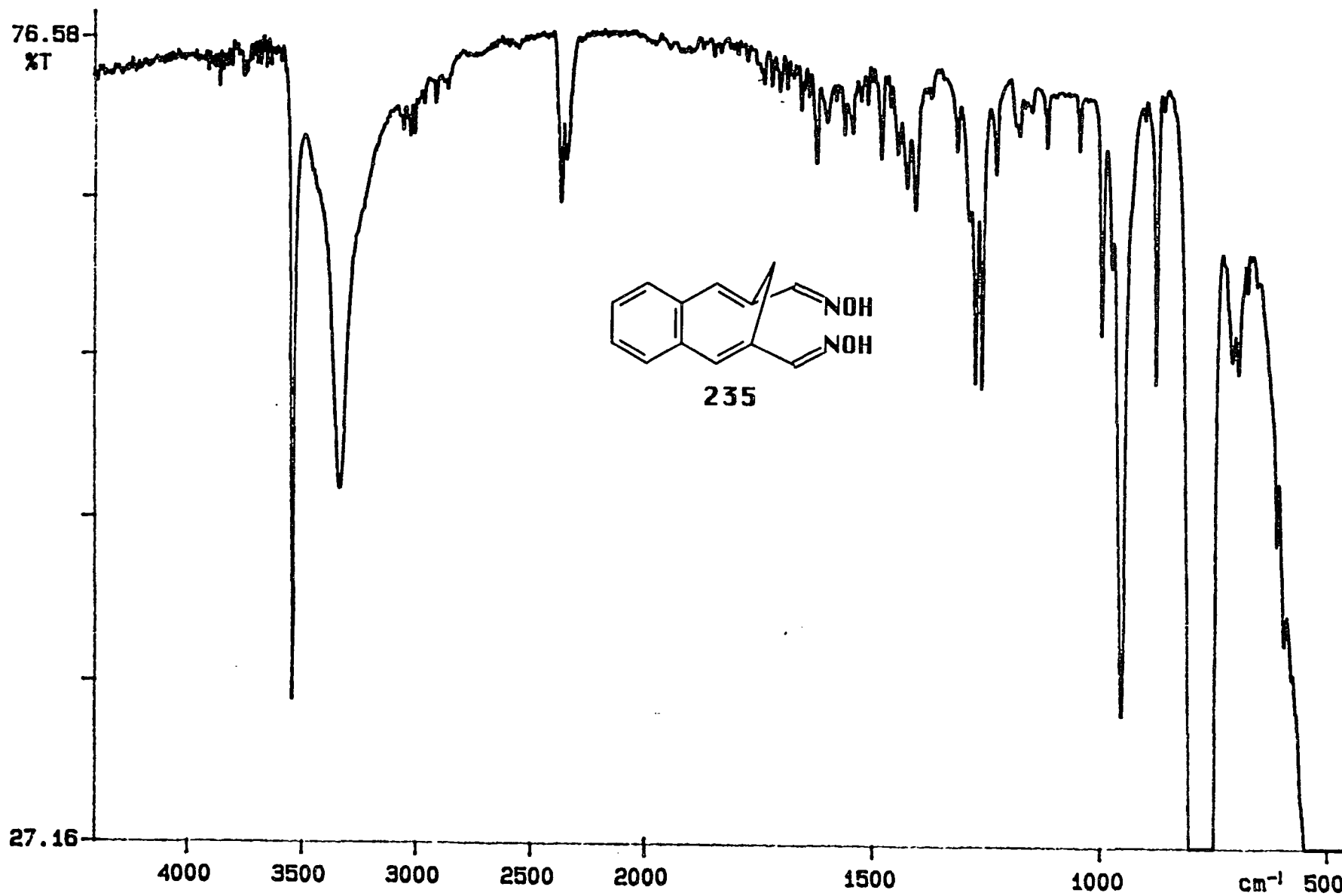




235

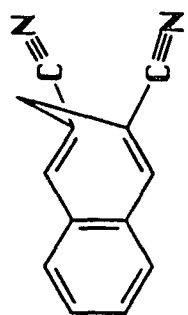






95/12/25 13:35

SCAN: 1 scan, 4.0cm⁻¹, flat



236

398

F

2

3

4

5

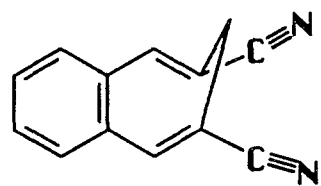
6

7

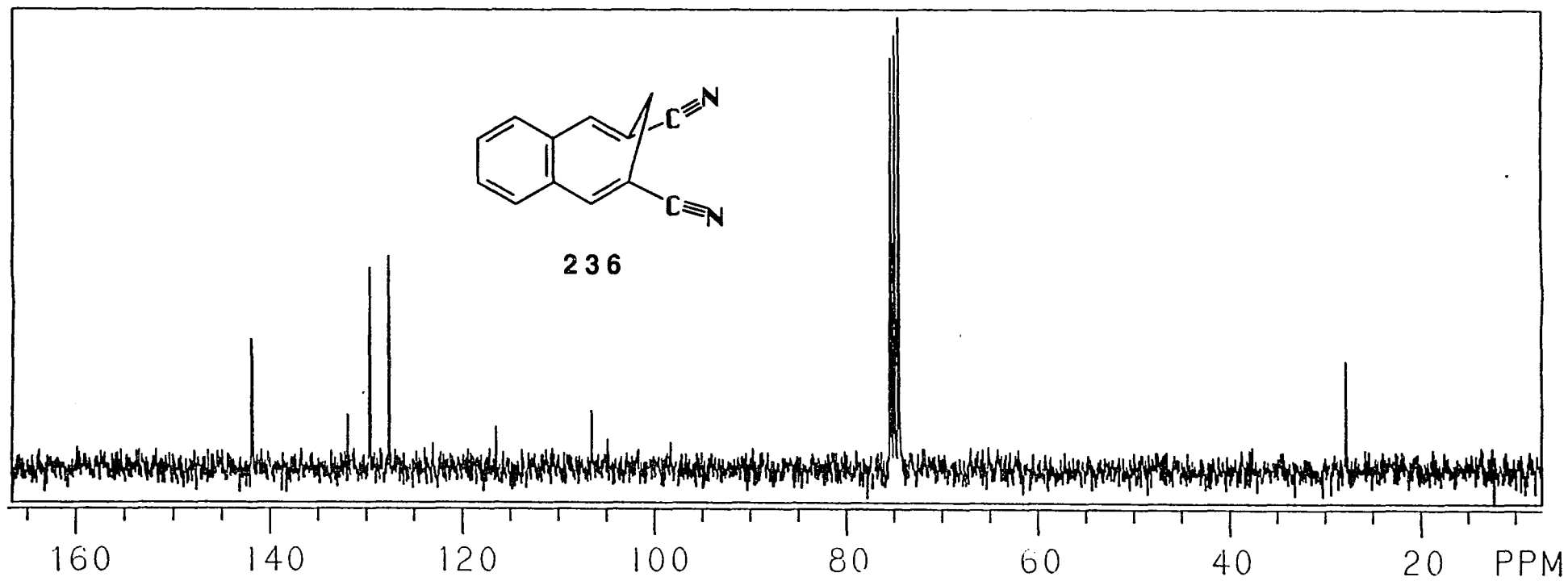
8

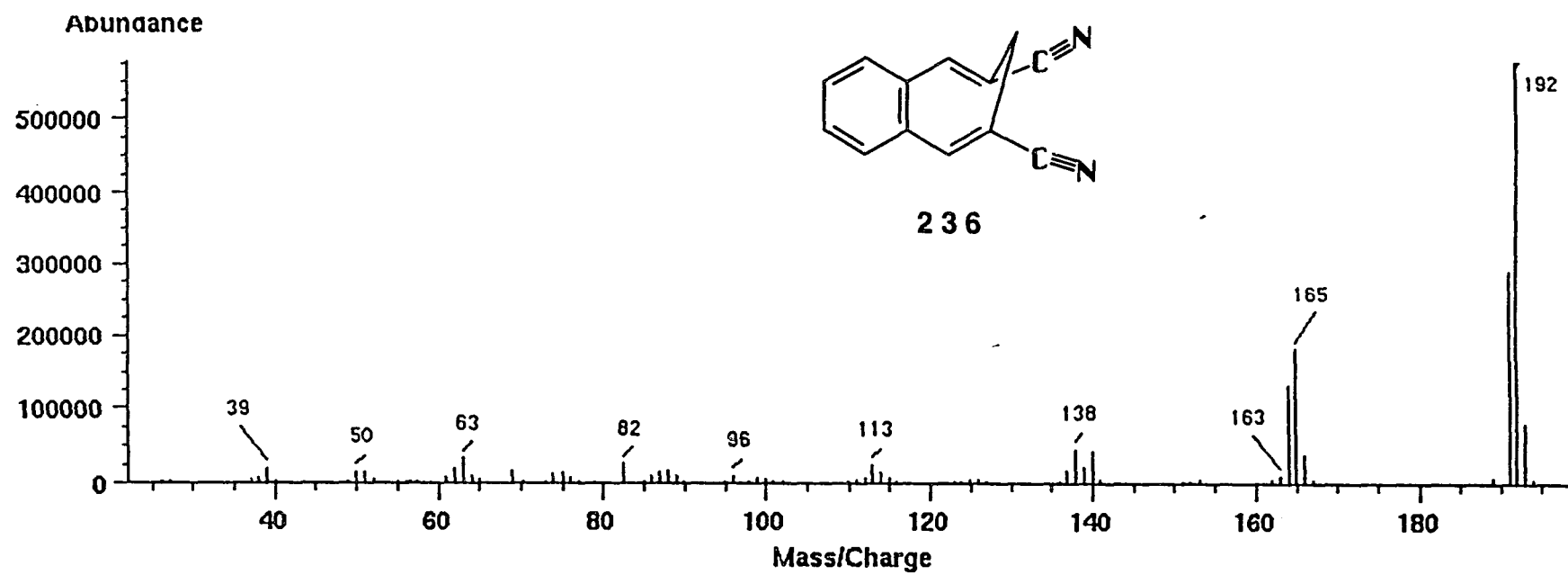
9

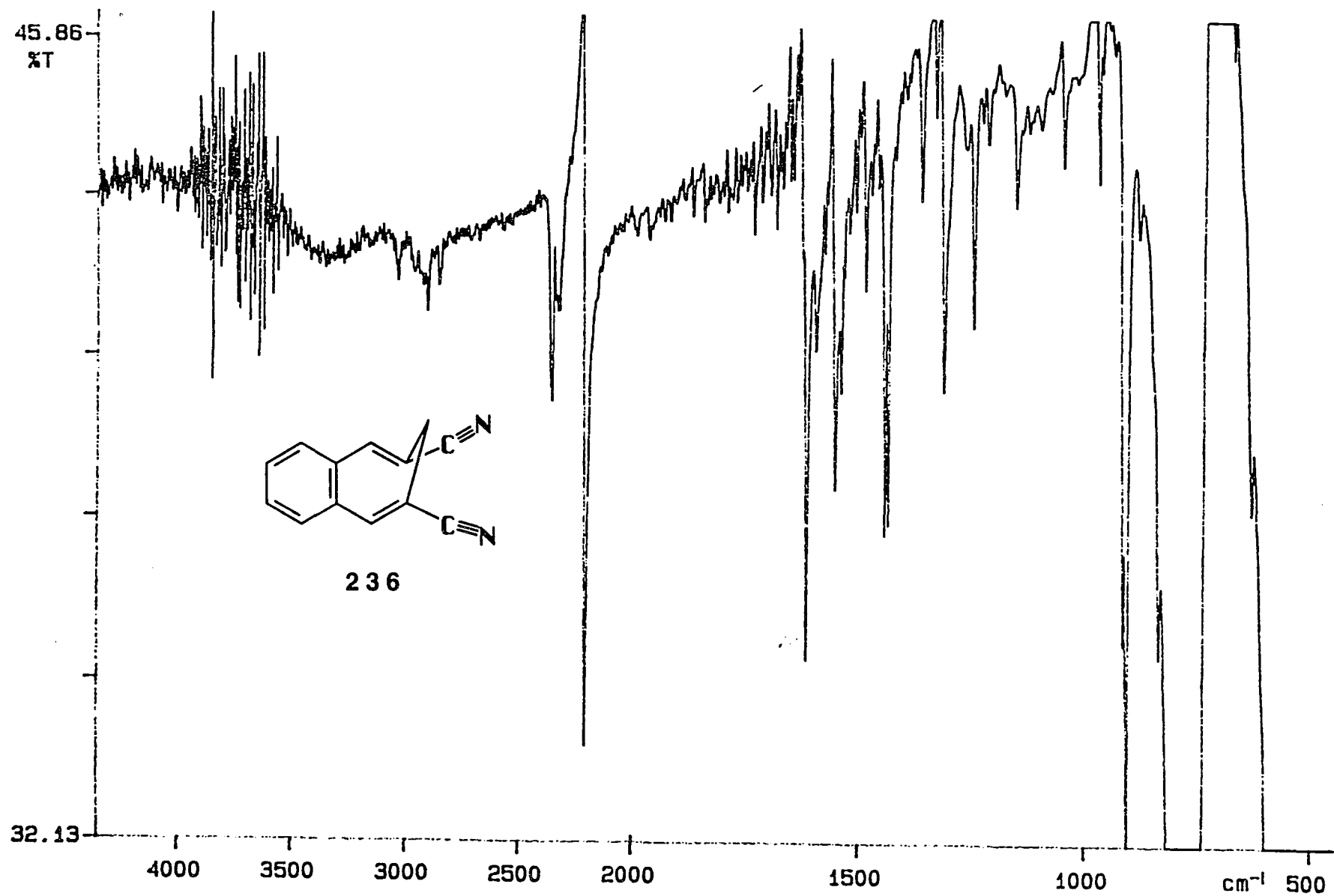
10



236

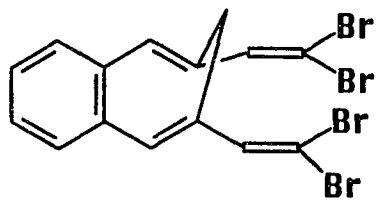




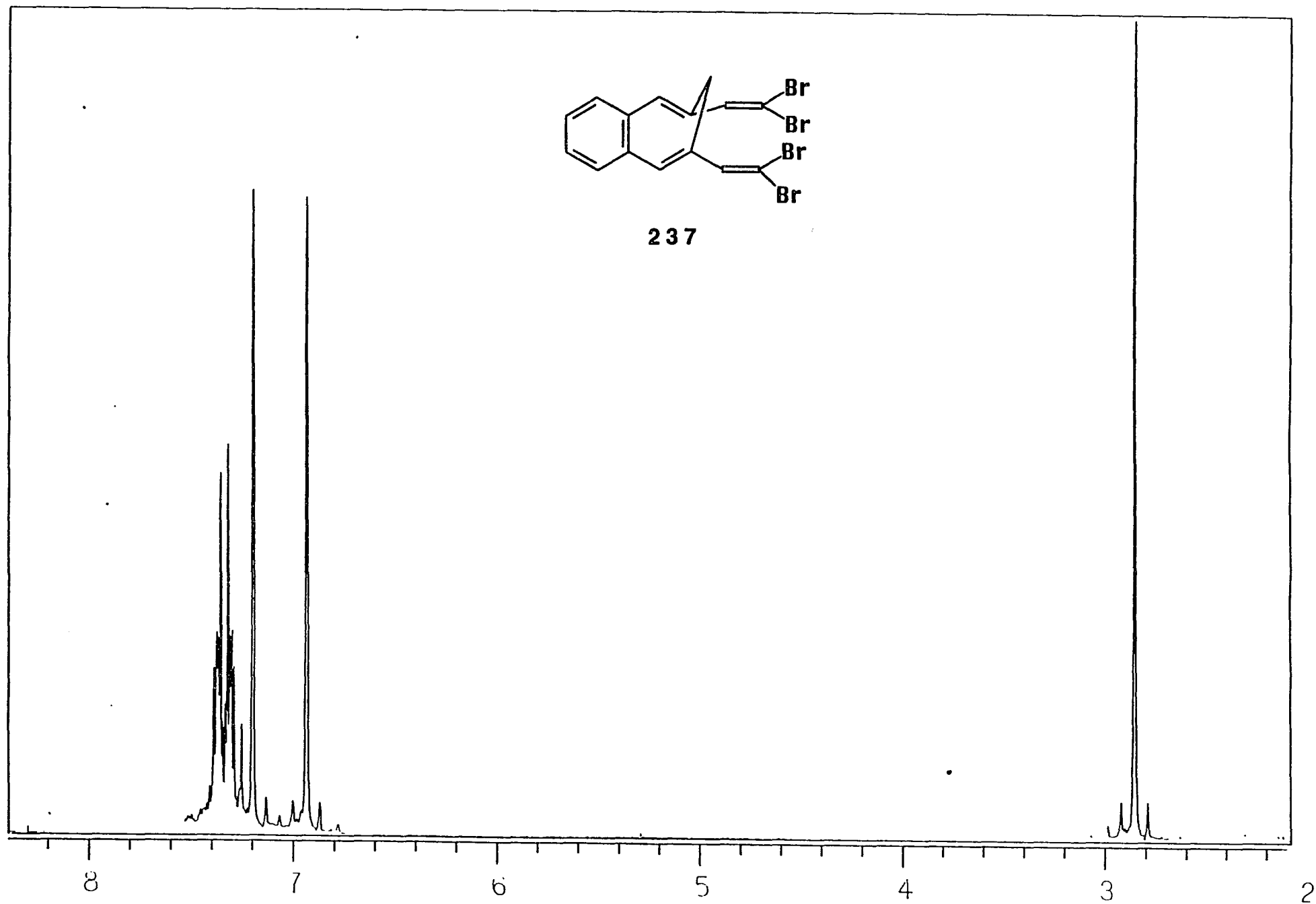


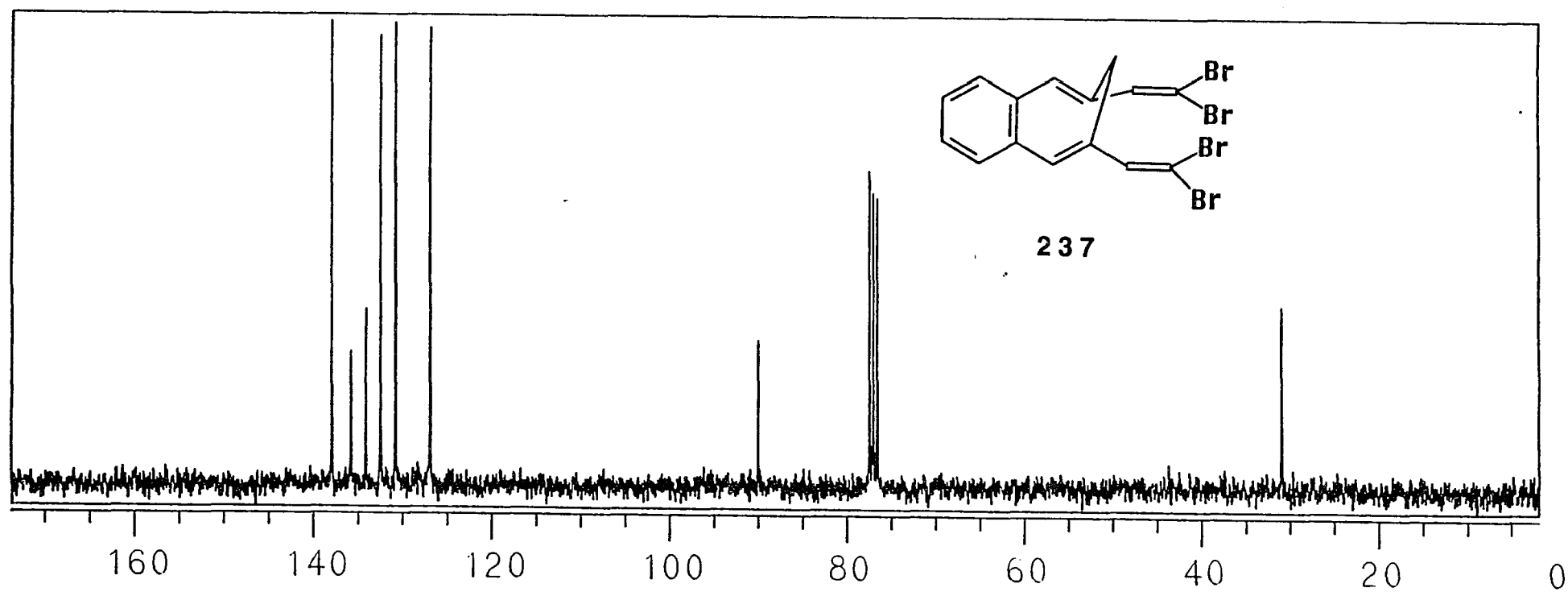
95/09/07 18:59

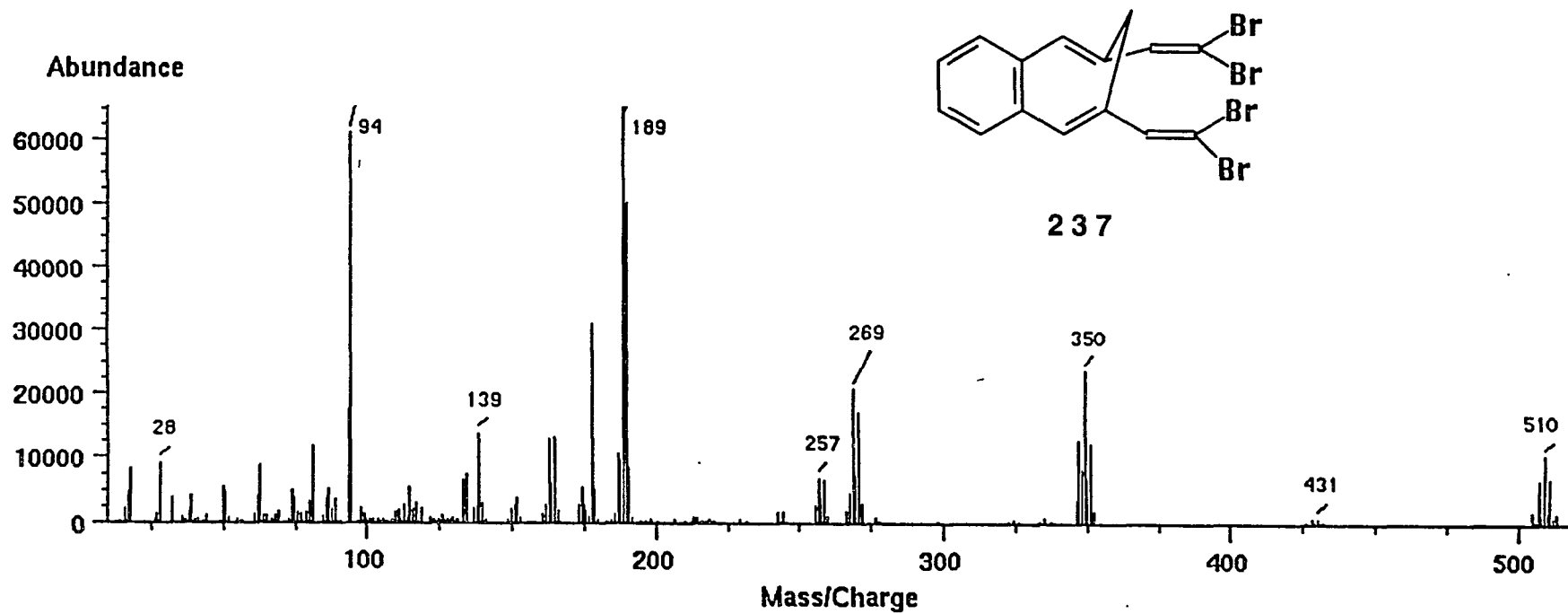
X: 1 scan, 4.0 cm^{-1} , flat

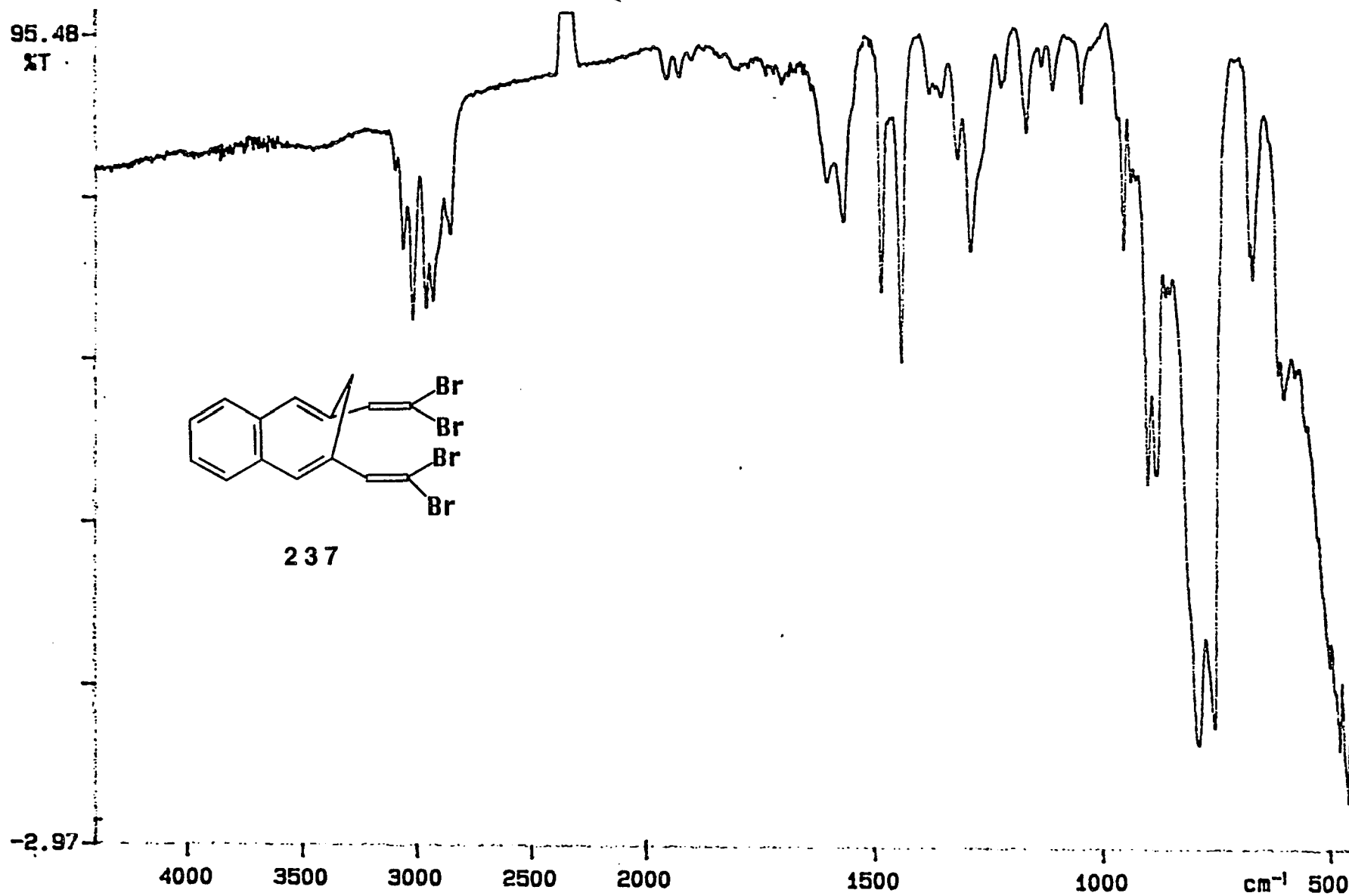


237

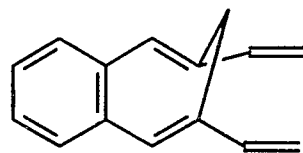




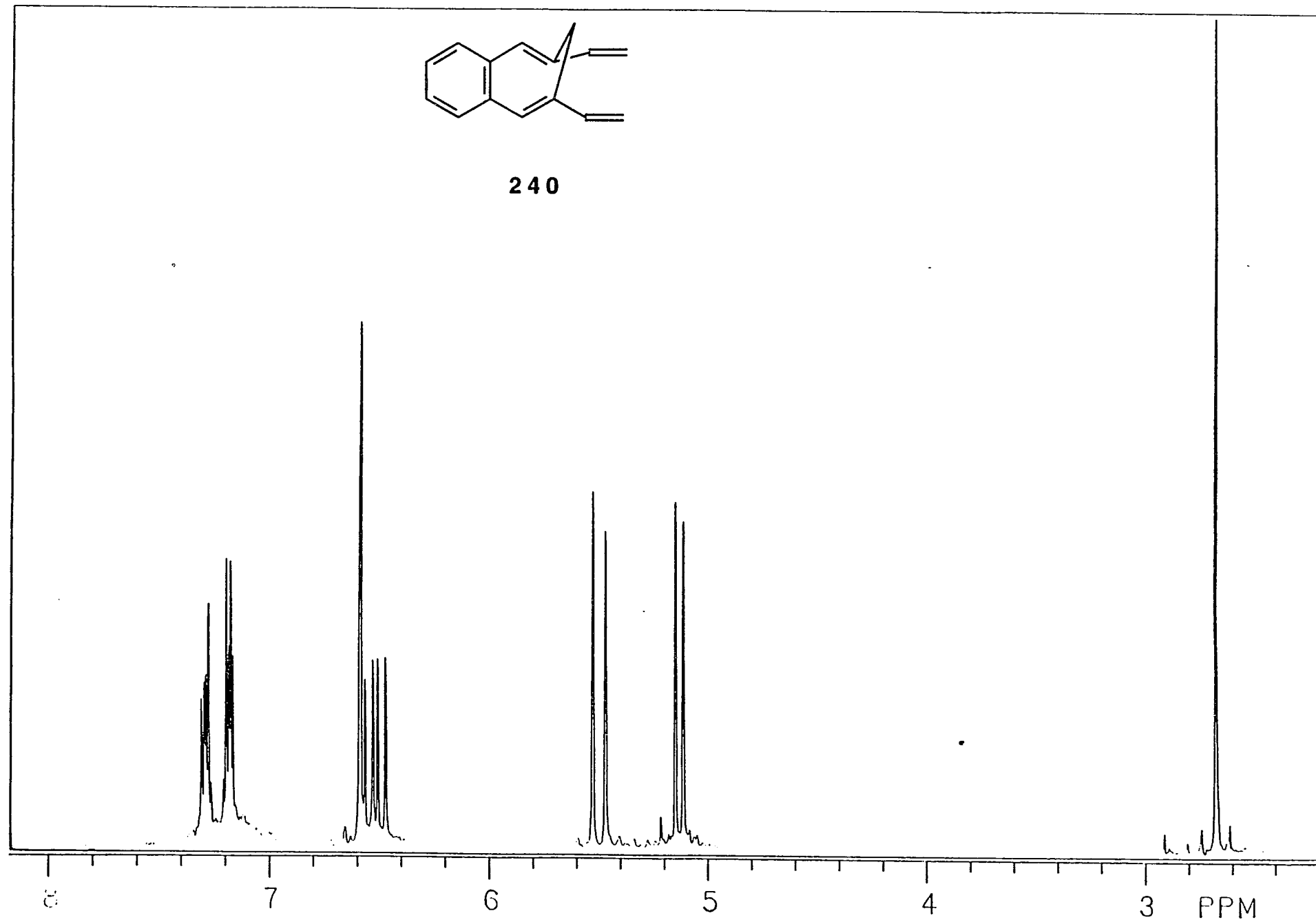


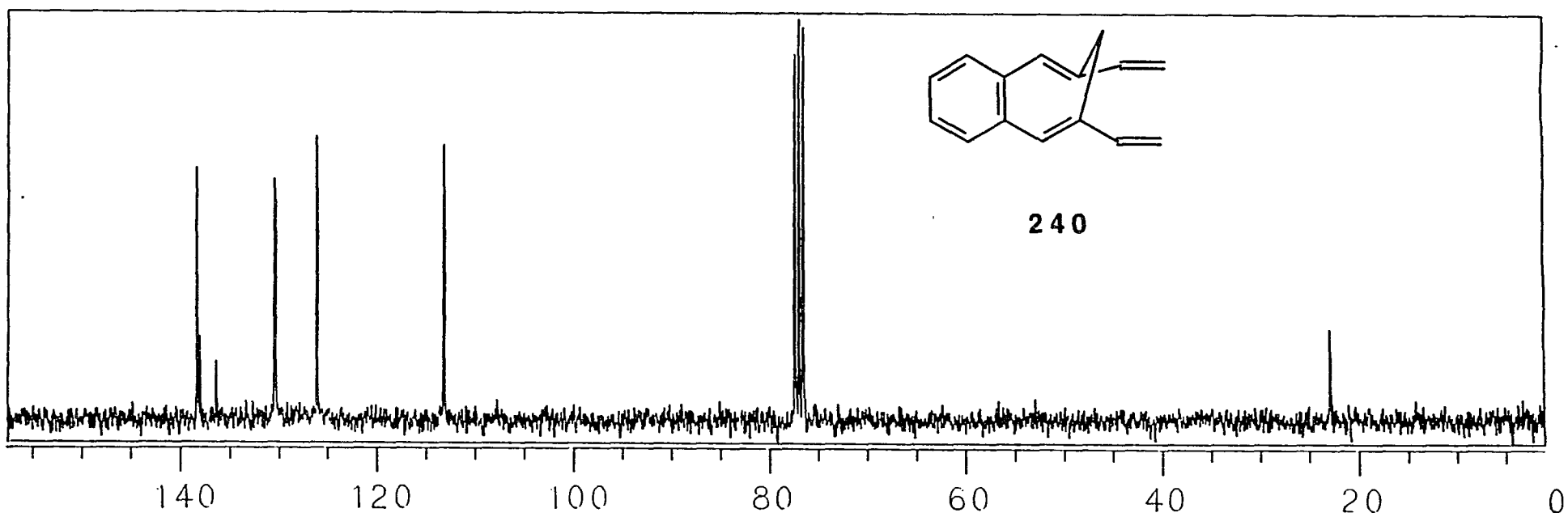


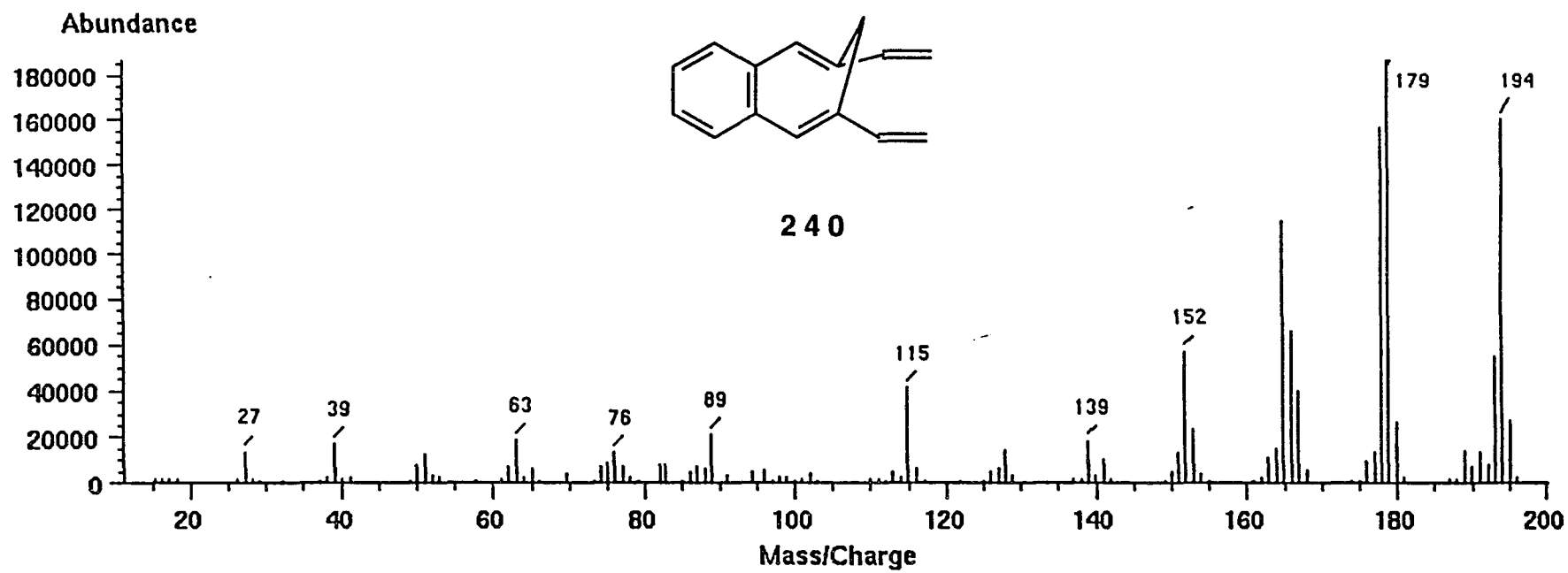
95/06/12 21:29
X: 1 scan, 4.0cm-1

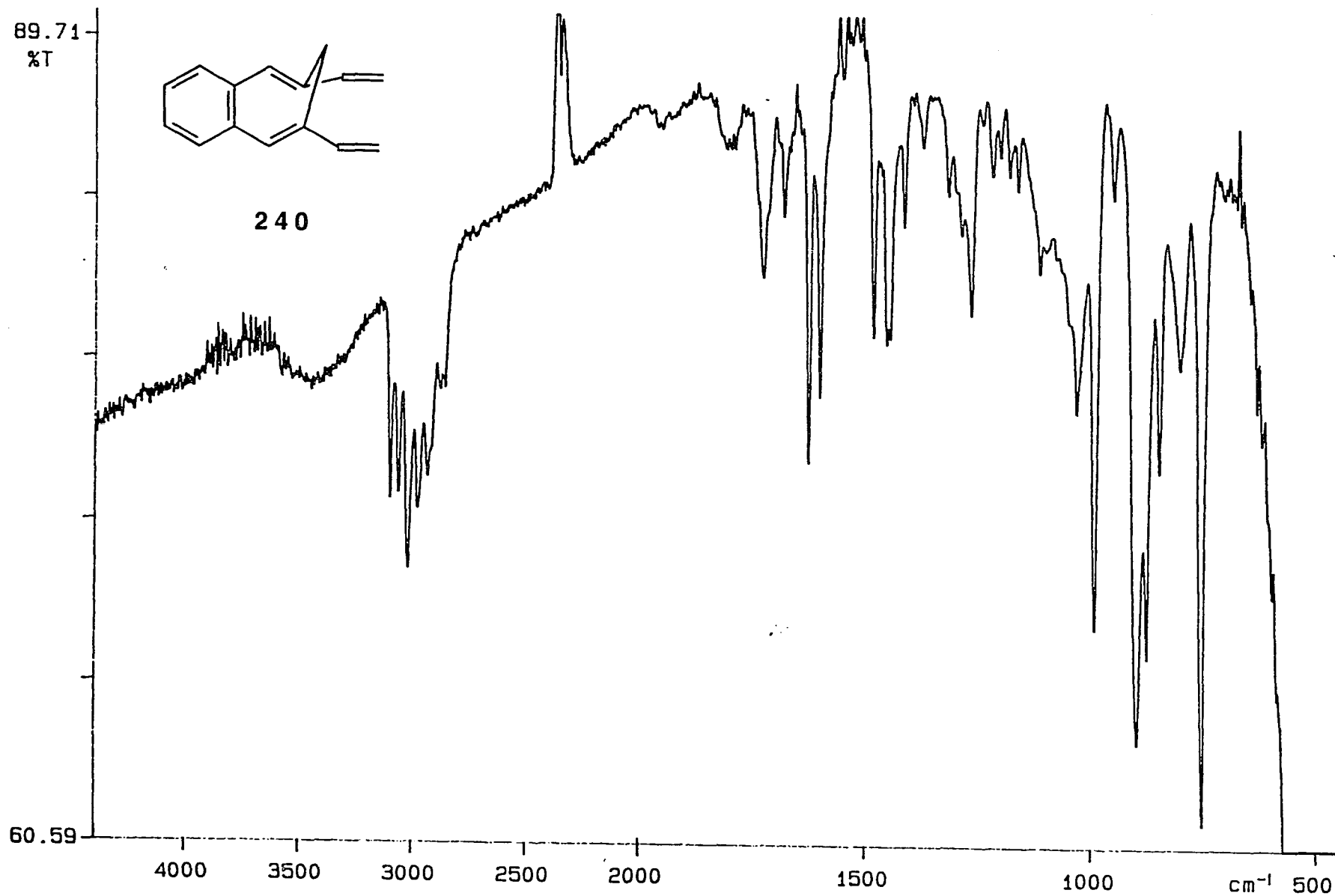


240

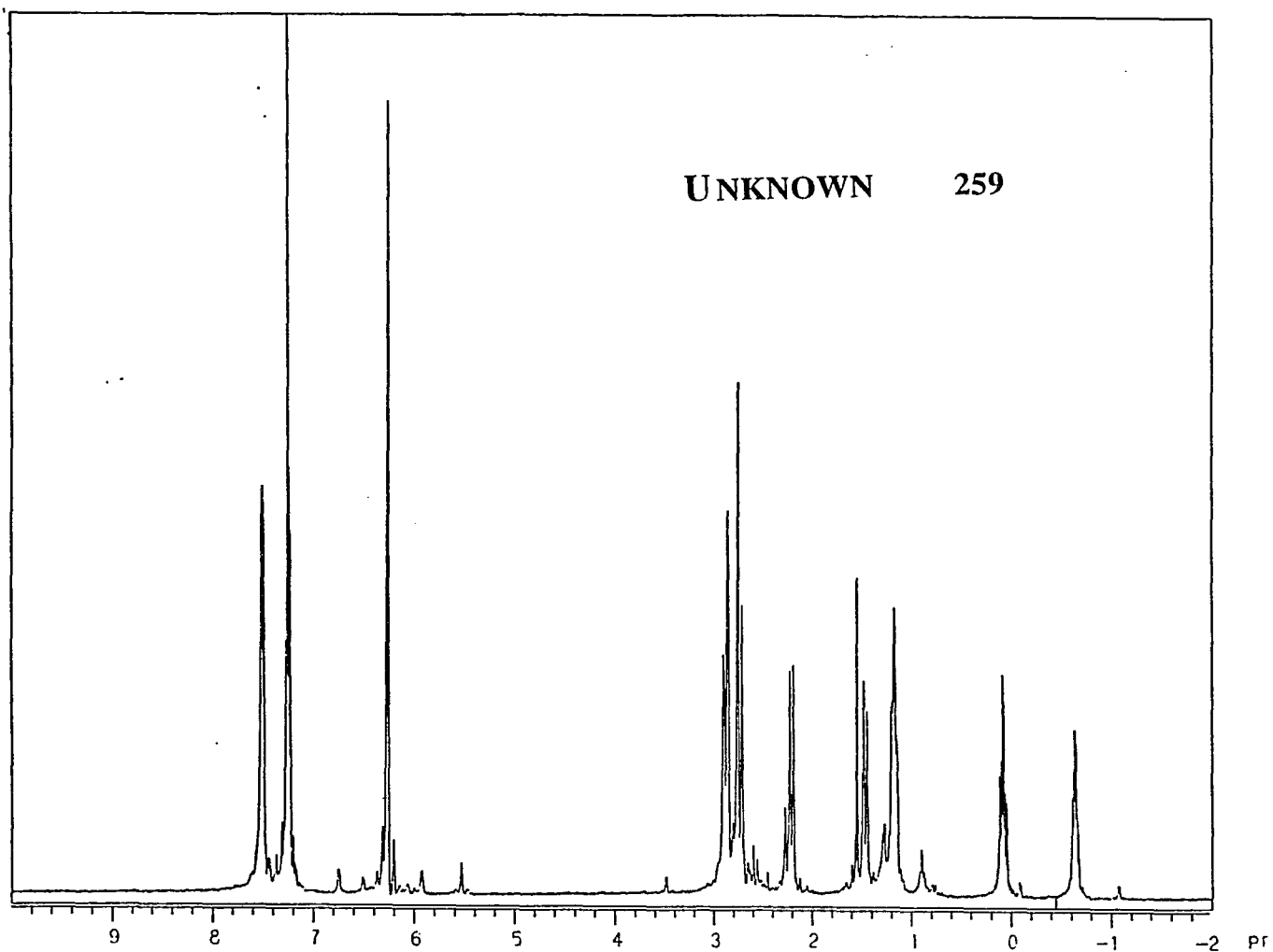


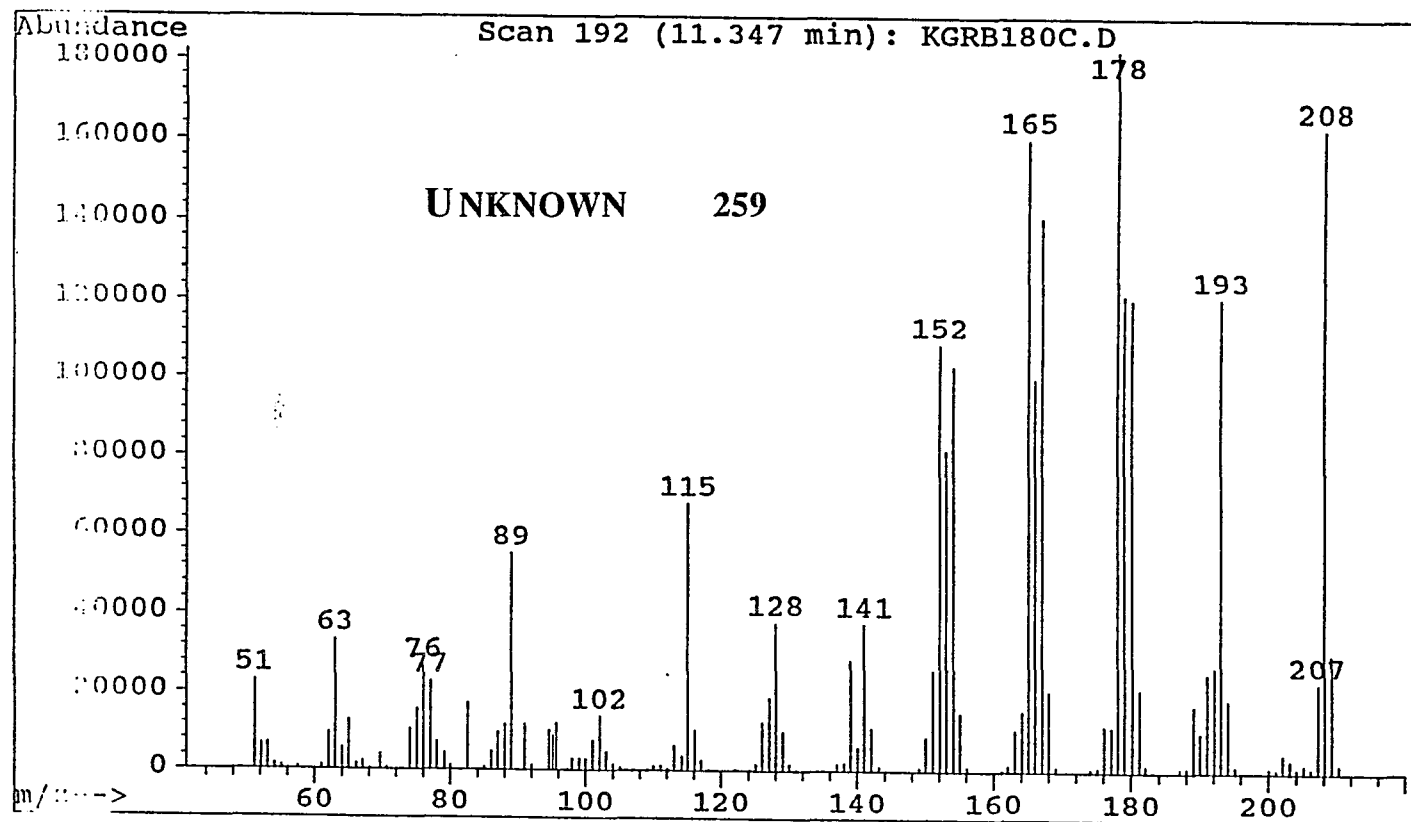




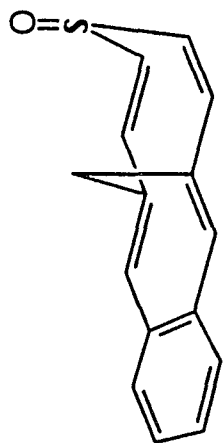


95/06/21 13:27
X: 1 scan, 4.0cm⁻¹

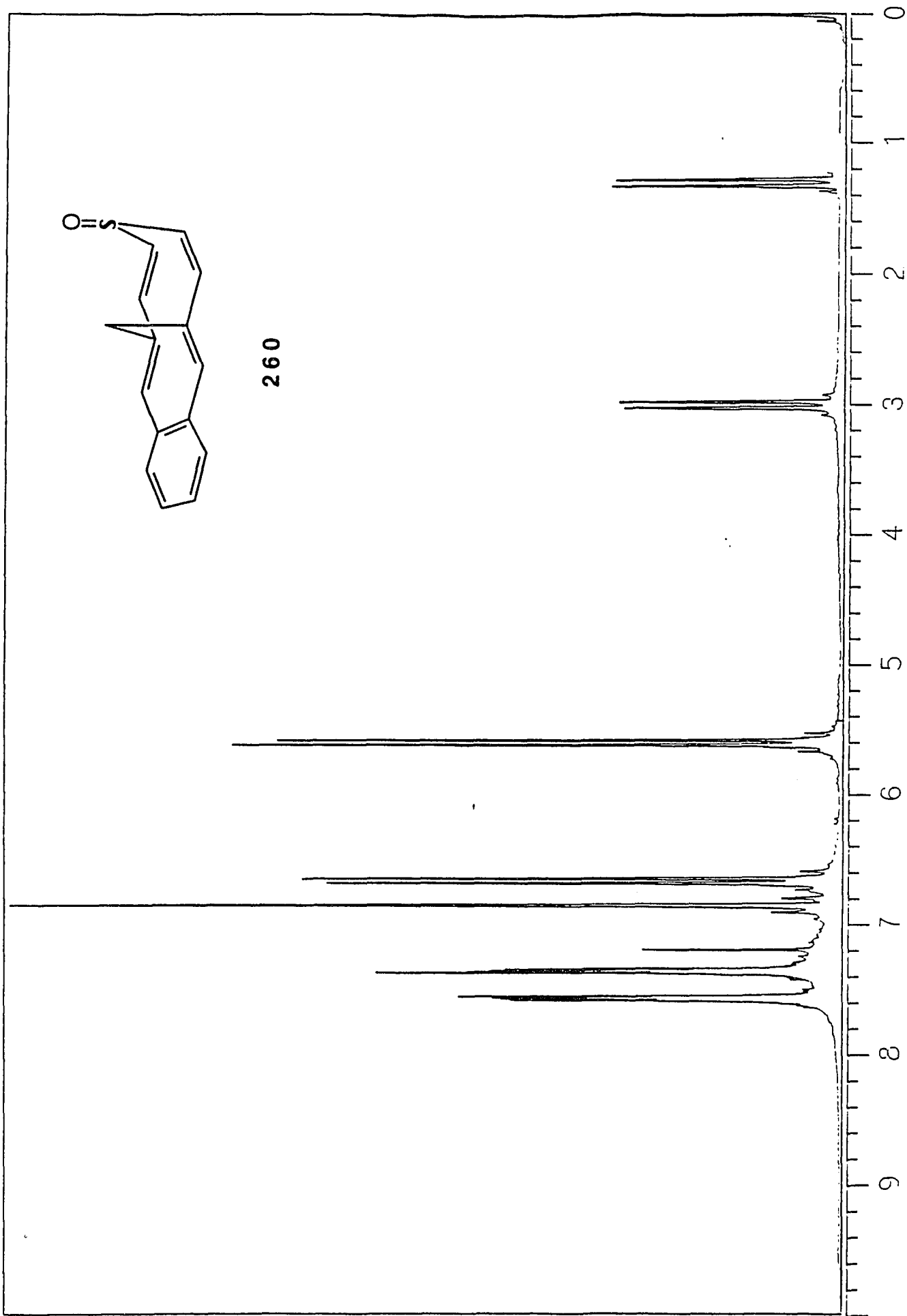


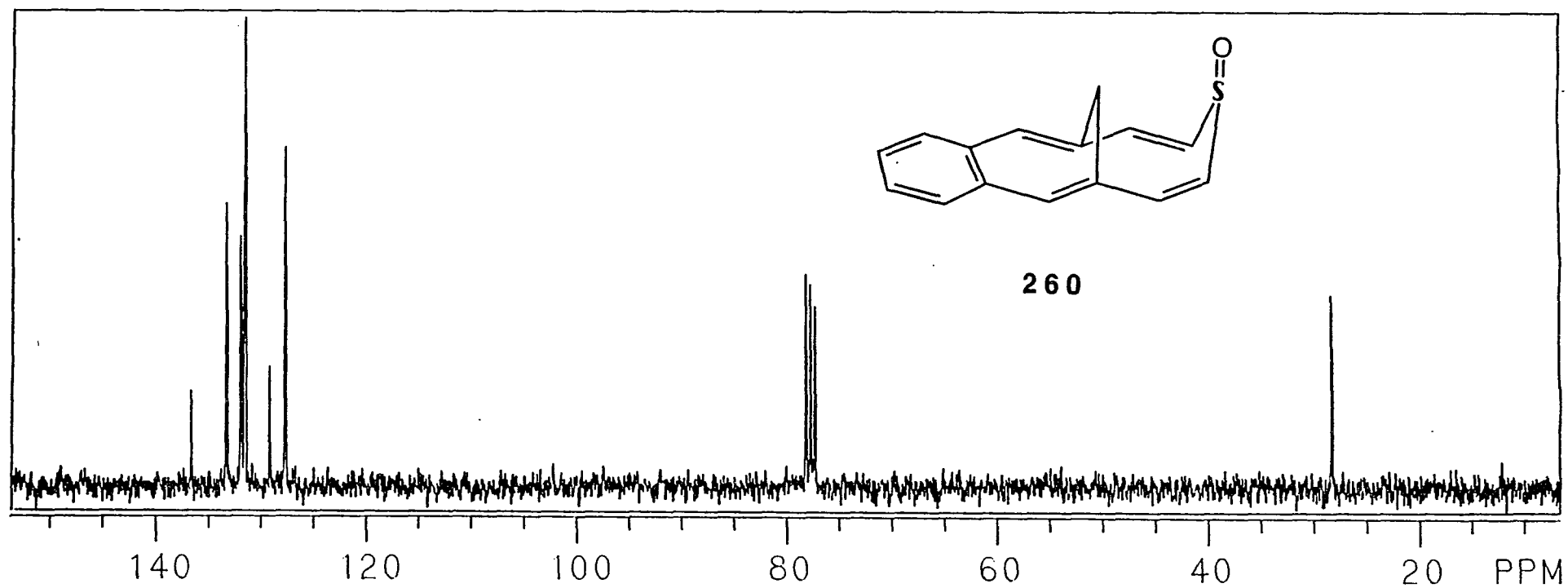


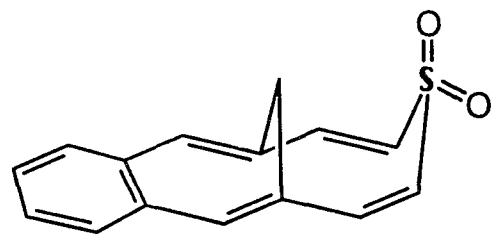
412



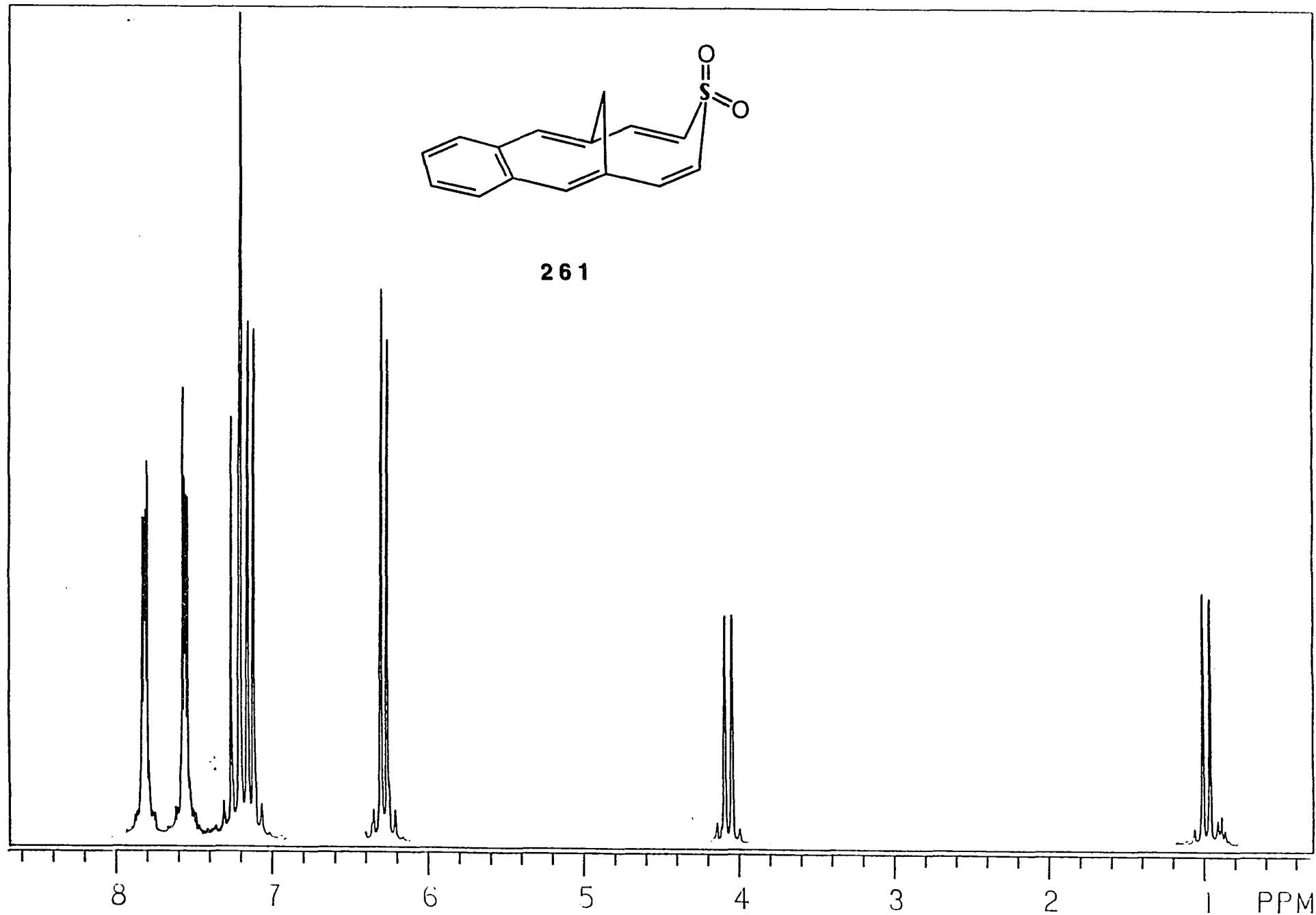
260



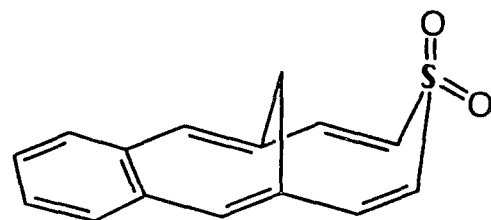




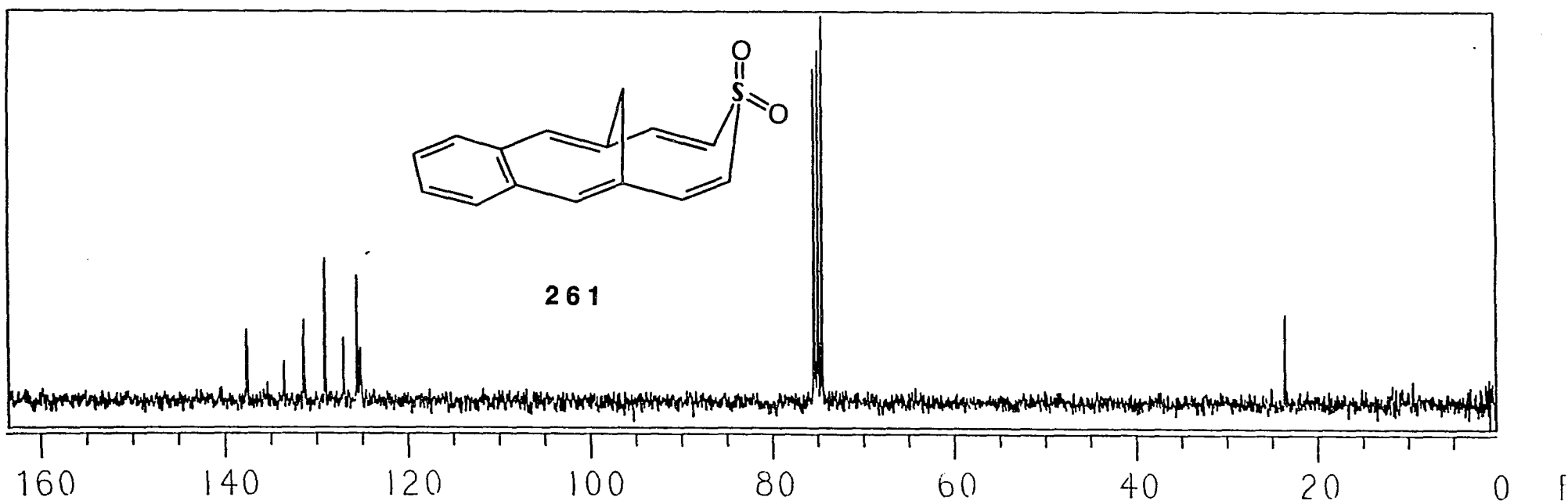
261

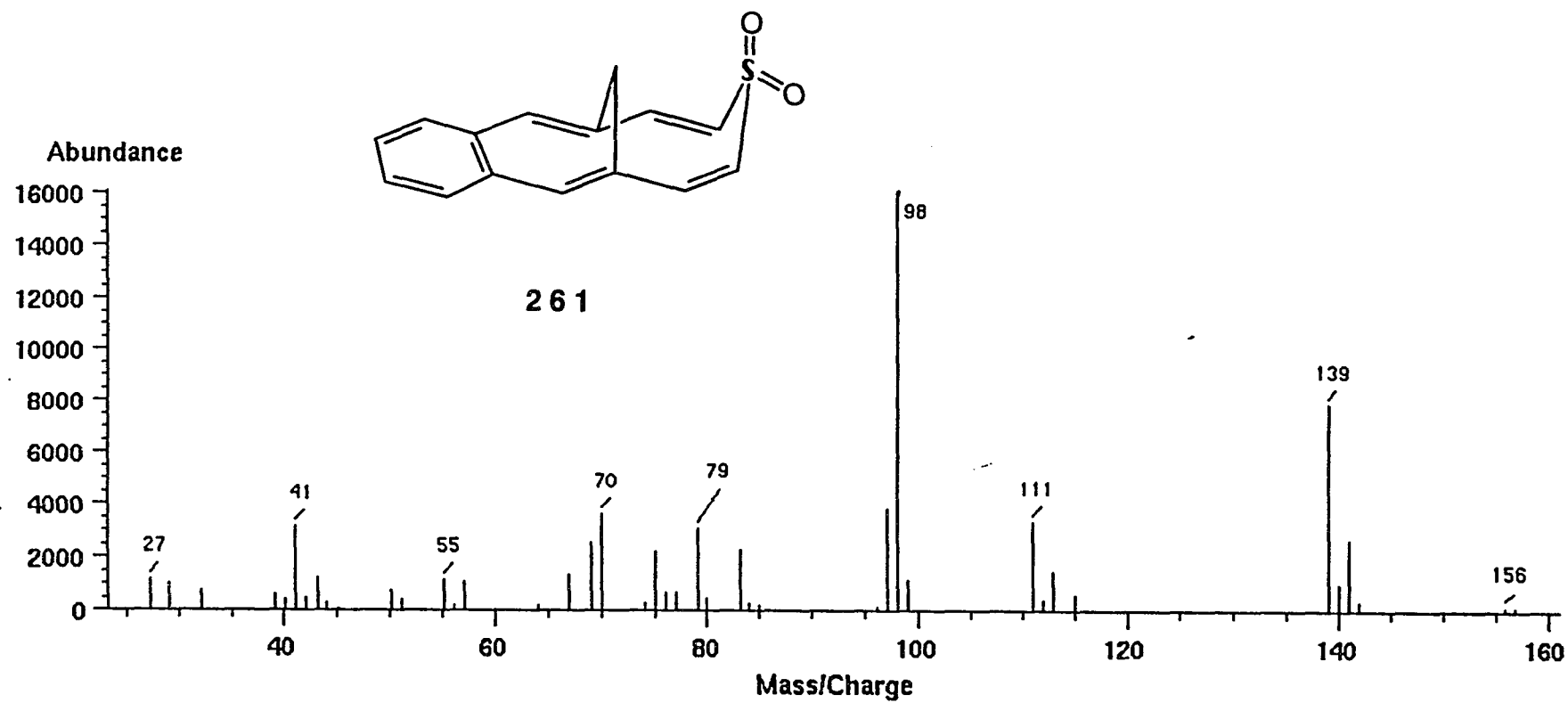


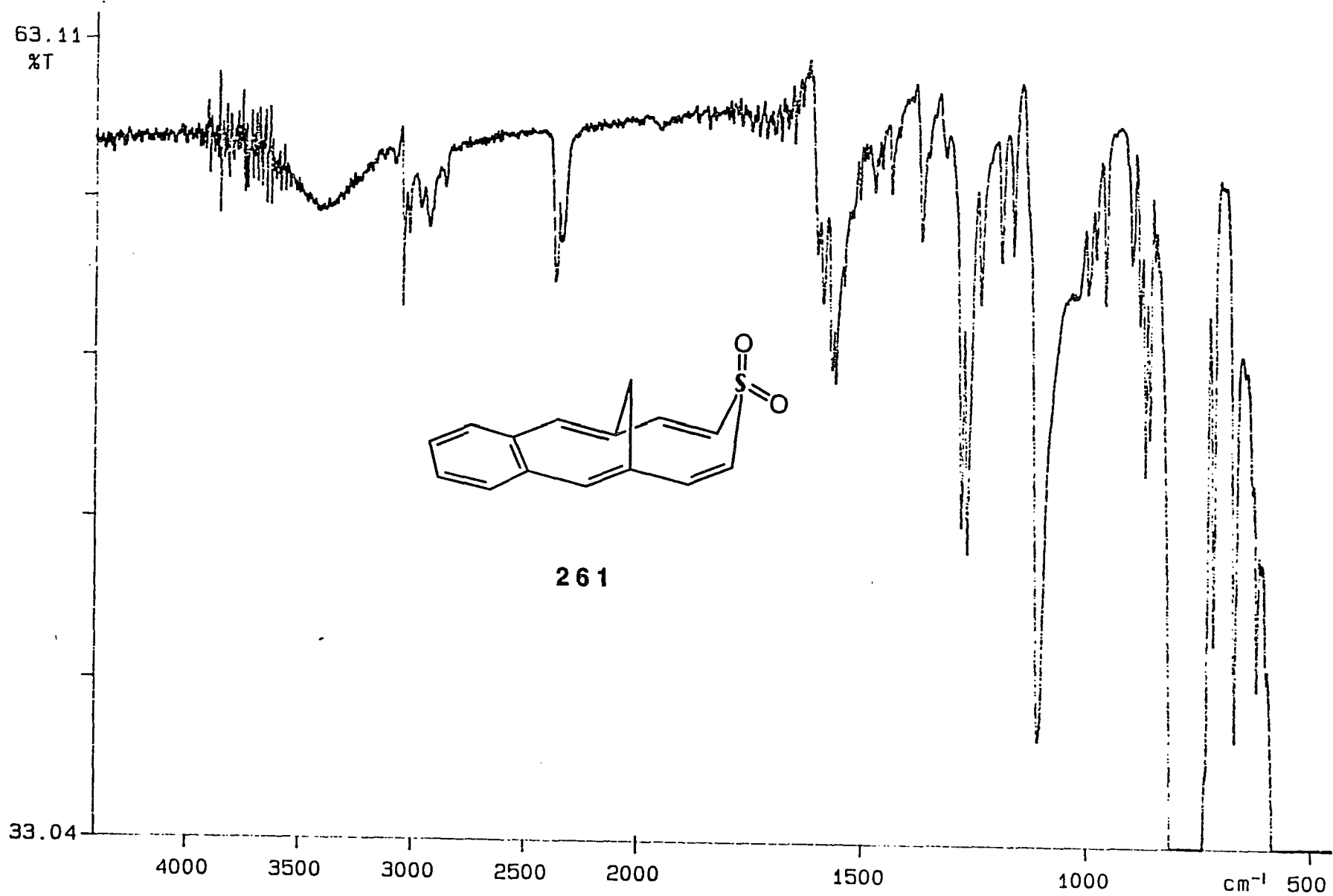
4.14
4.14



261

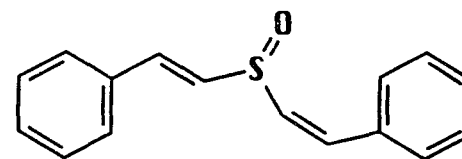




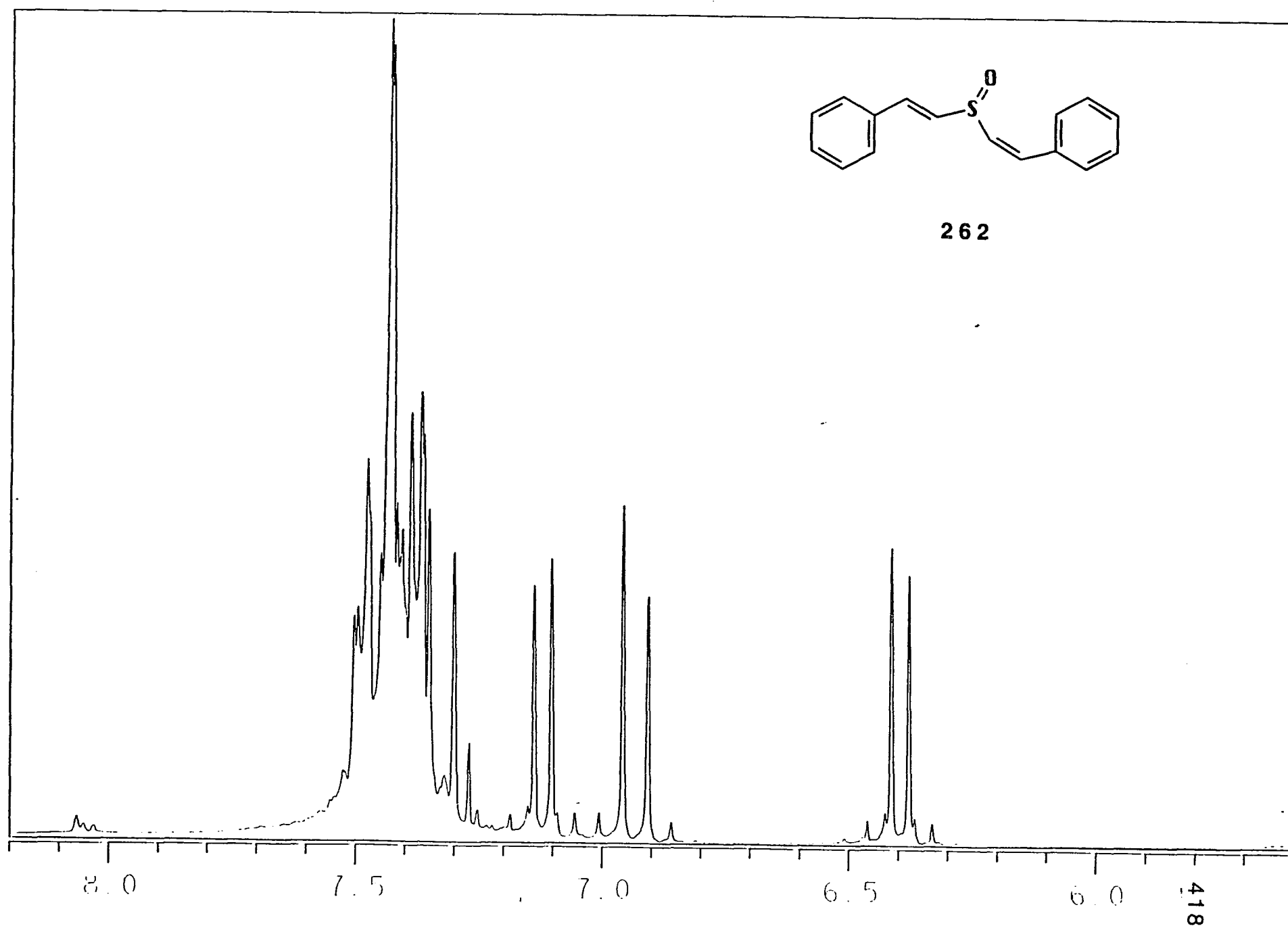


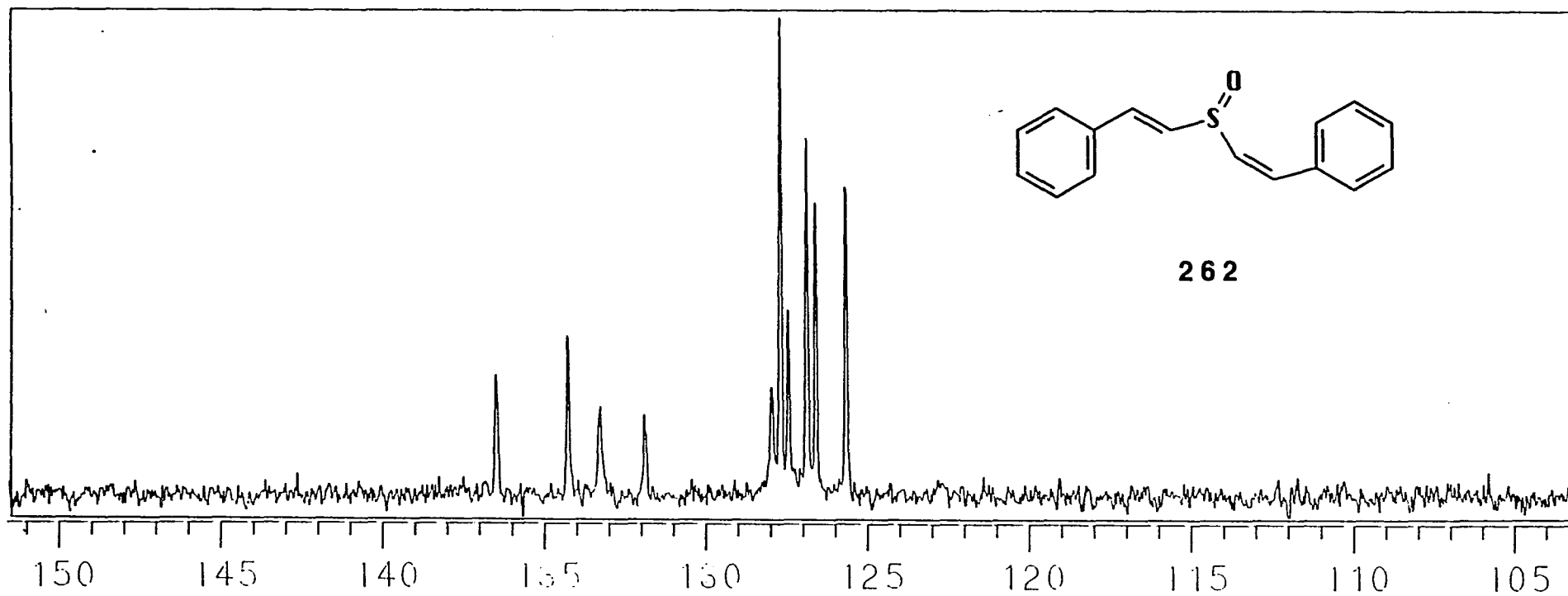
95/10/20 09:04

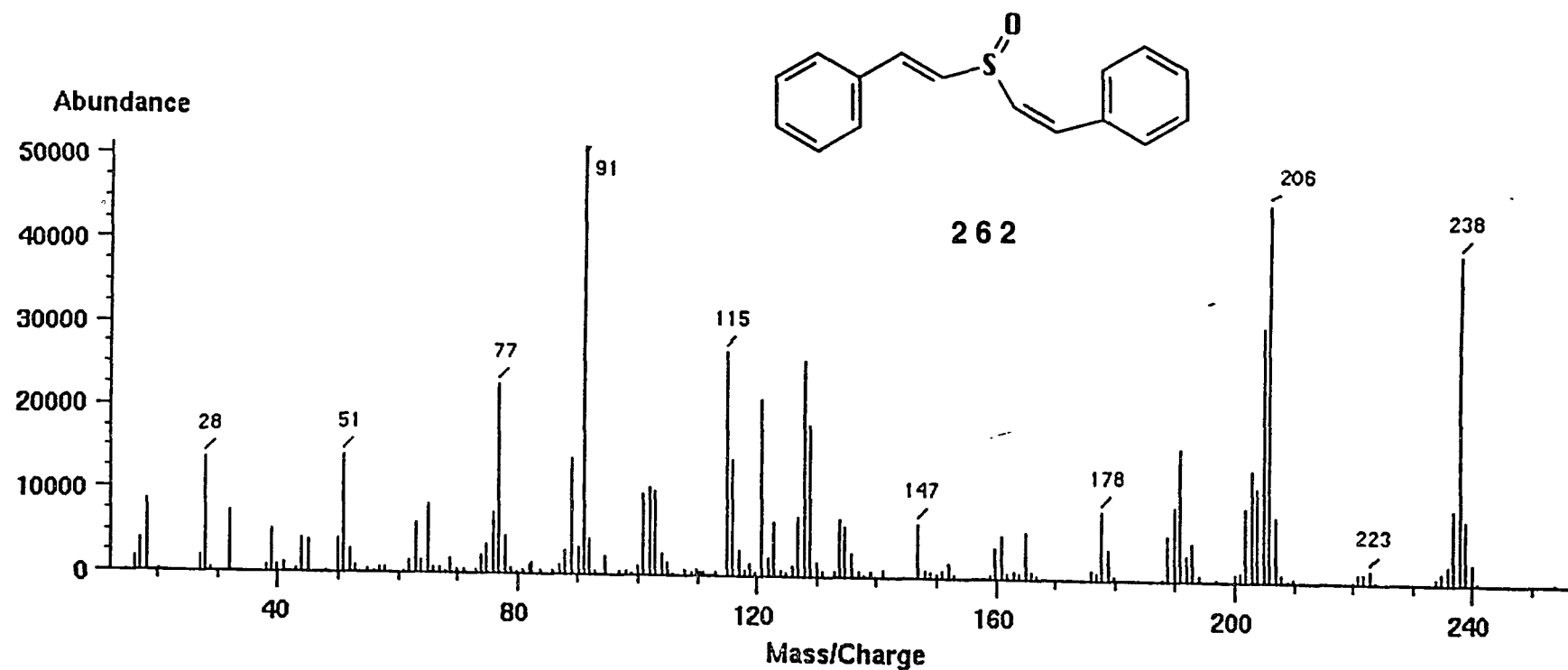
X: 1 scan, 4.0cm⁻¹, flat

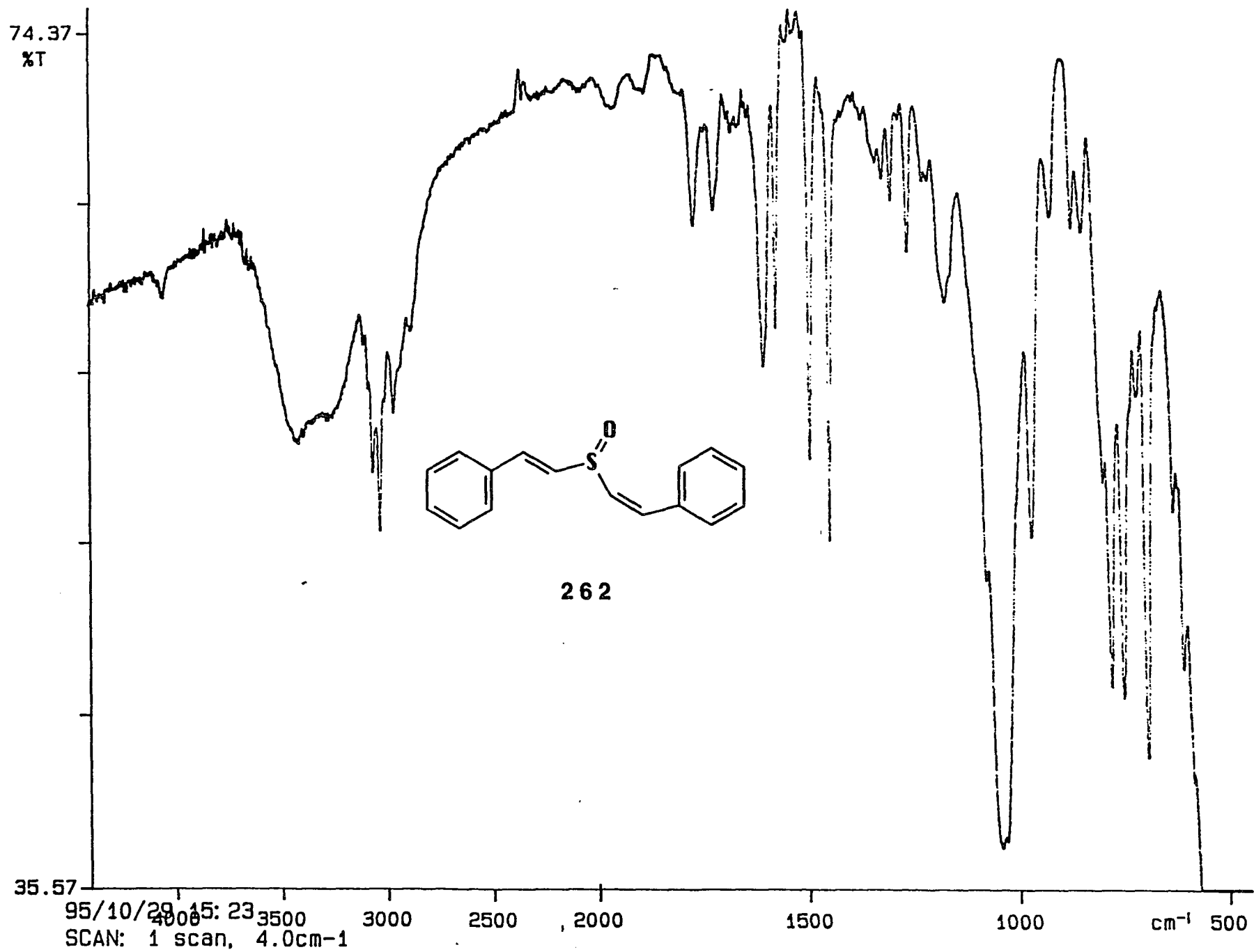


262



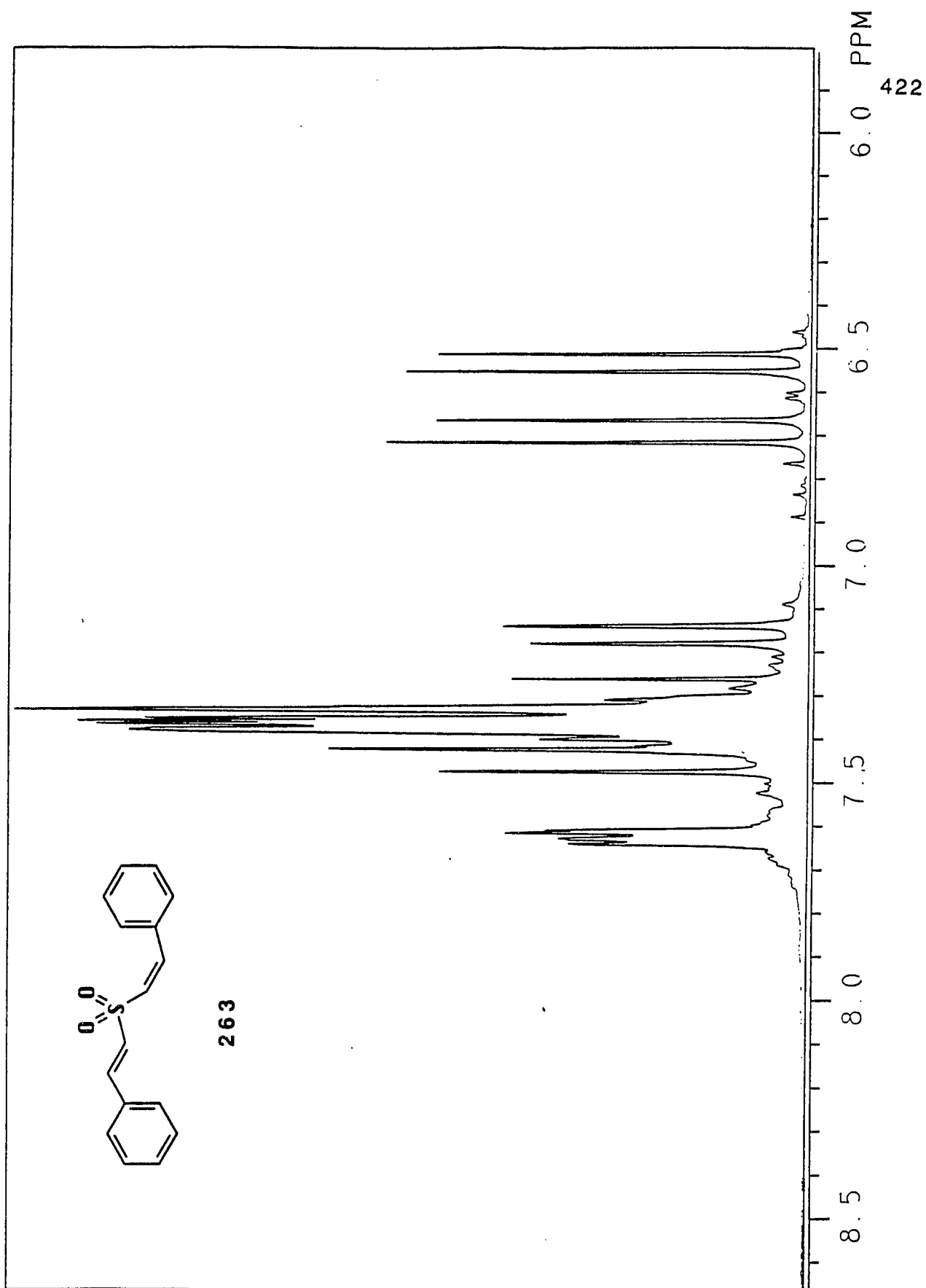


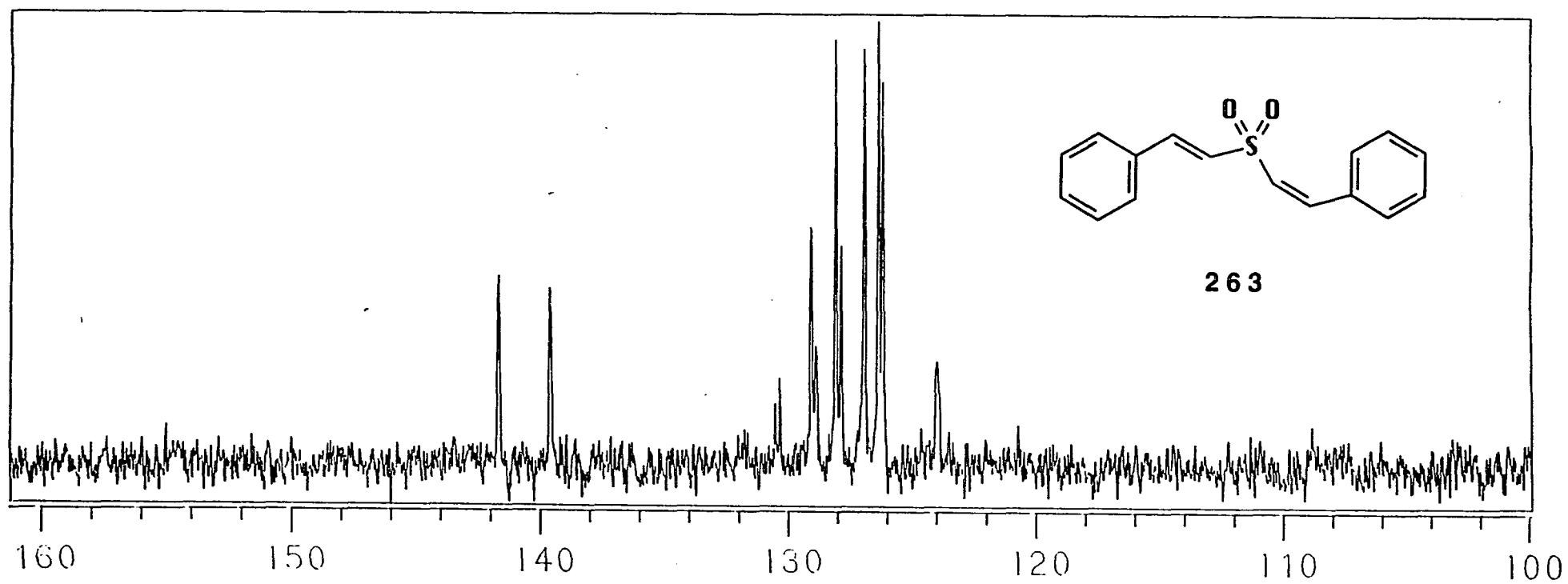


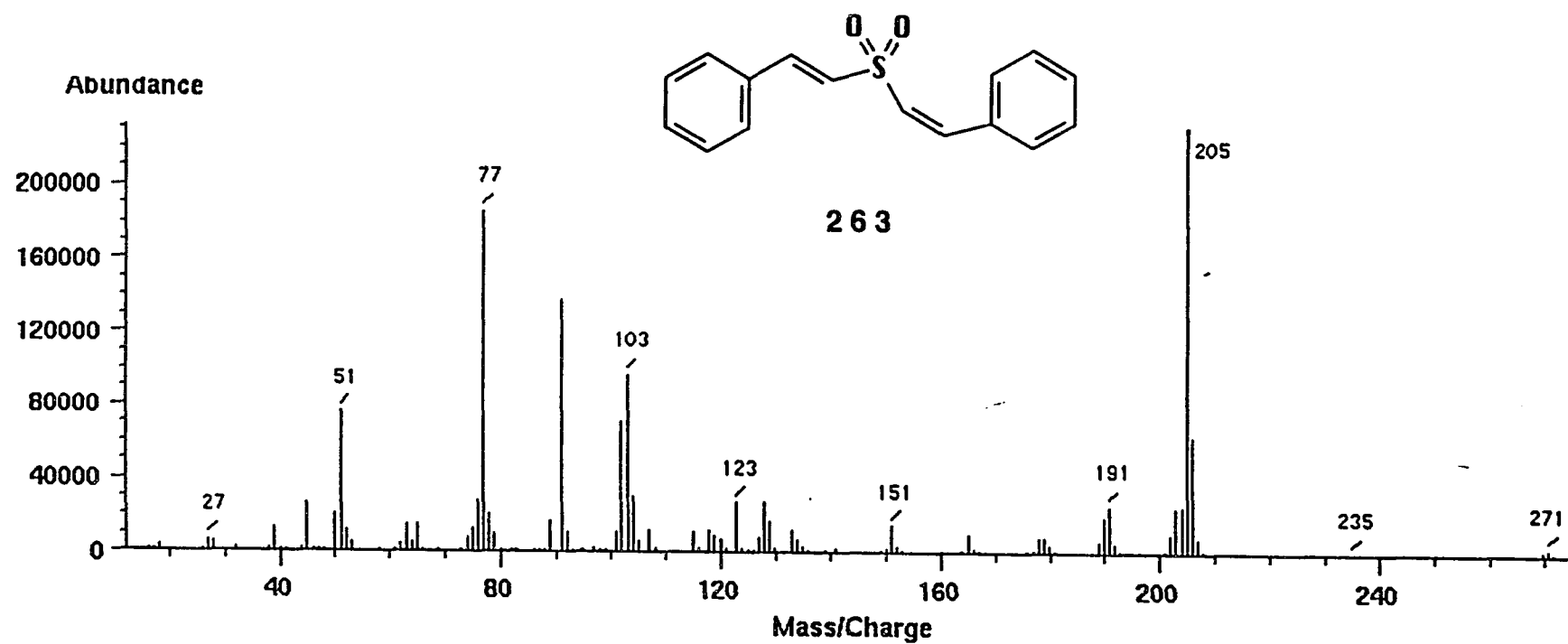


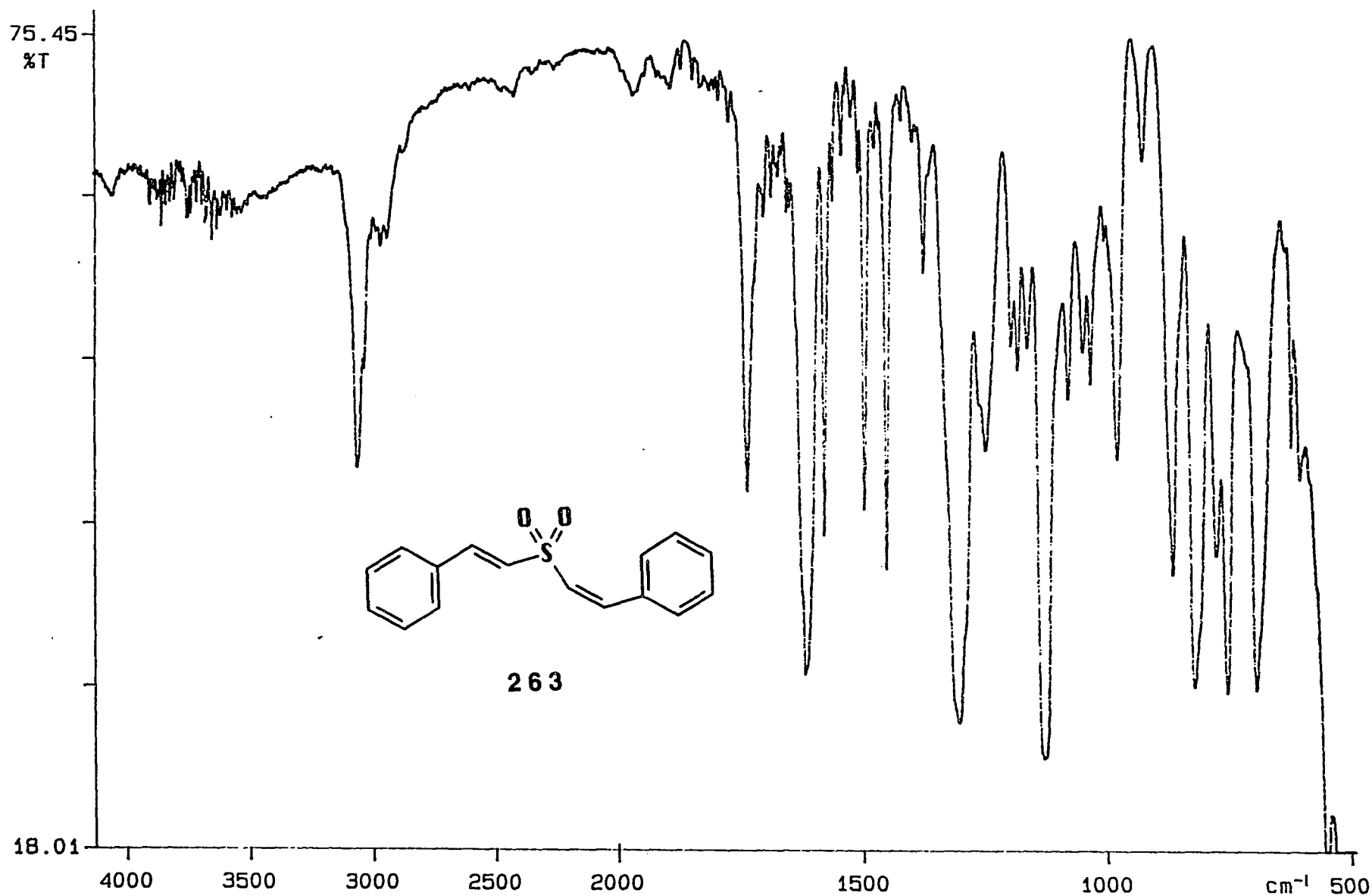


263



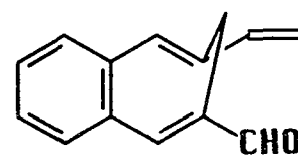




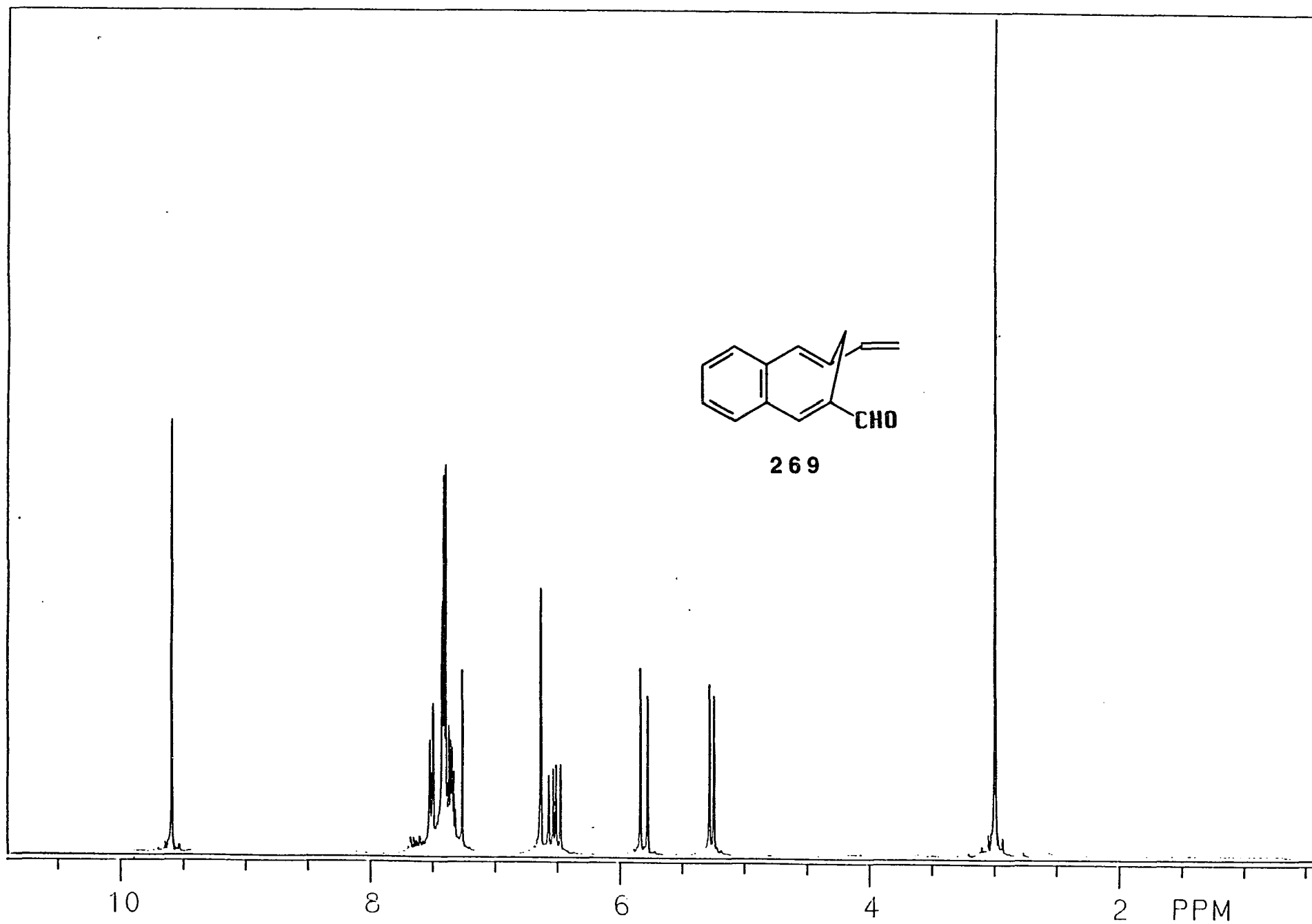


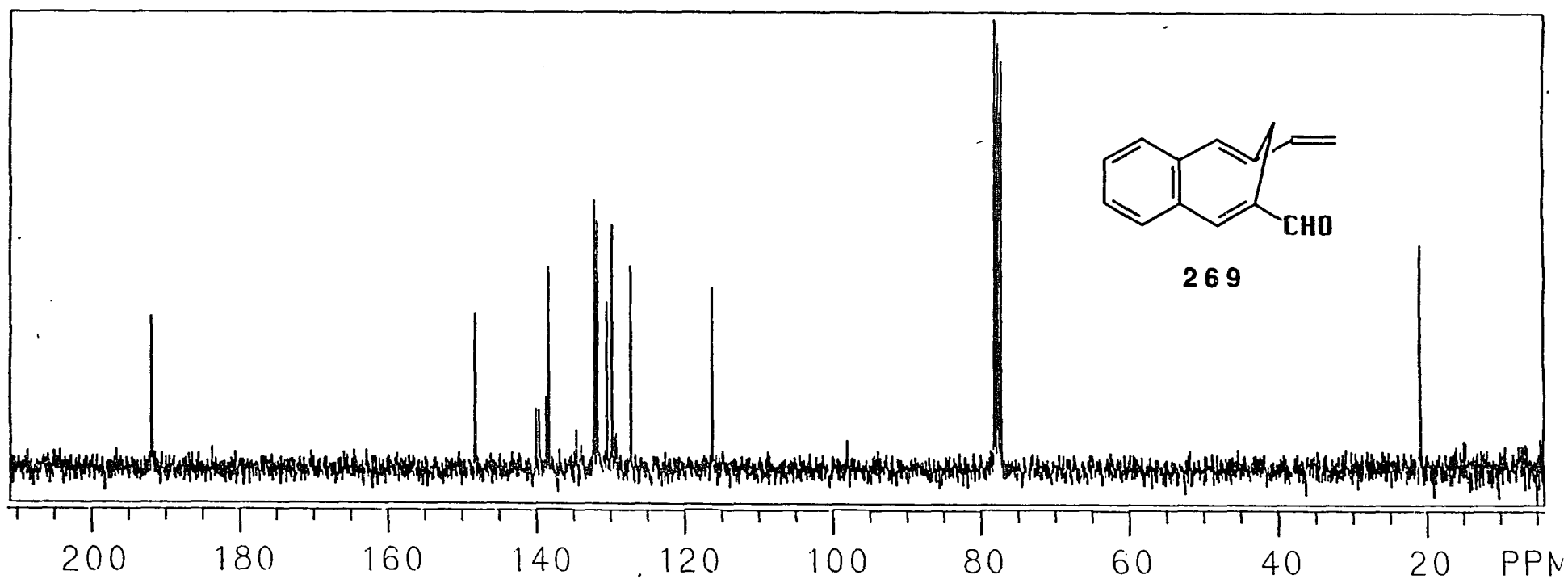
95/10/24 10:56
X: 1 scan, 4.0cm-1

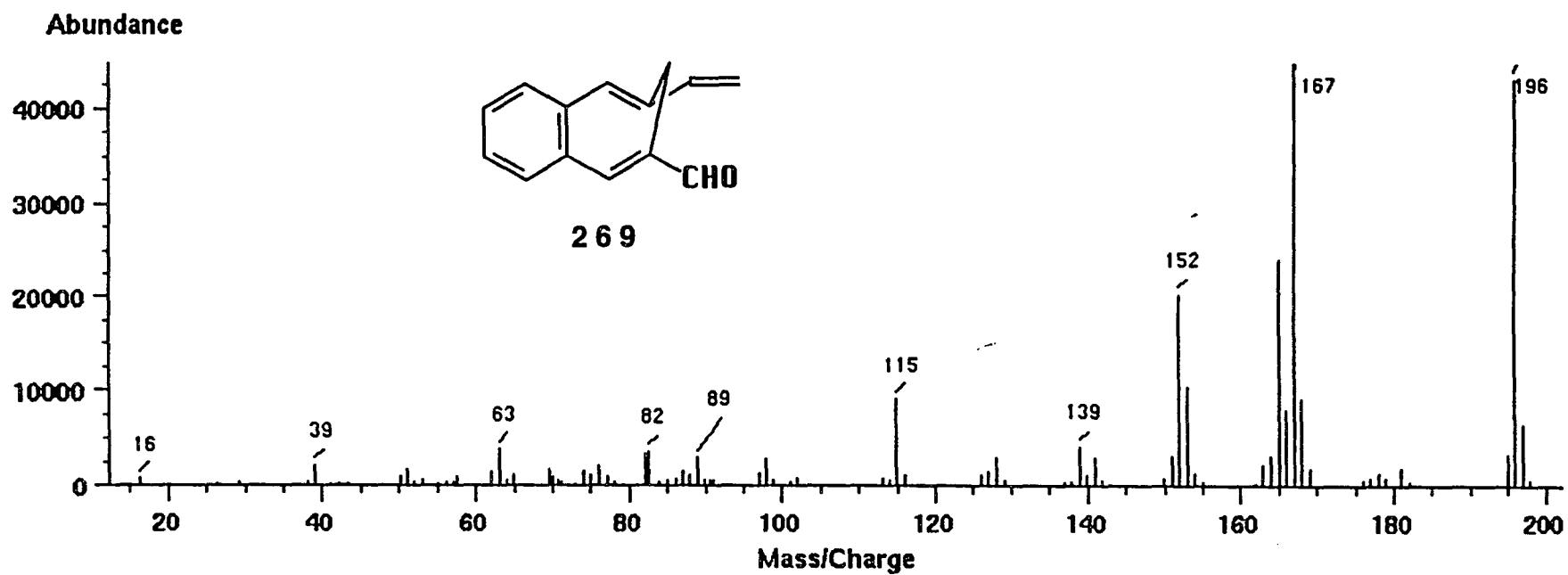
425

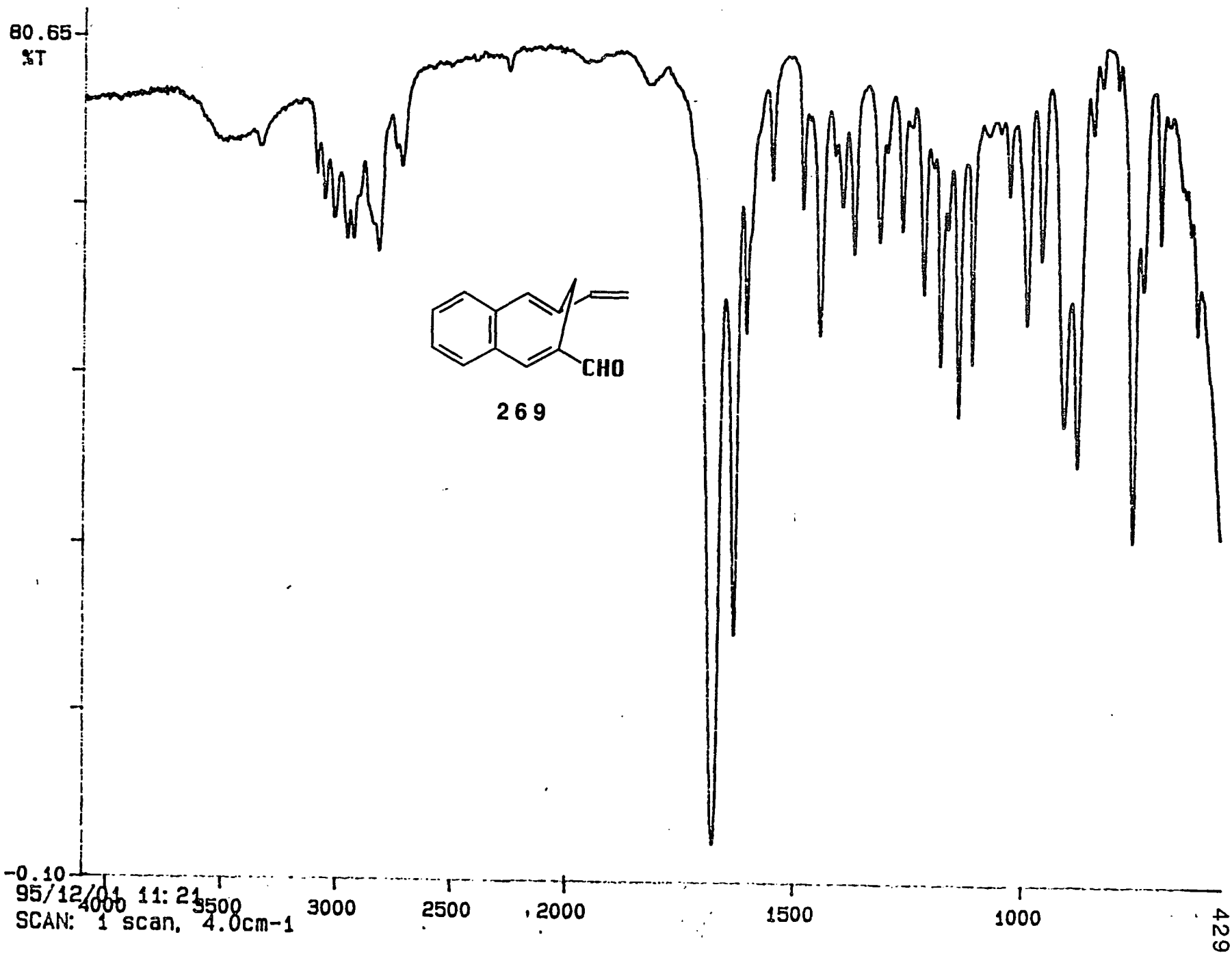


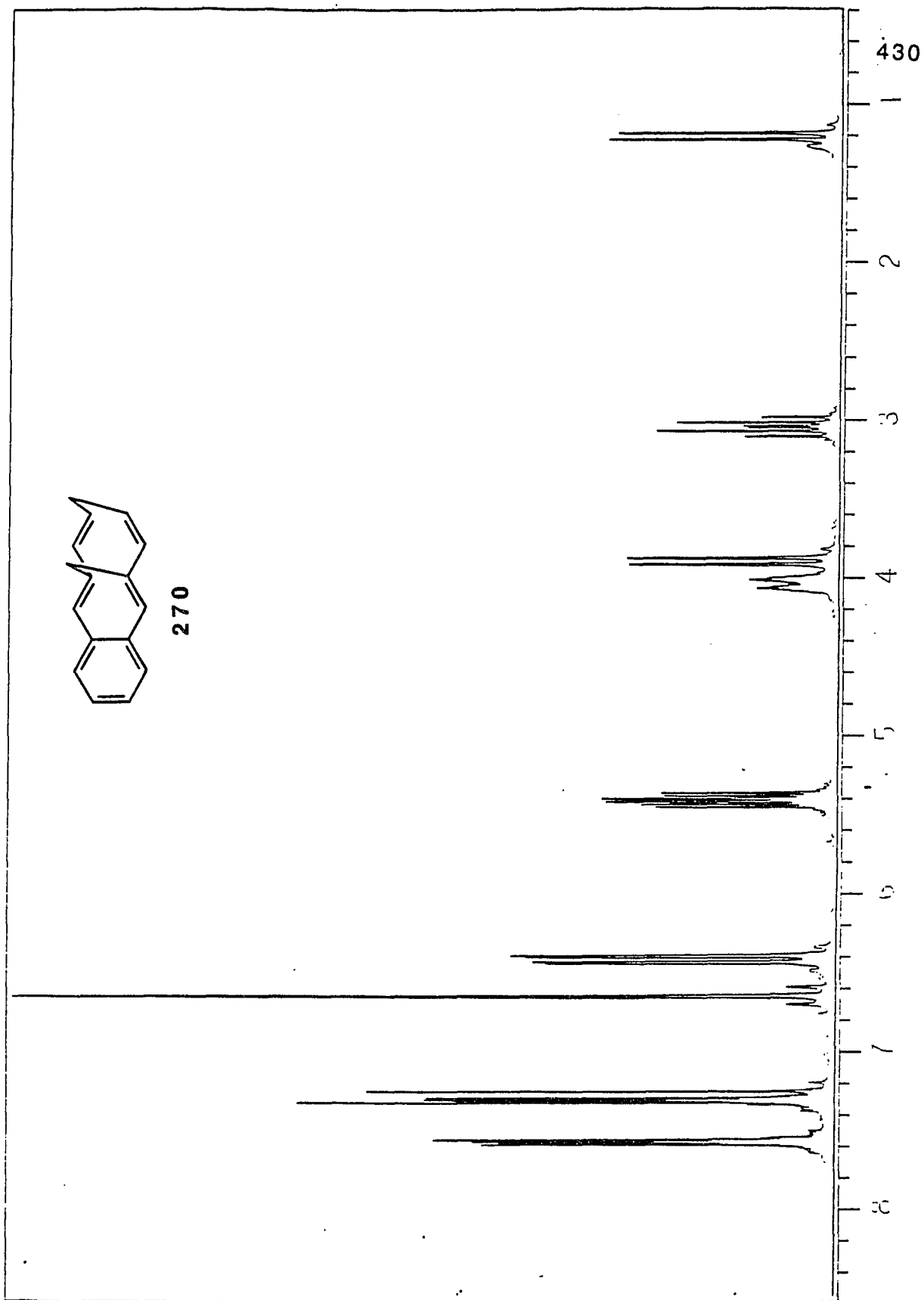
269

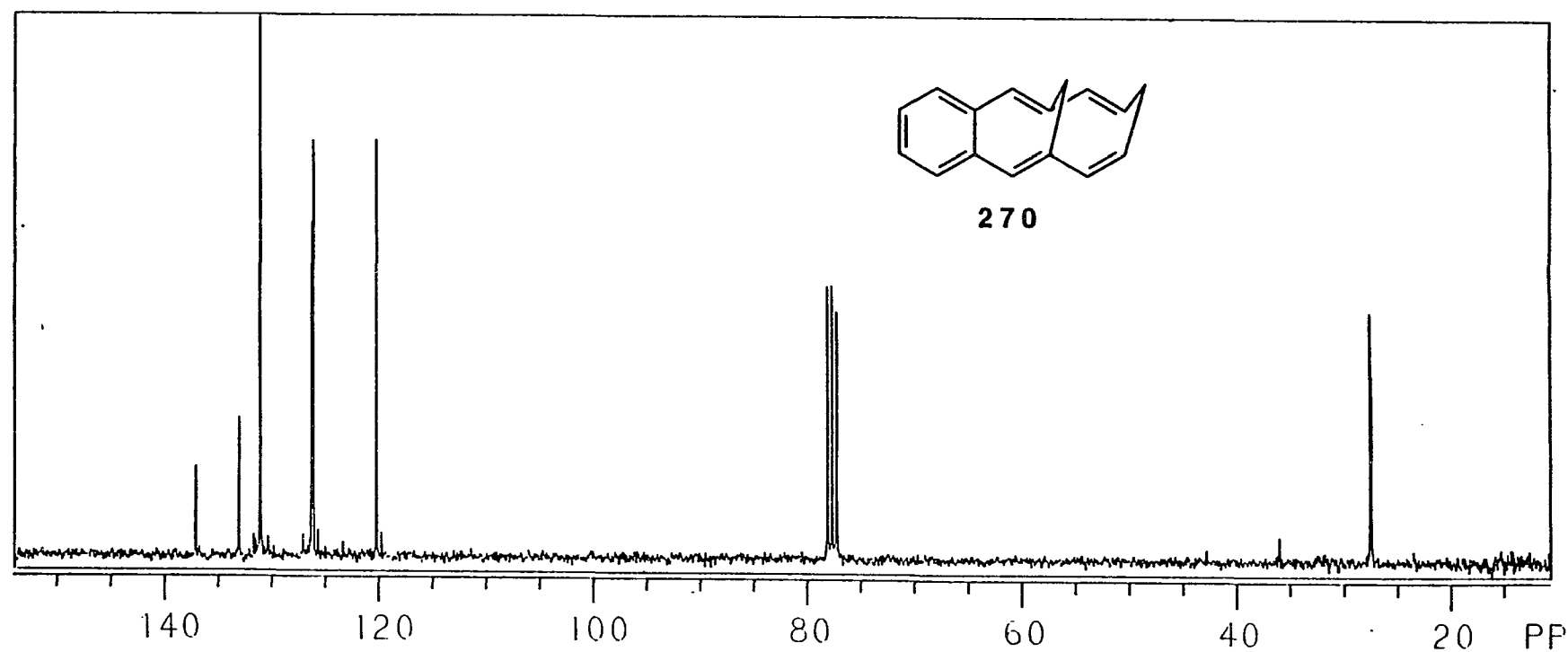




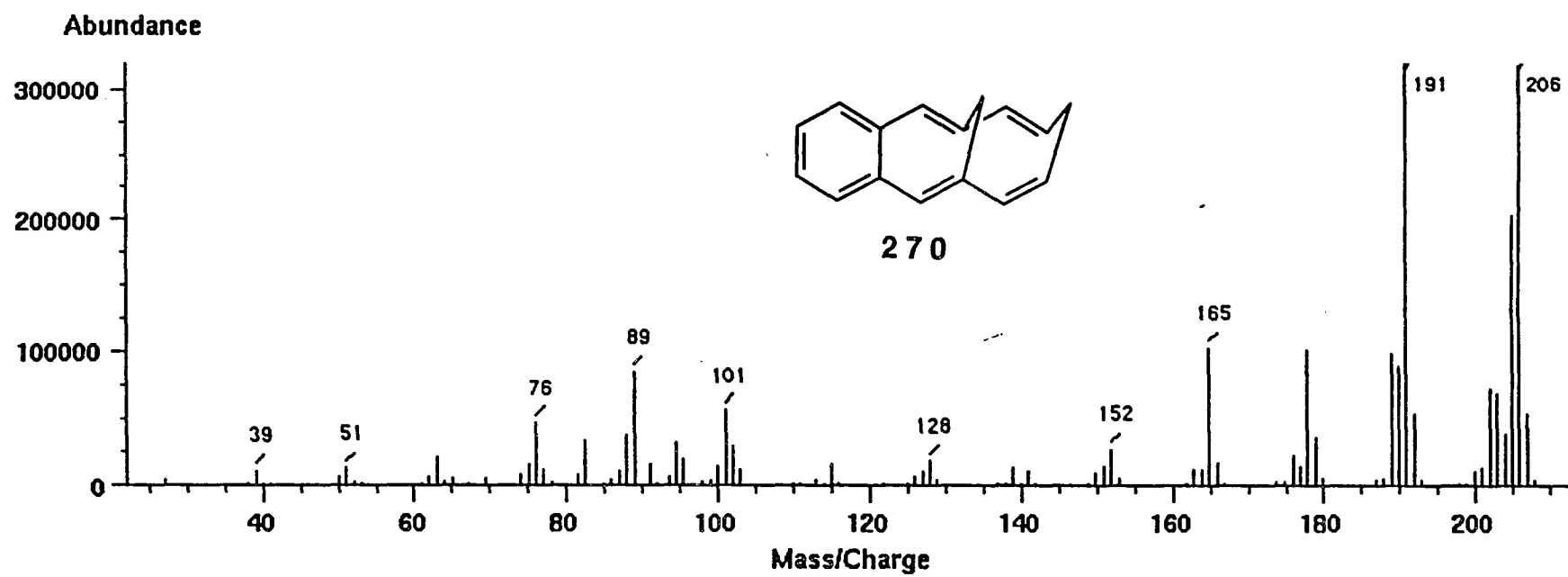


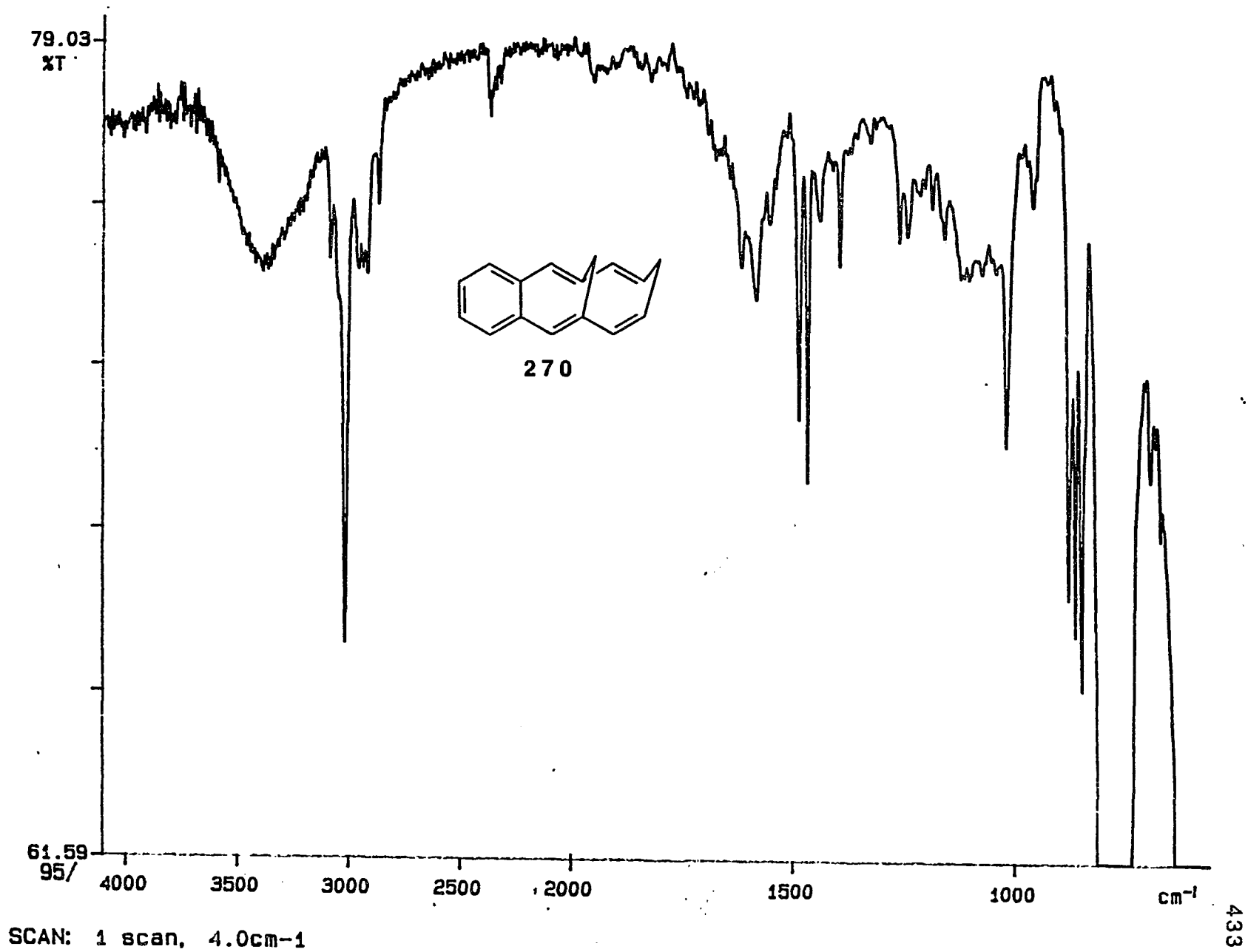


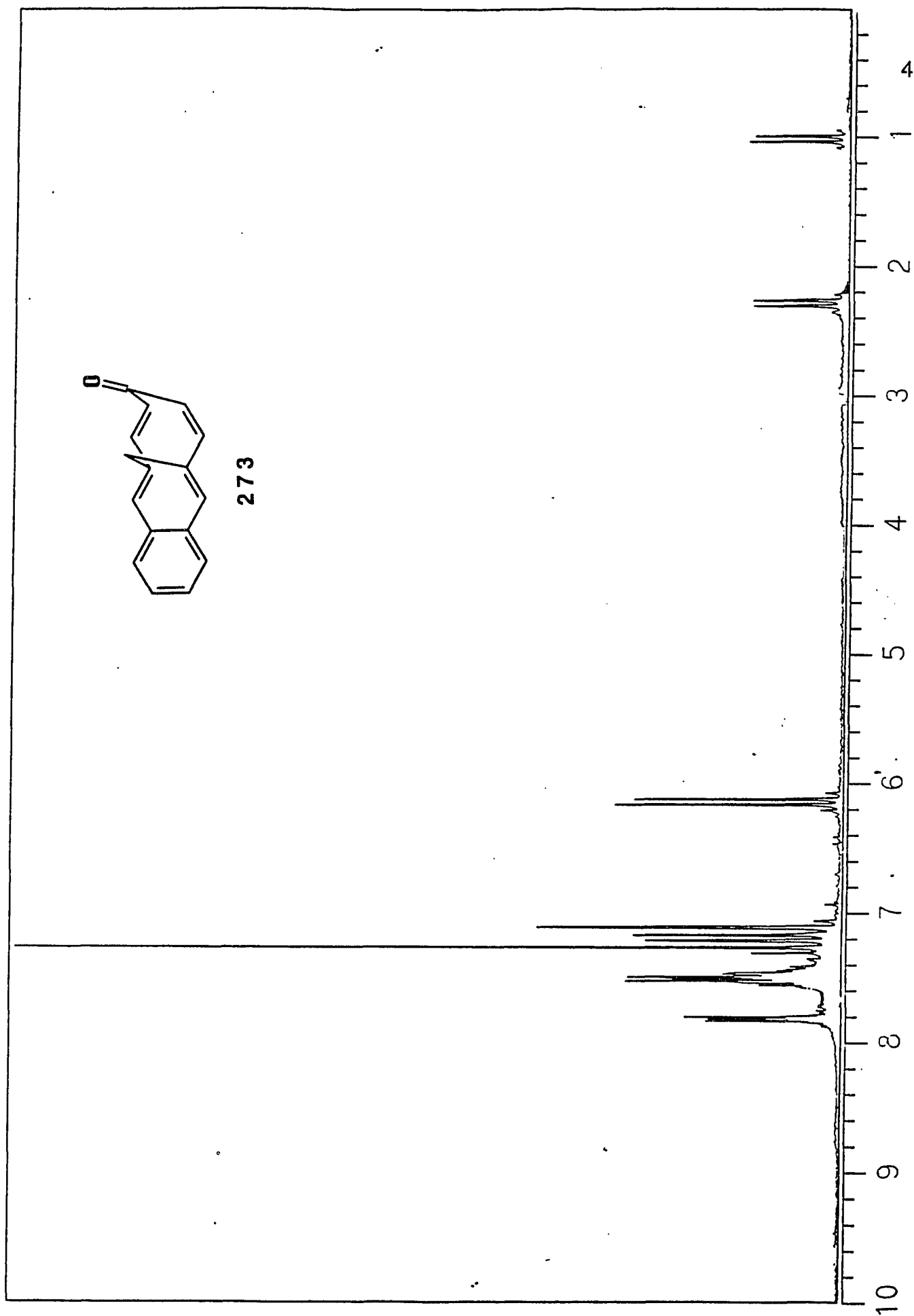


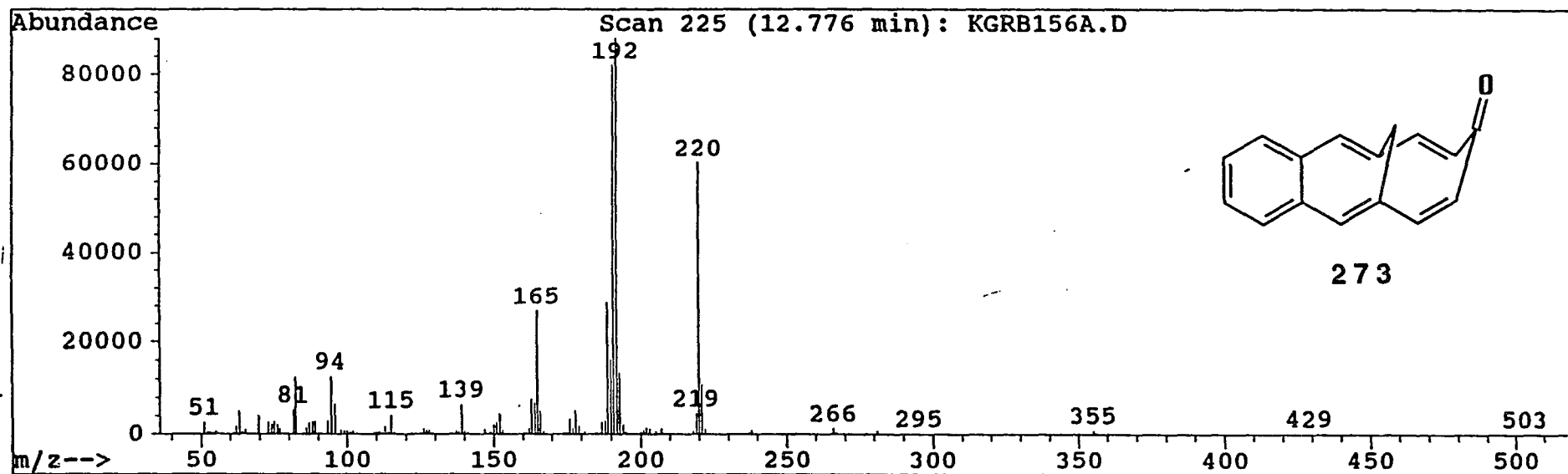


431



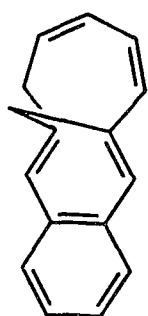




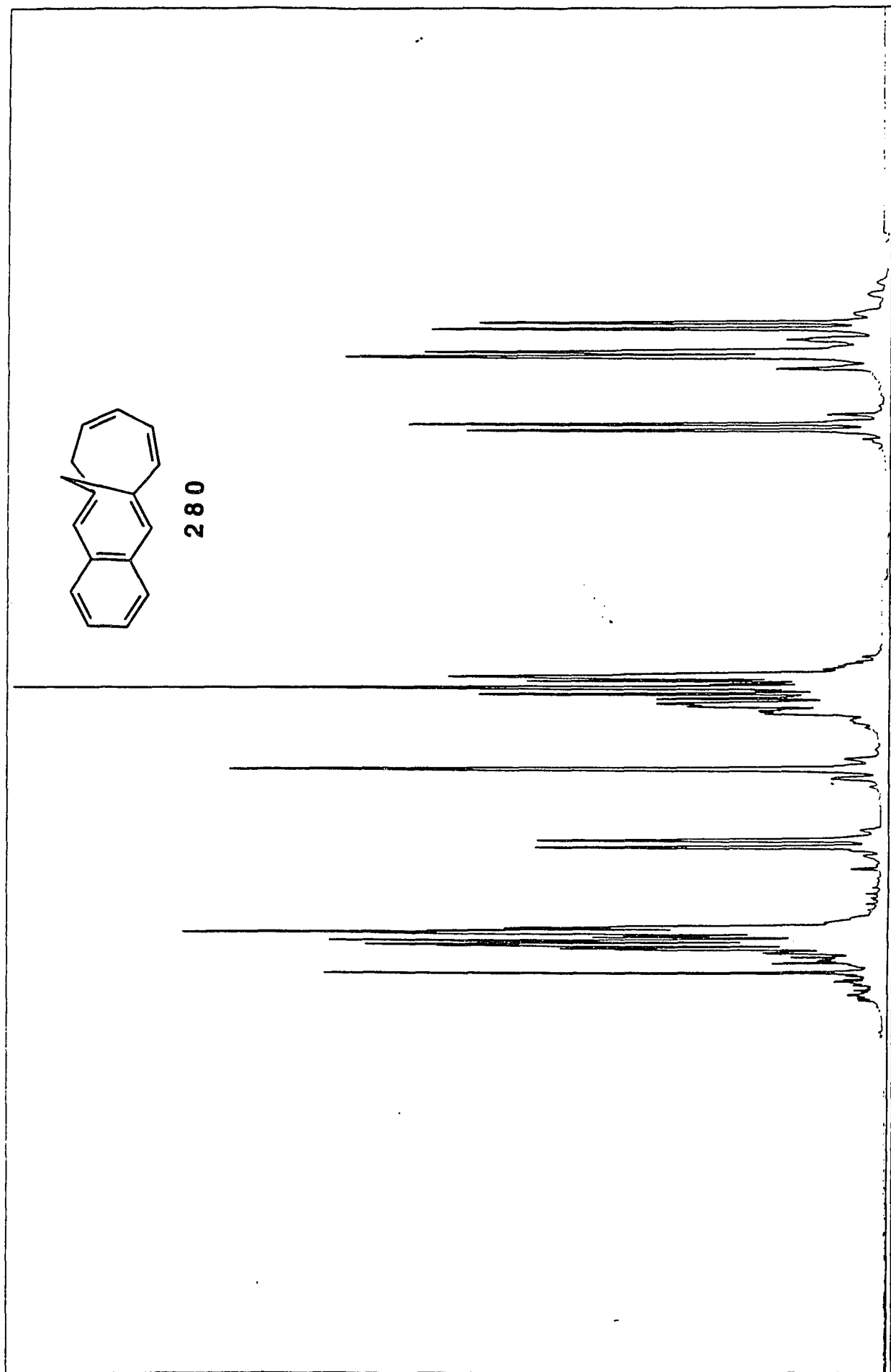


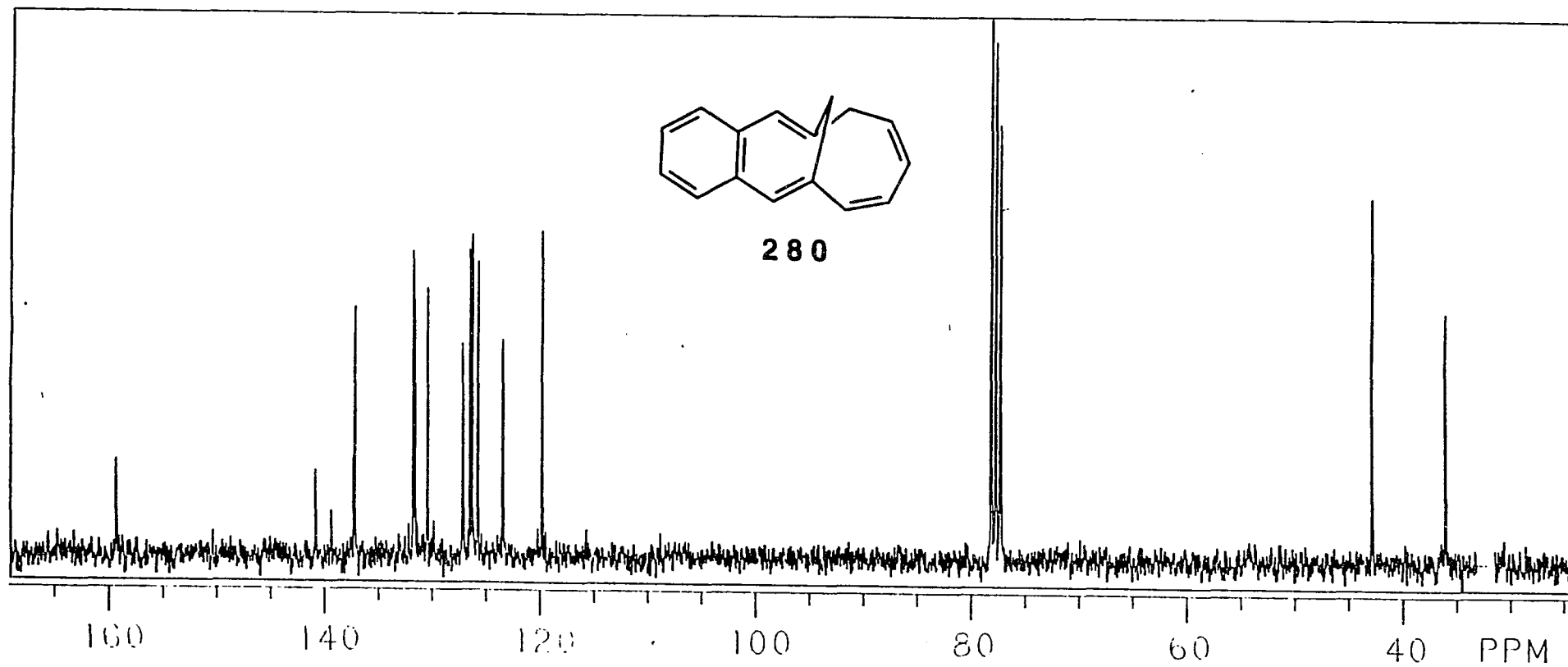
436

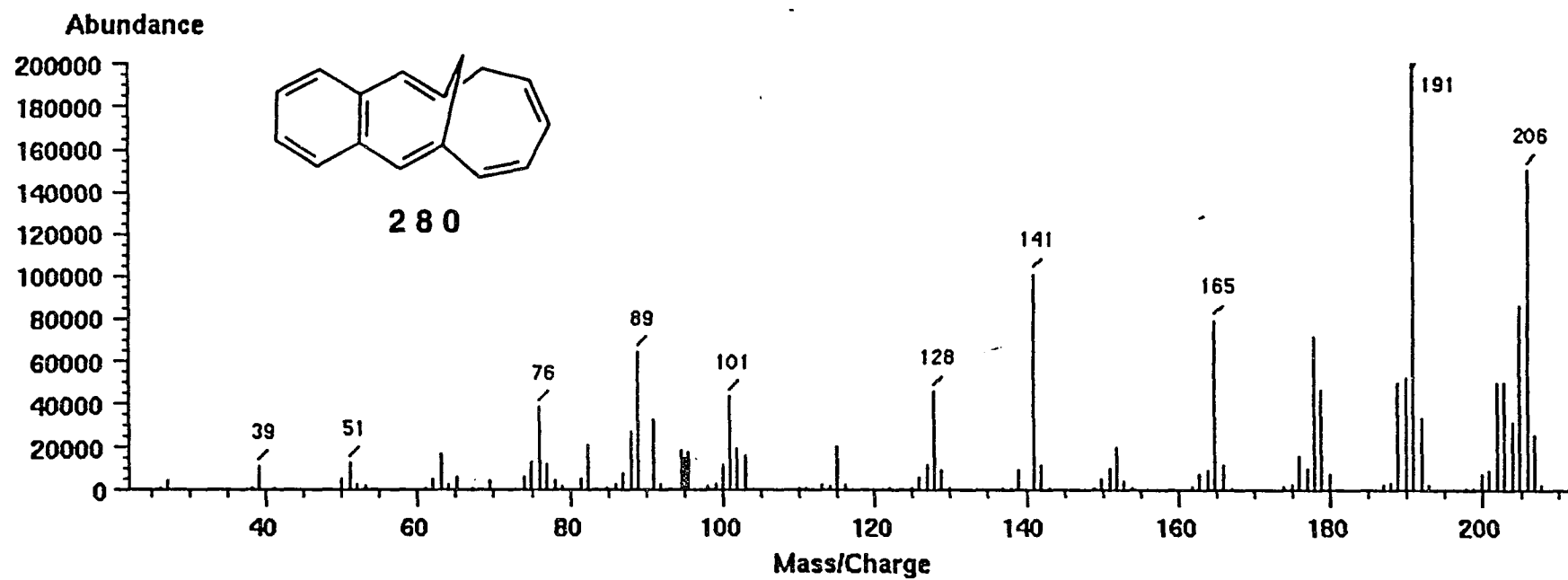
2 3 4 5 6 7 8 9

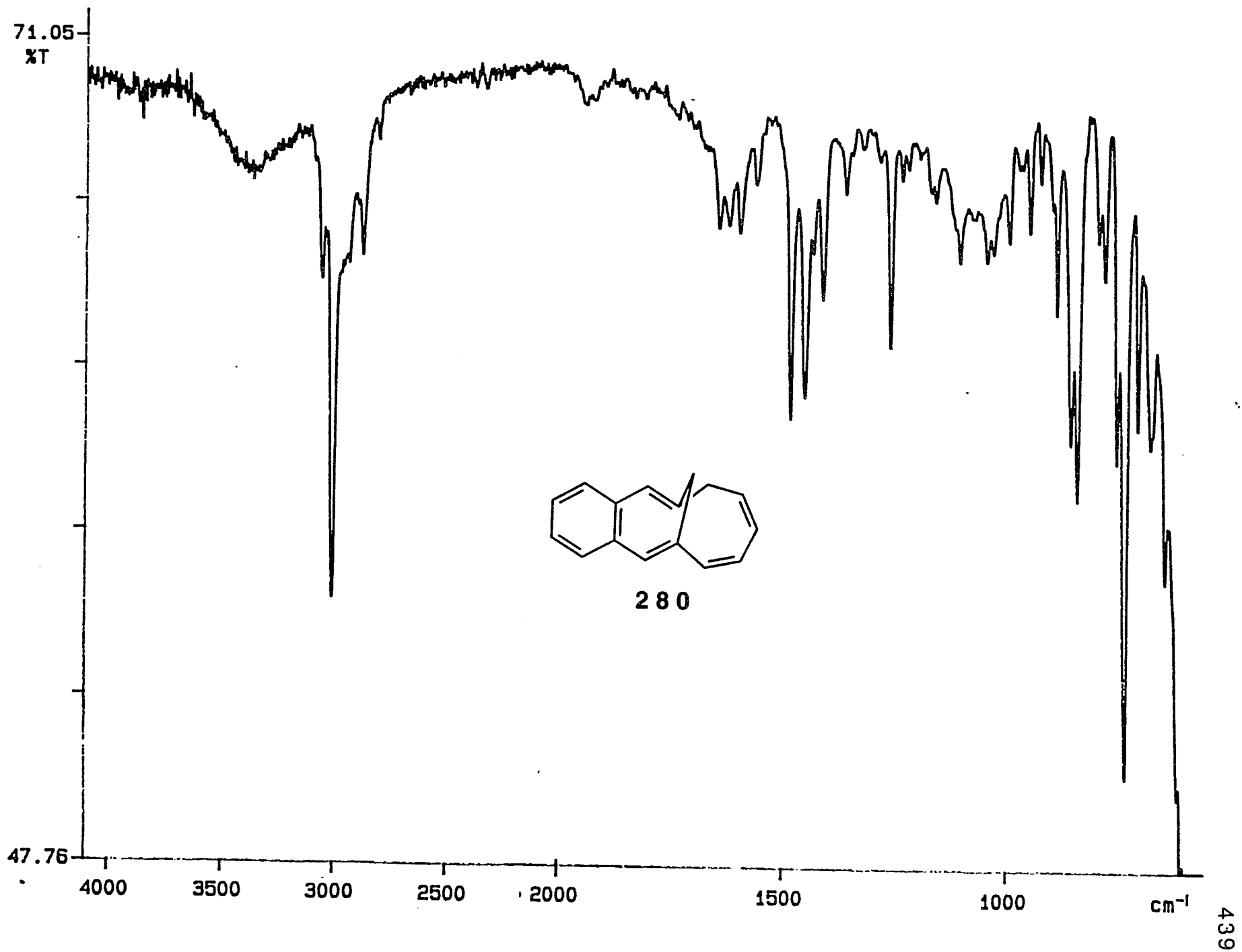


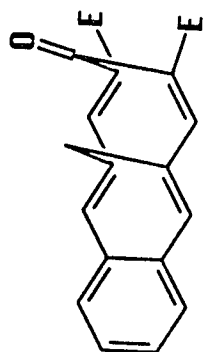
280



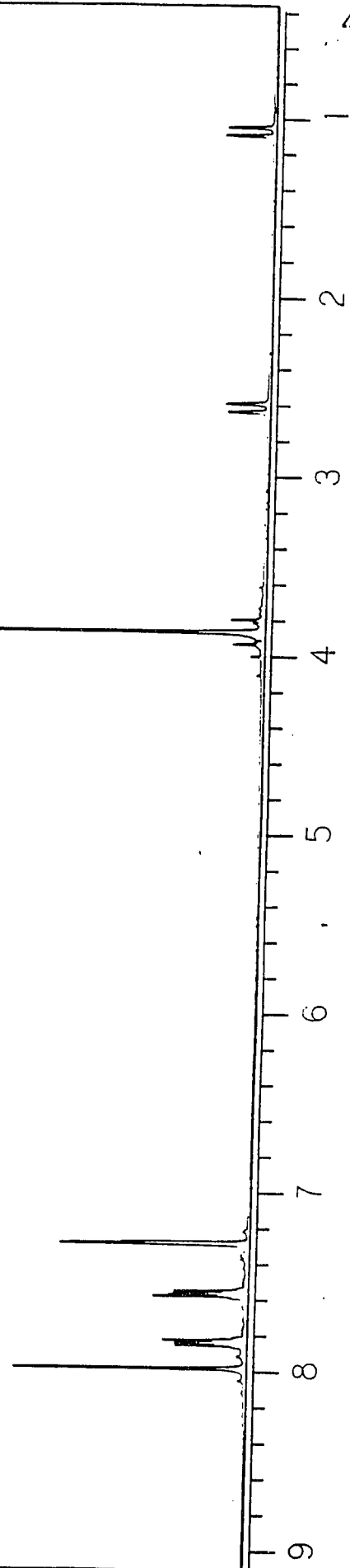


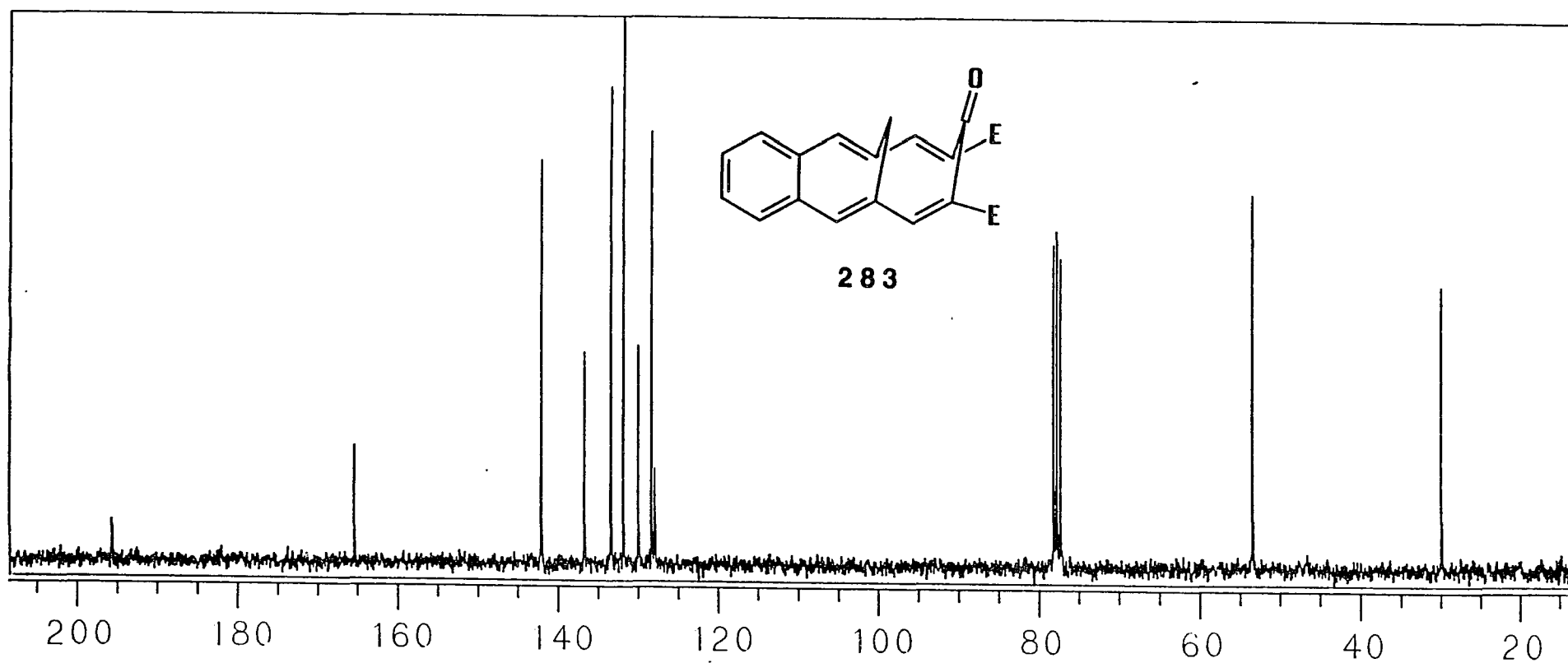


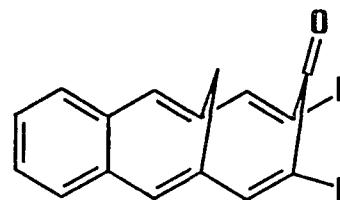
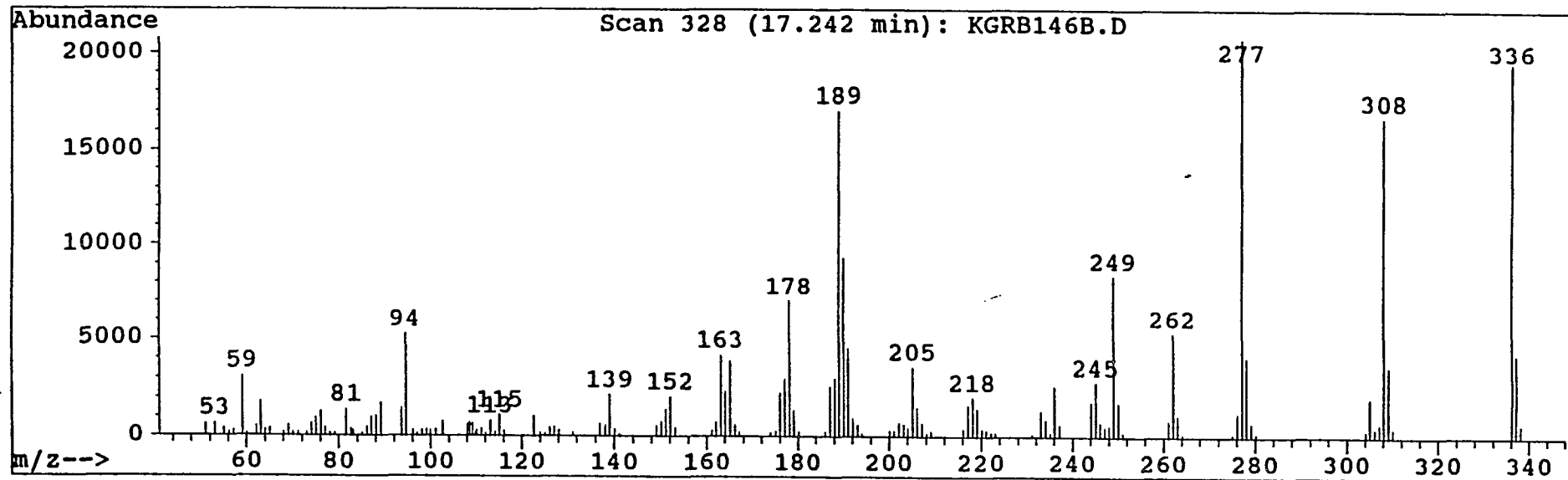




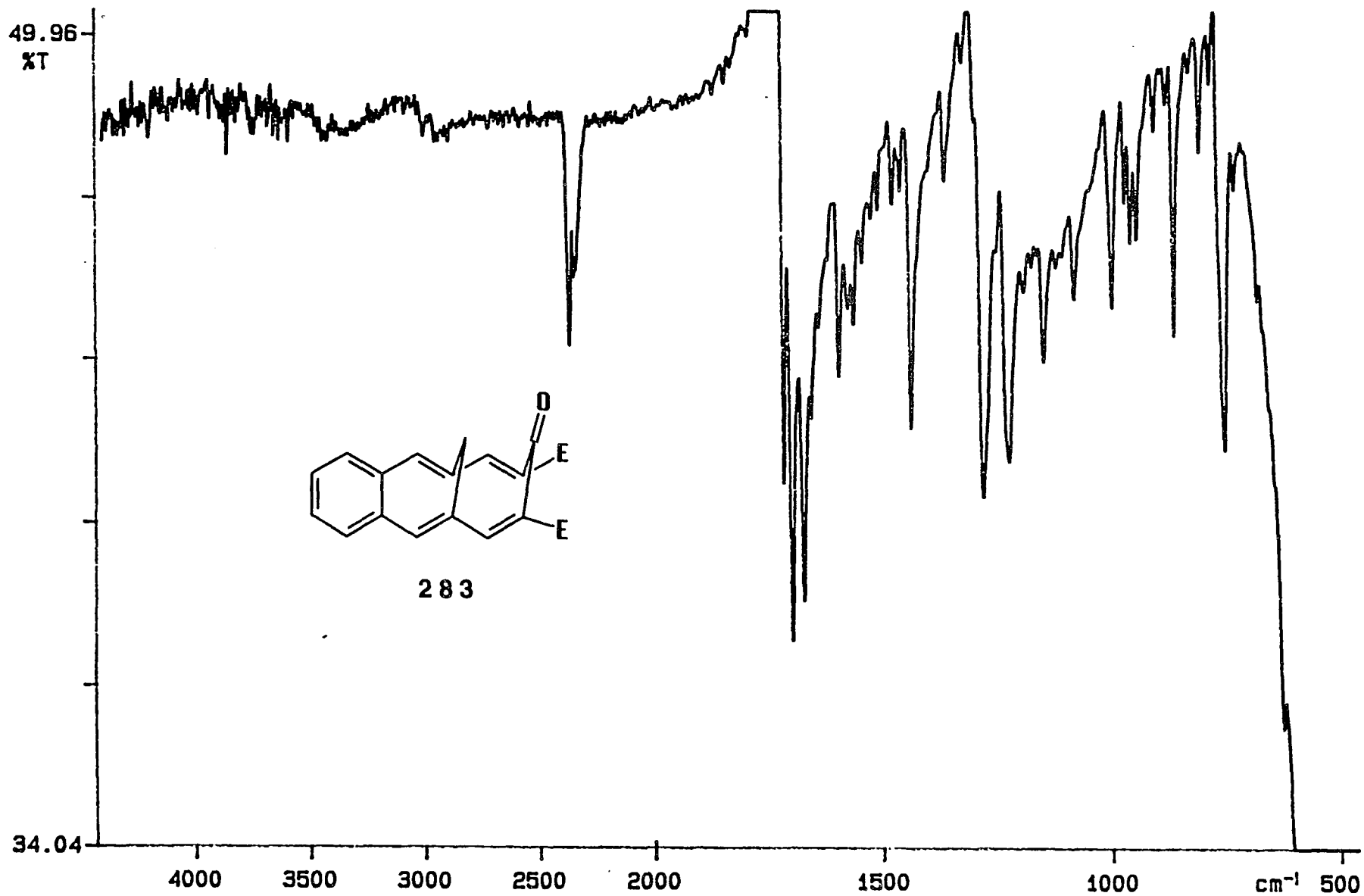
283





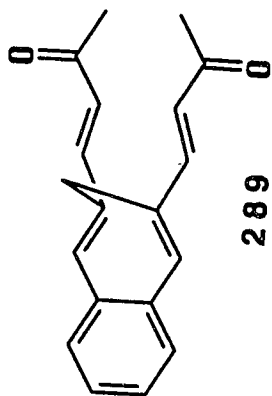


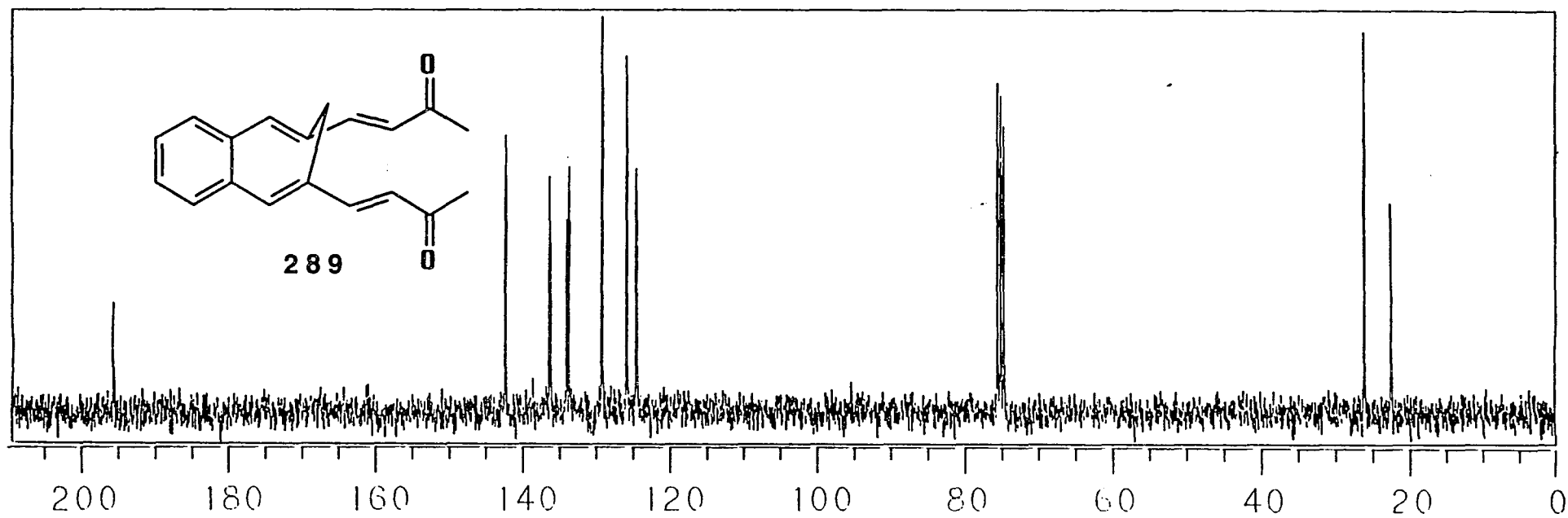
283

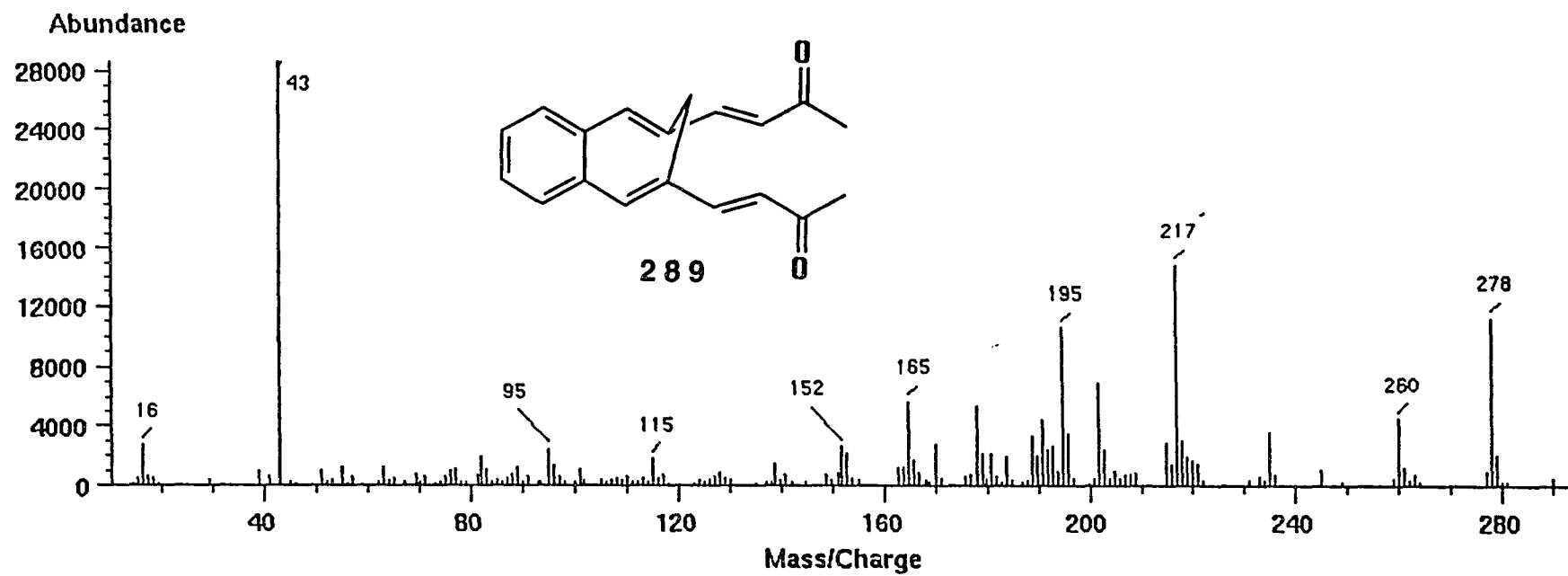


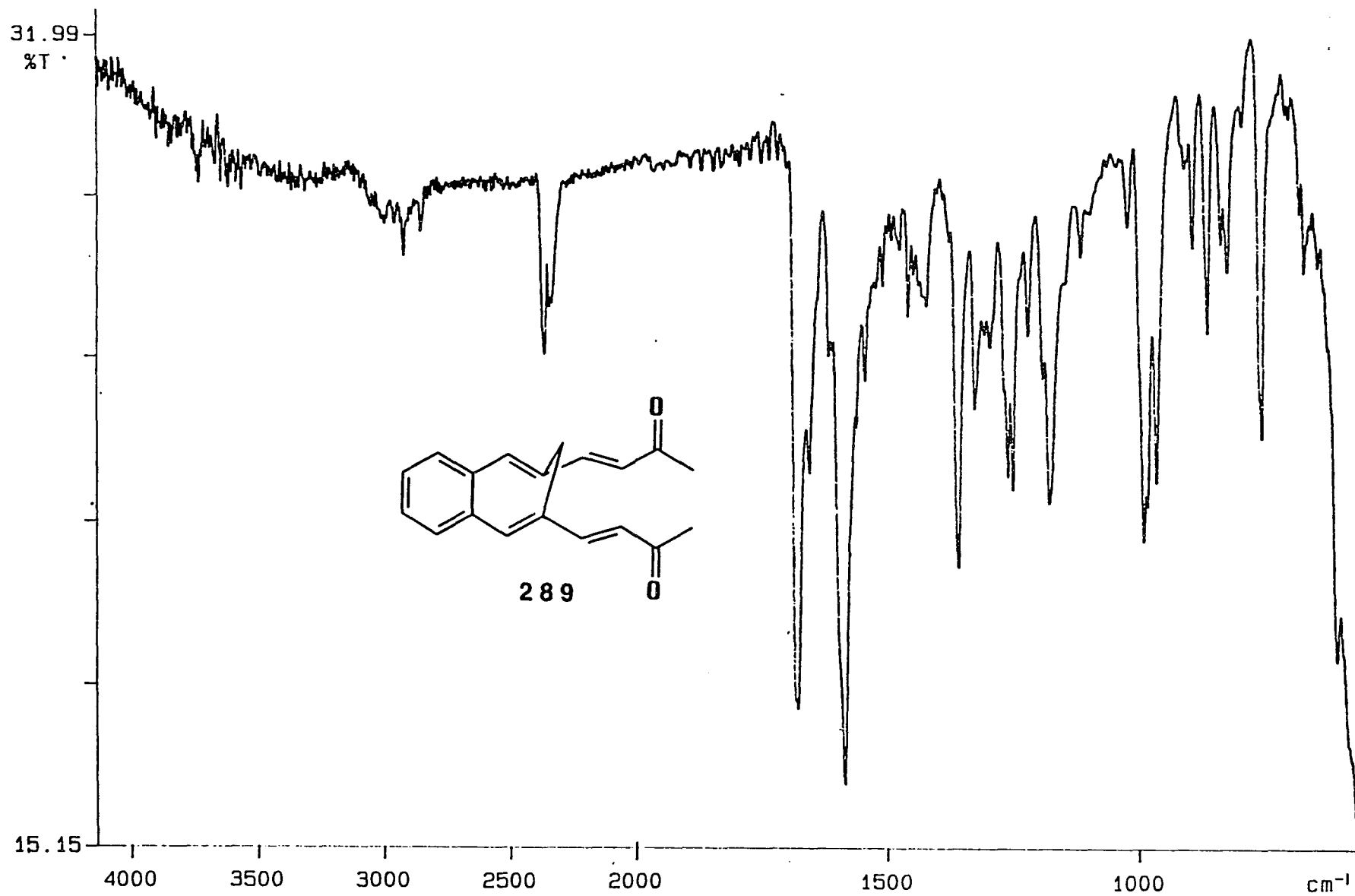
95/12/12 10:39

SCAN: 1 scan, 4.0 cm^{-1} , flat, smooth

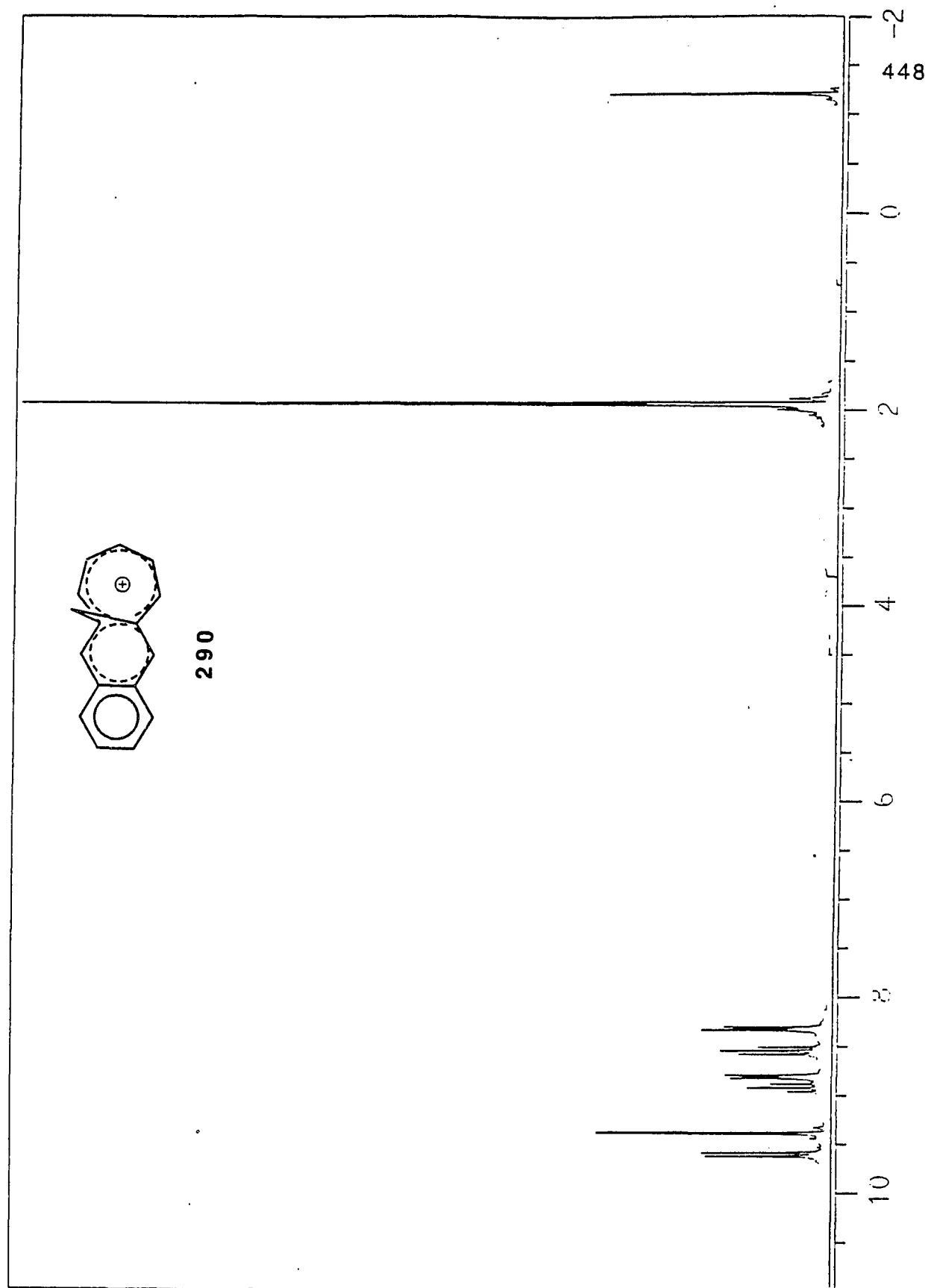


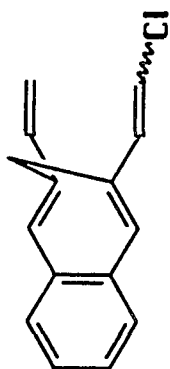






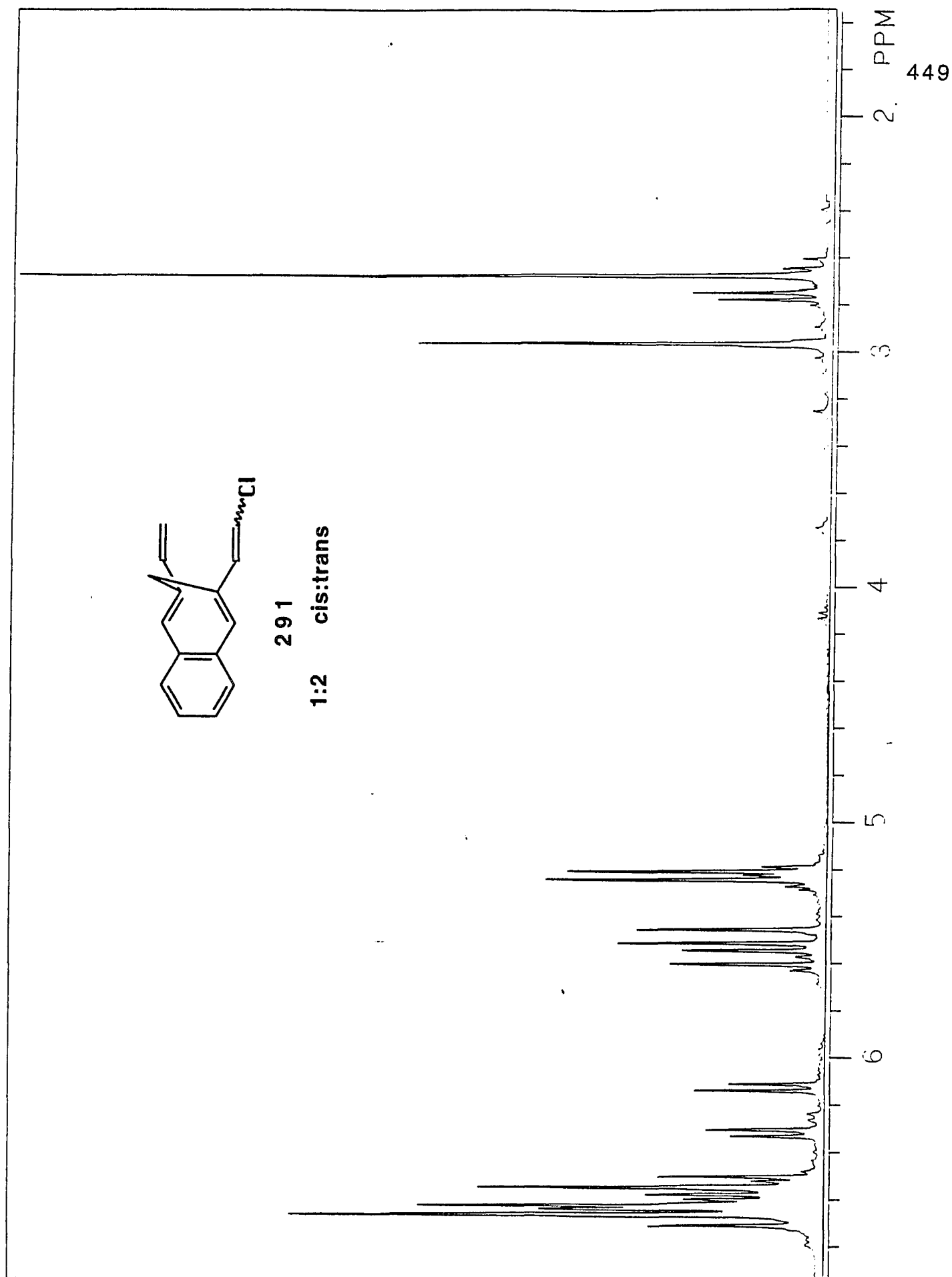
95/10/06 16:03
X: 1 scan, 4.0cm-1, flat

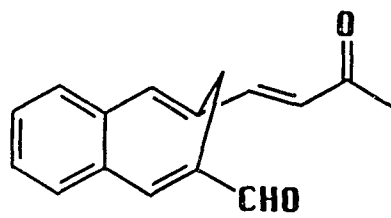




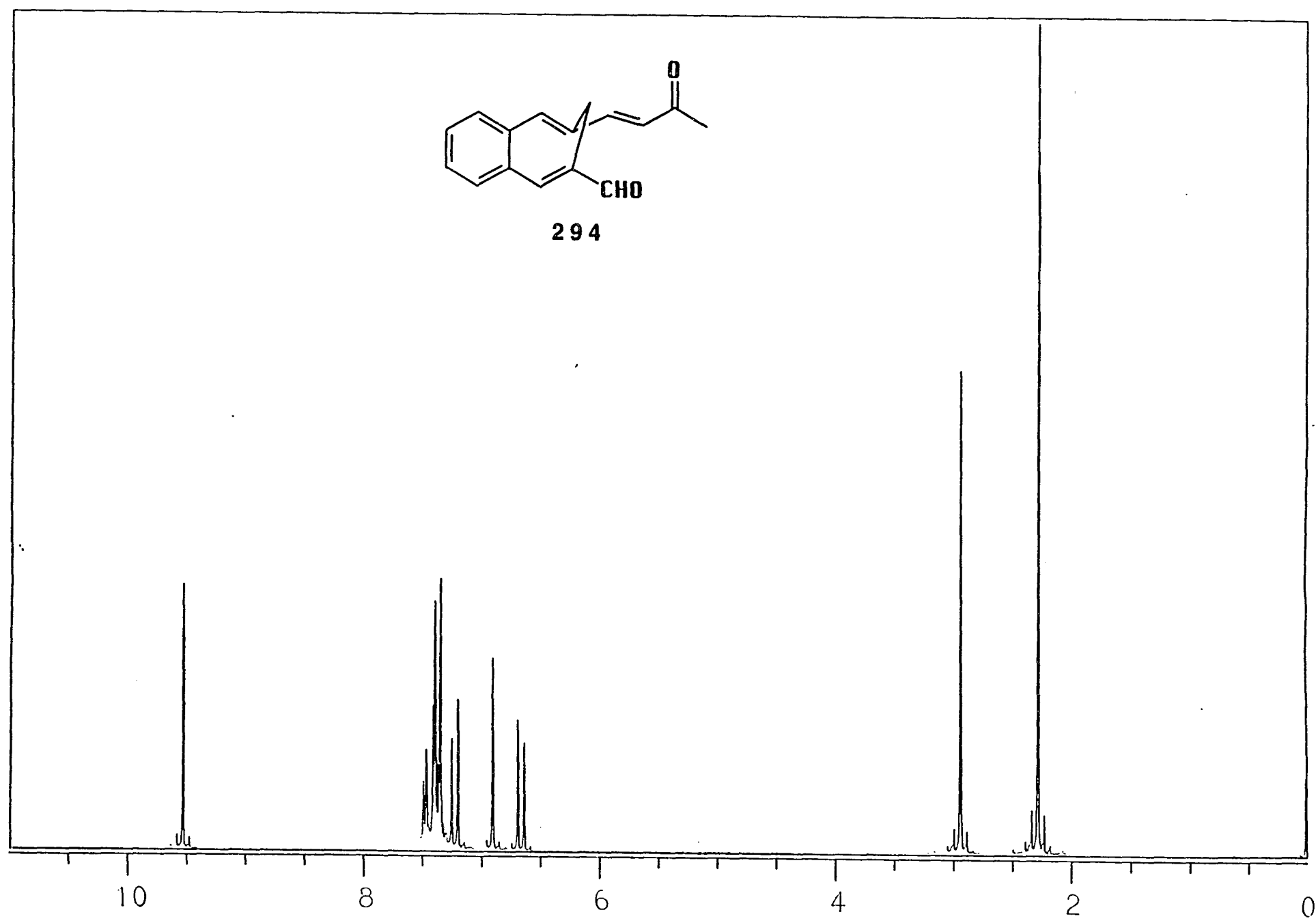
291

1:2 cis:trans

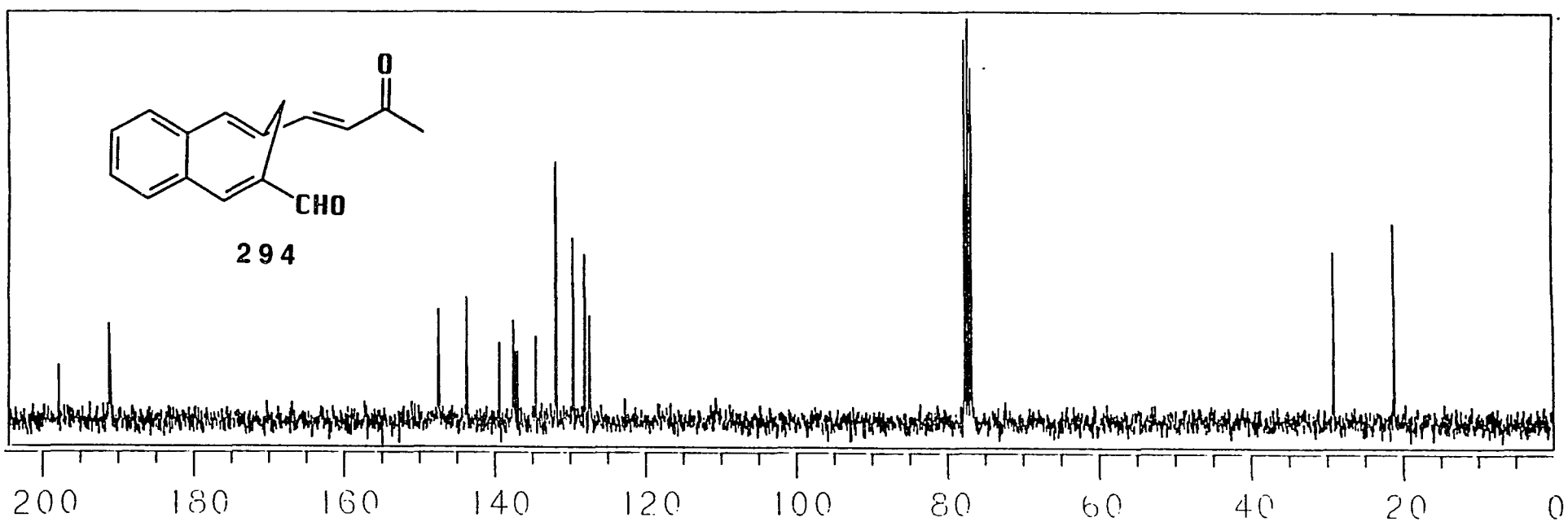


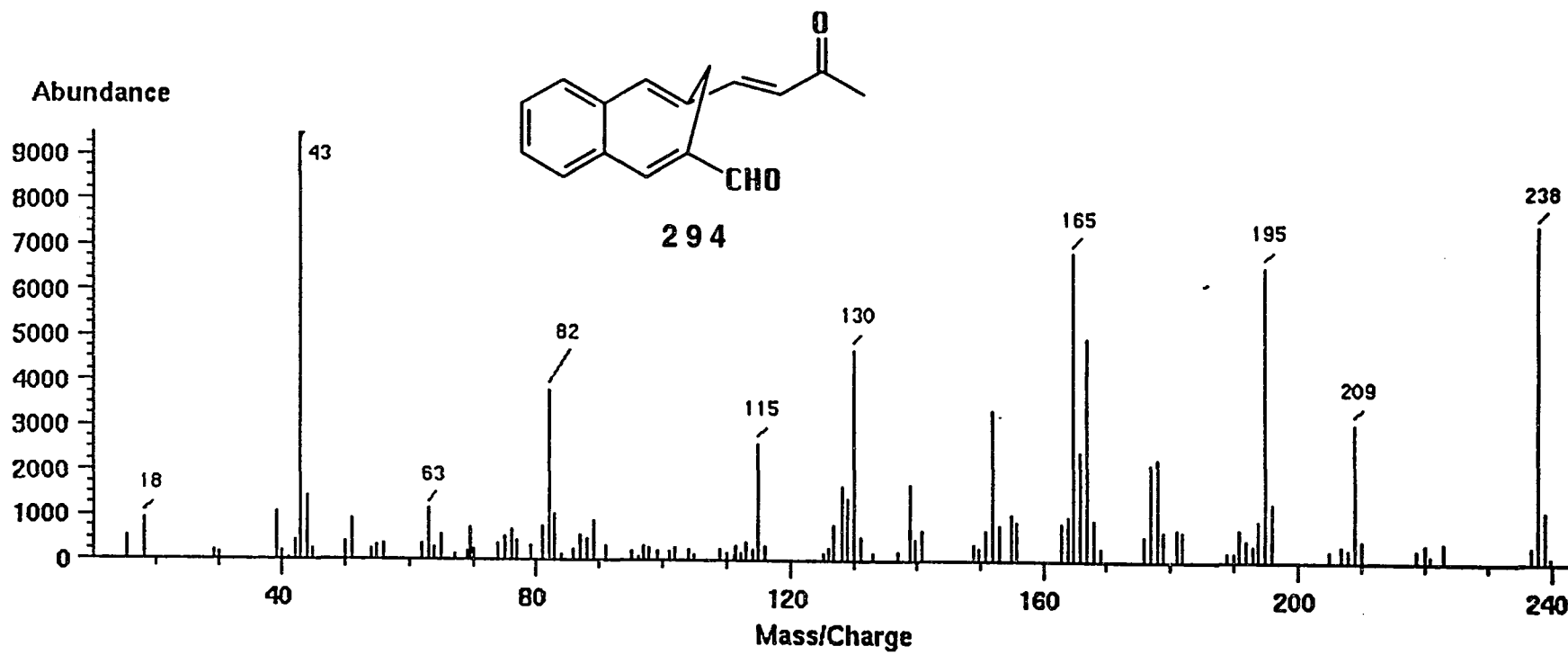


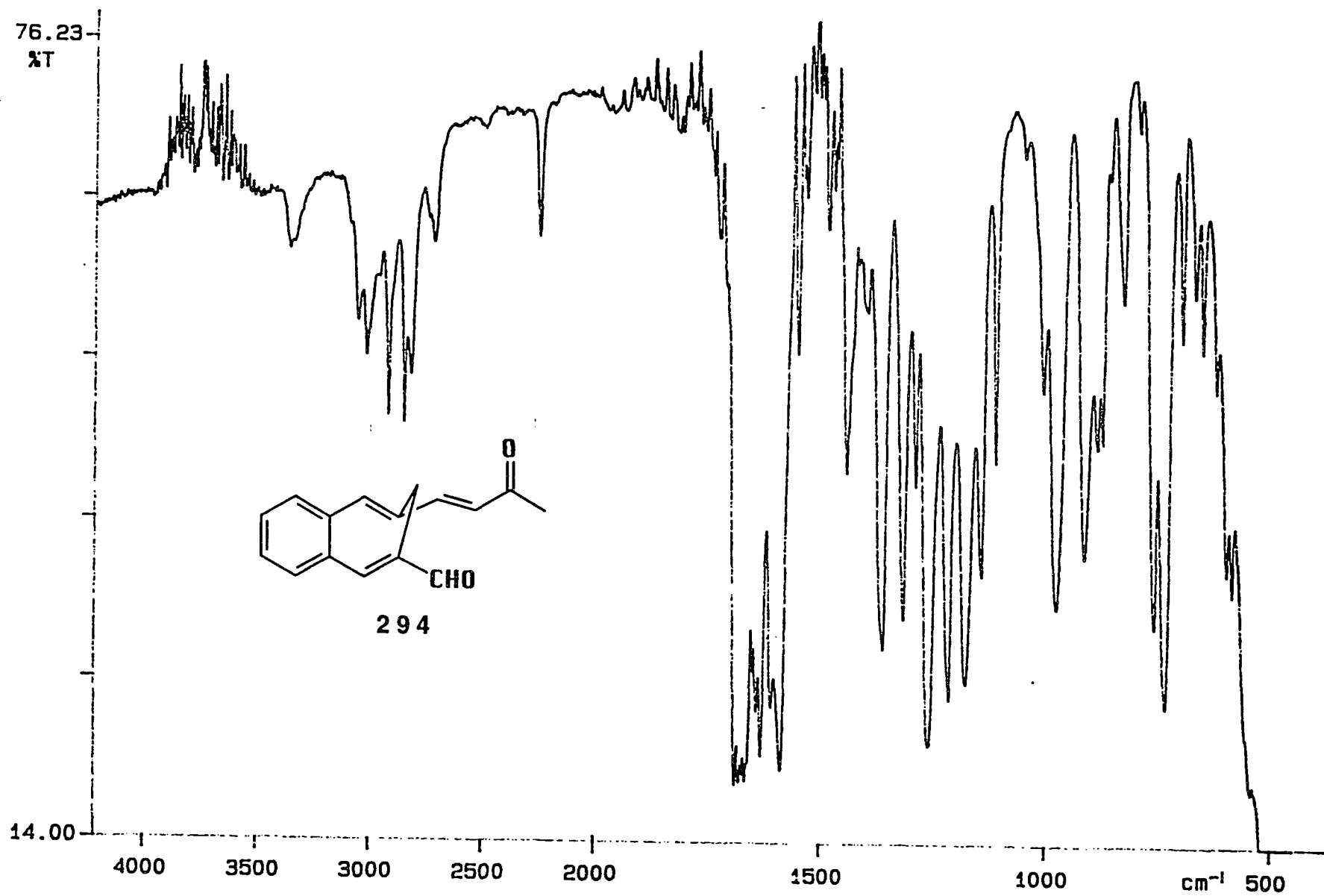
294



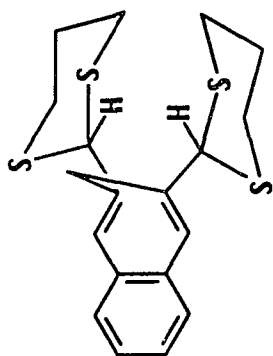
96



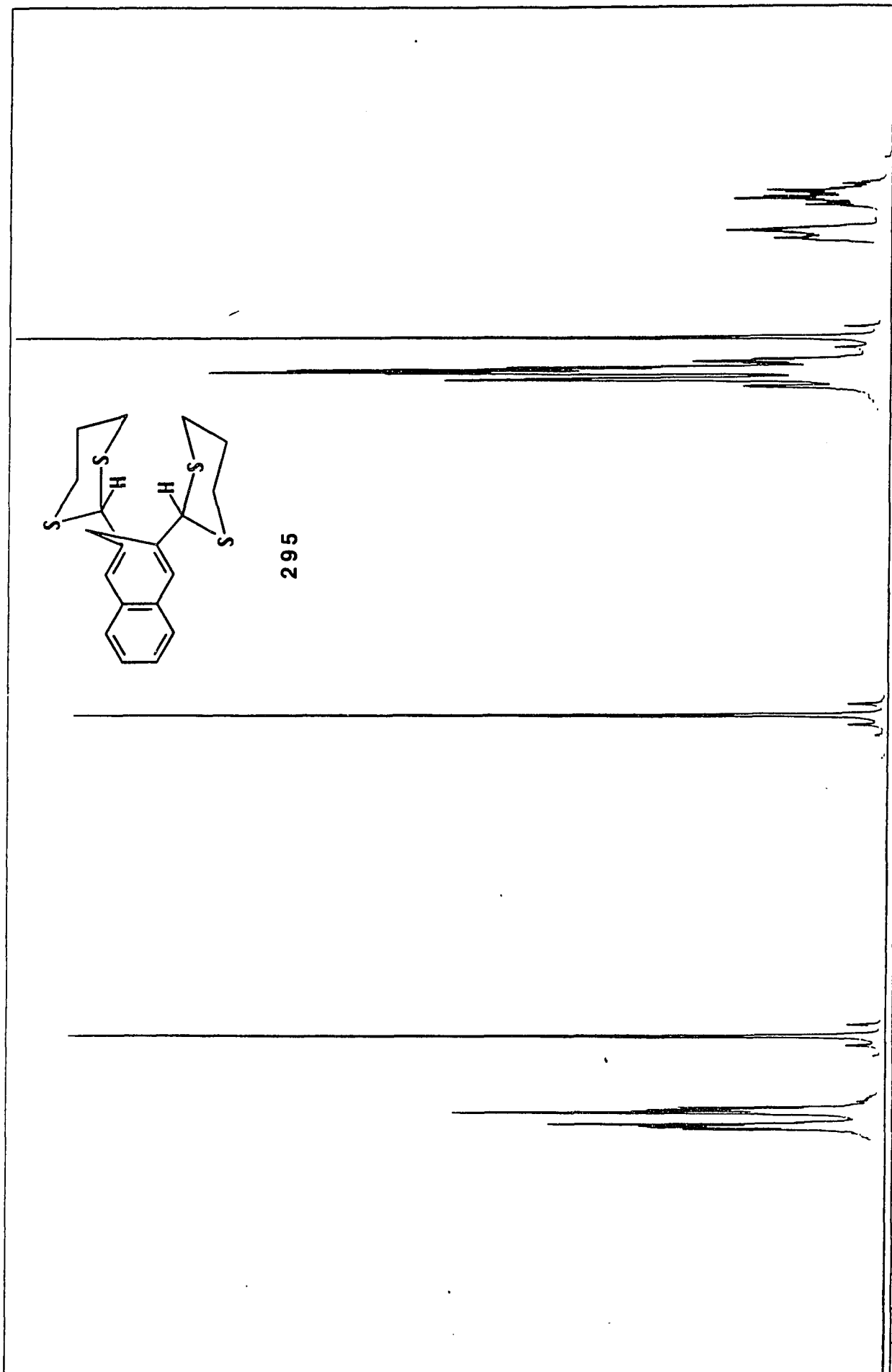


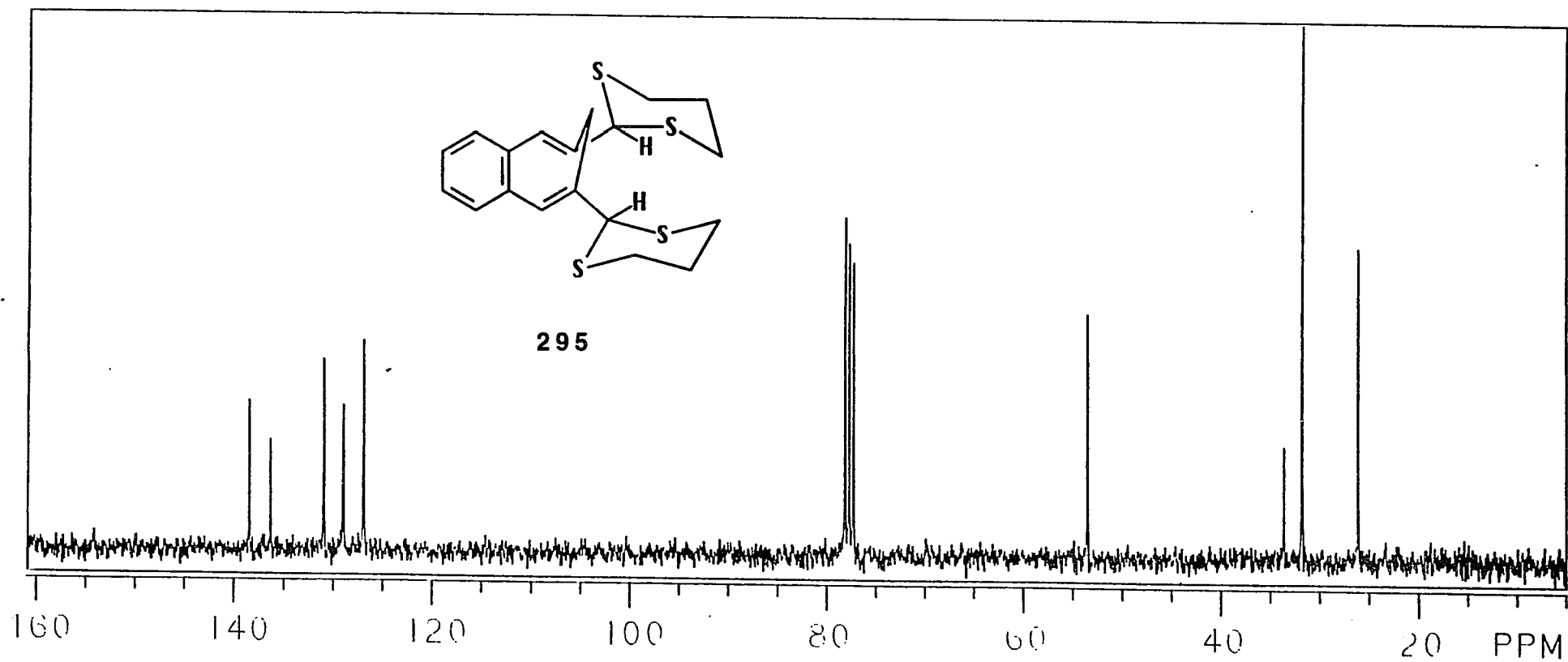


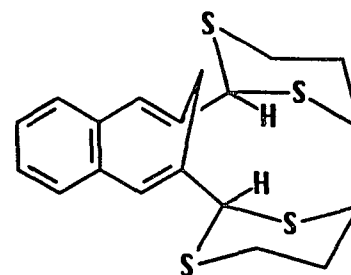
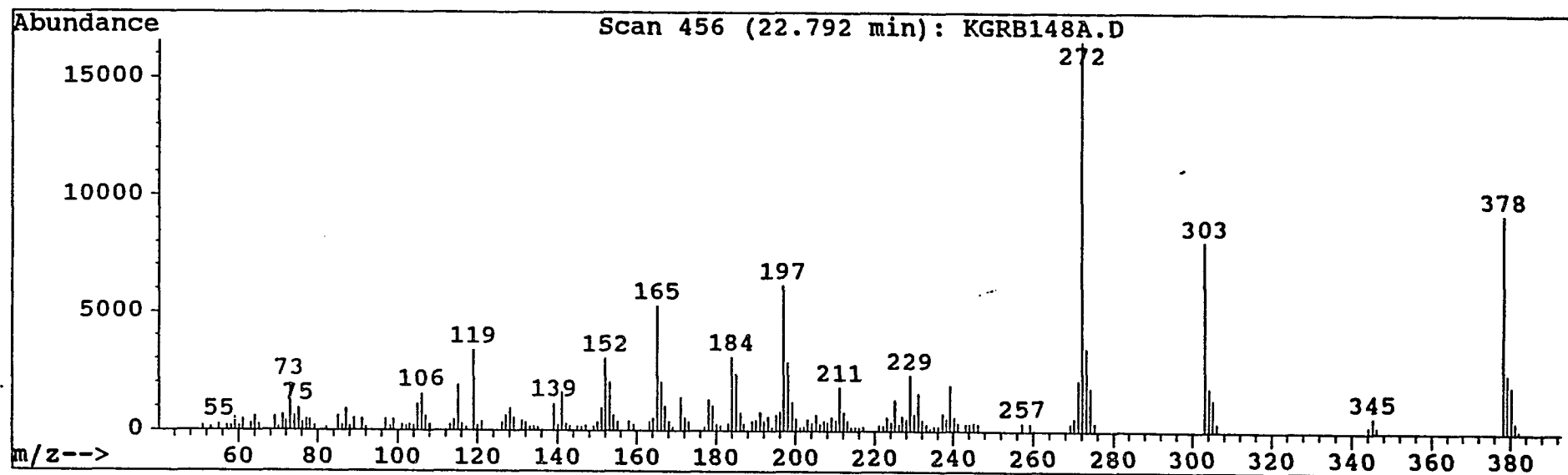
95/09/28 19:20
X: 1 scan, 4.0 cm^{-1}



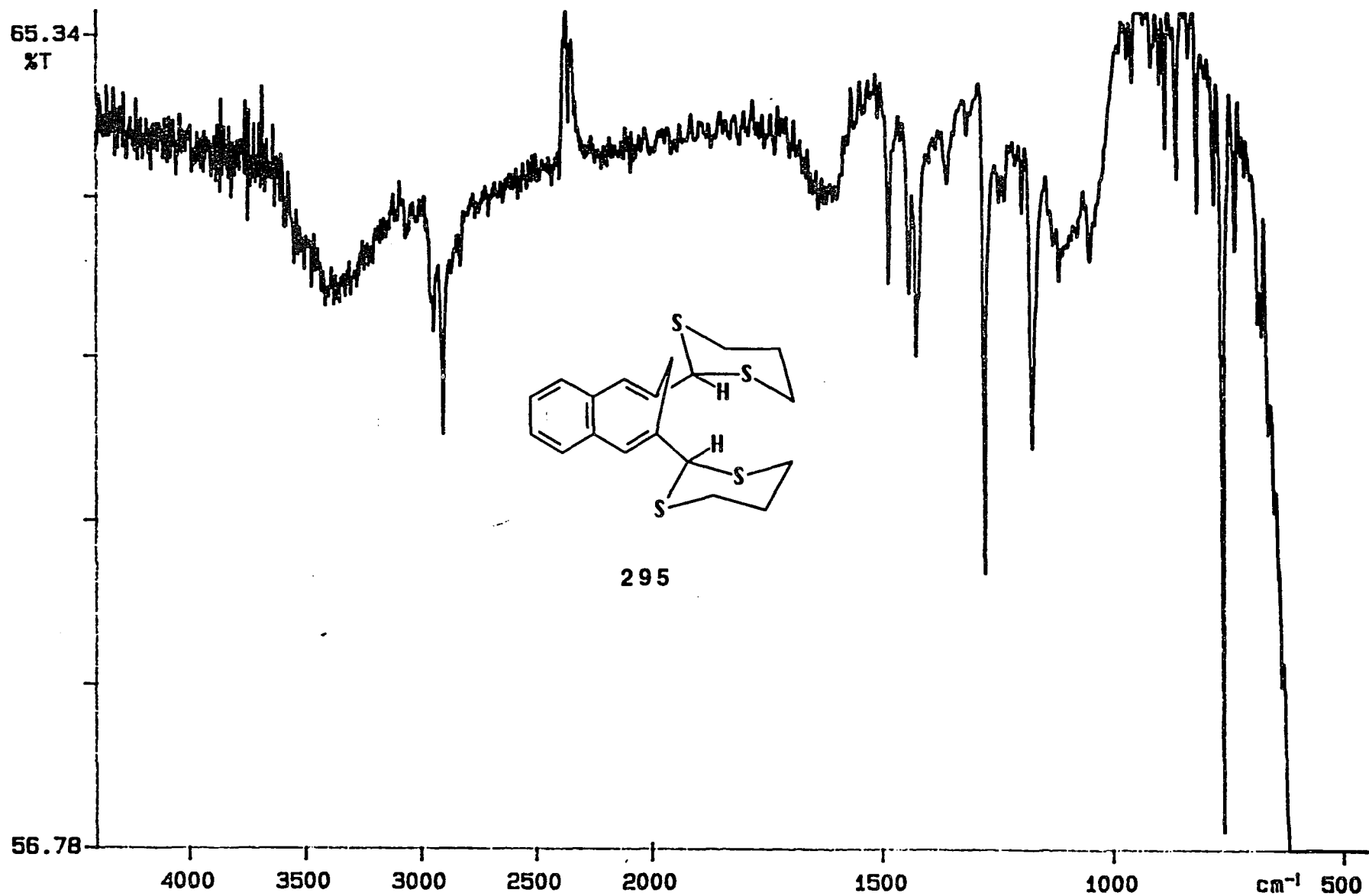
295



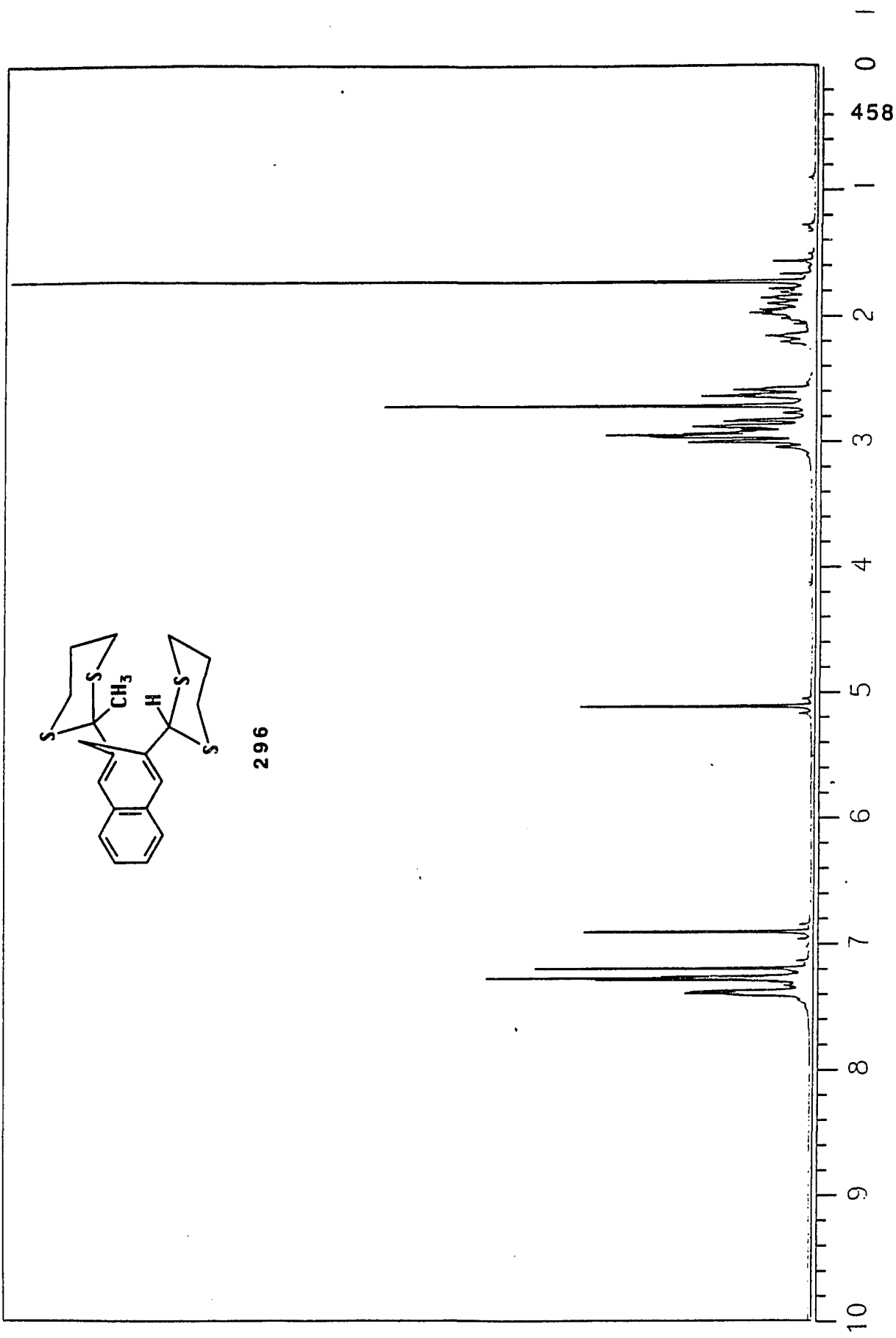


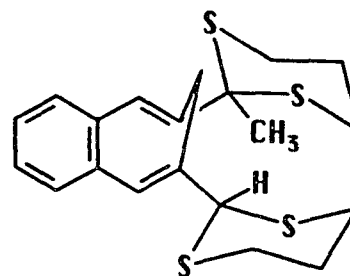
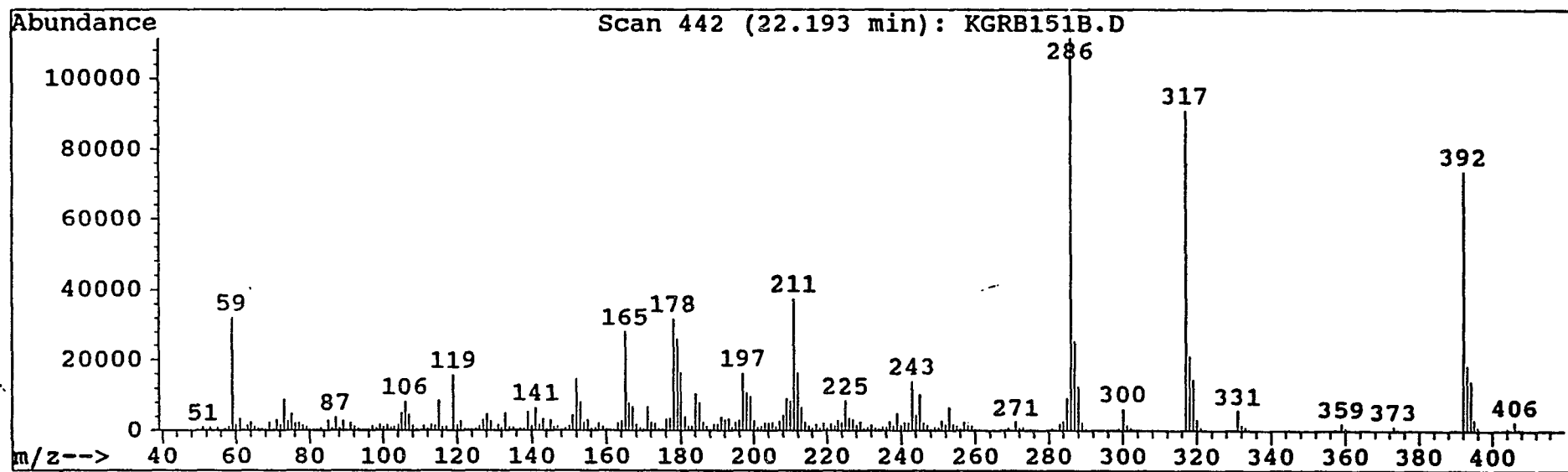


295



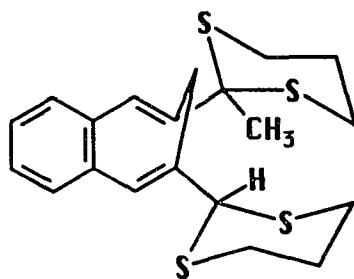
95/12/21 16:01
Y: 1 scan, 4.0cm⁻¹, flat





296

76.07
%T



296

64.05

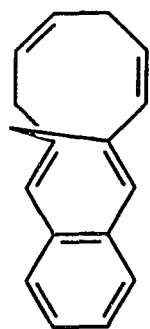
95/12/30 16:25
SCAN: 1 scan, 4.0cm⁻¹, flat

1500

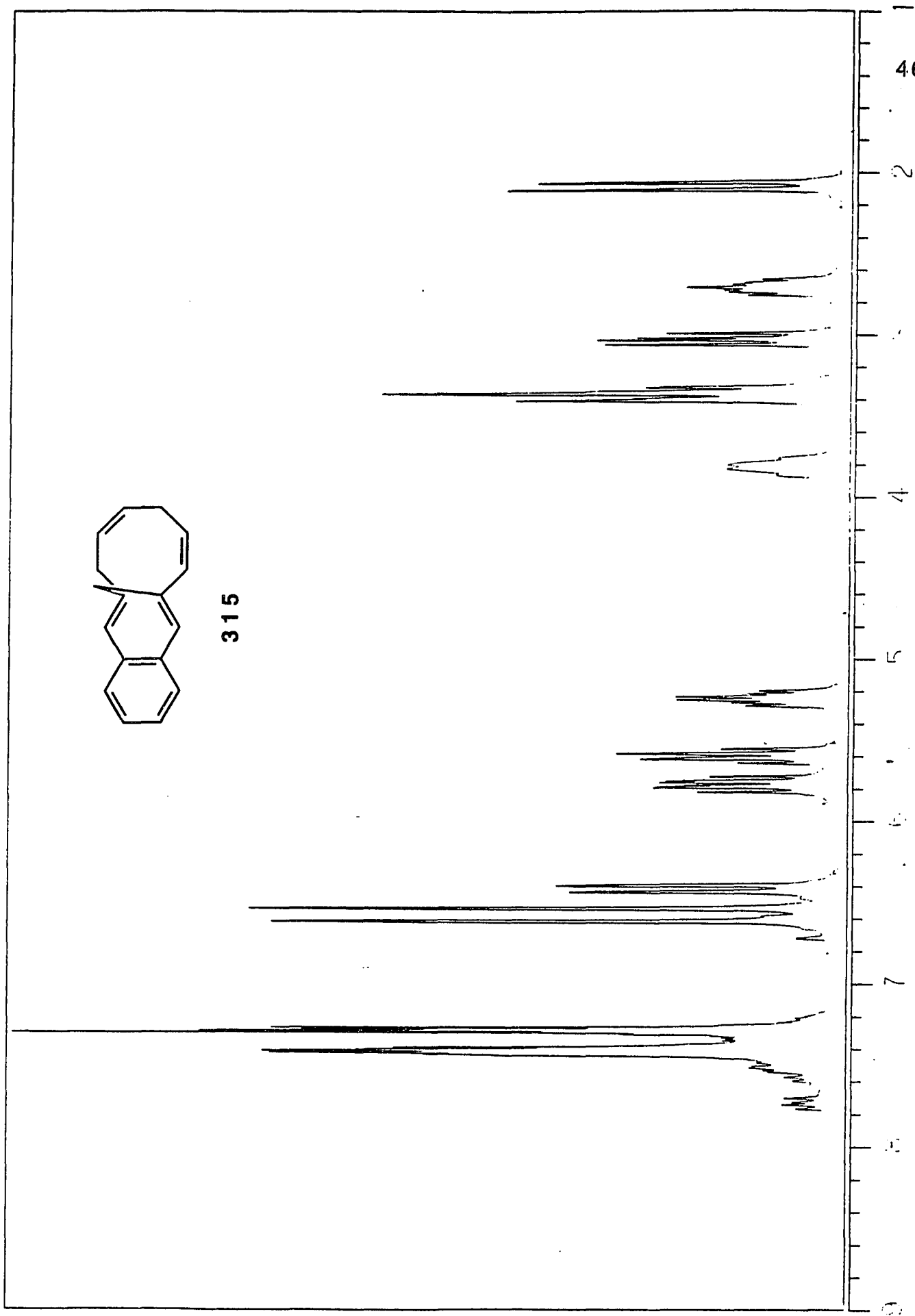
1000

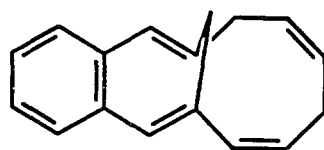
cm⁻¹

460

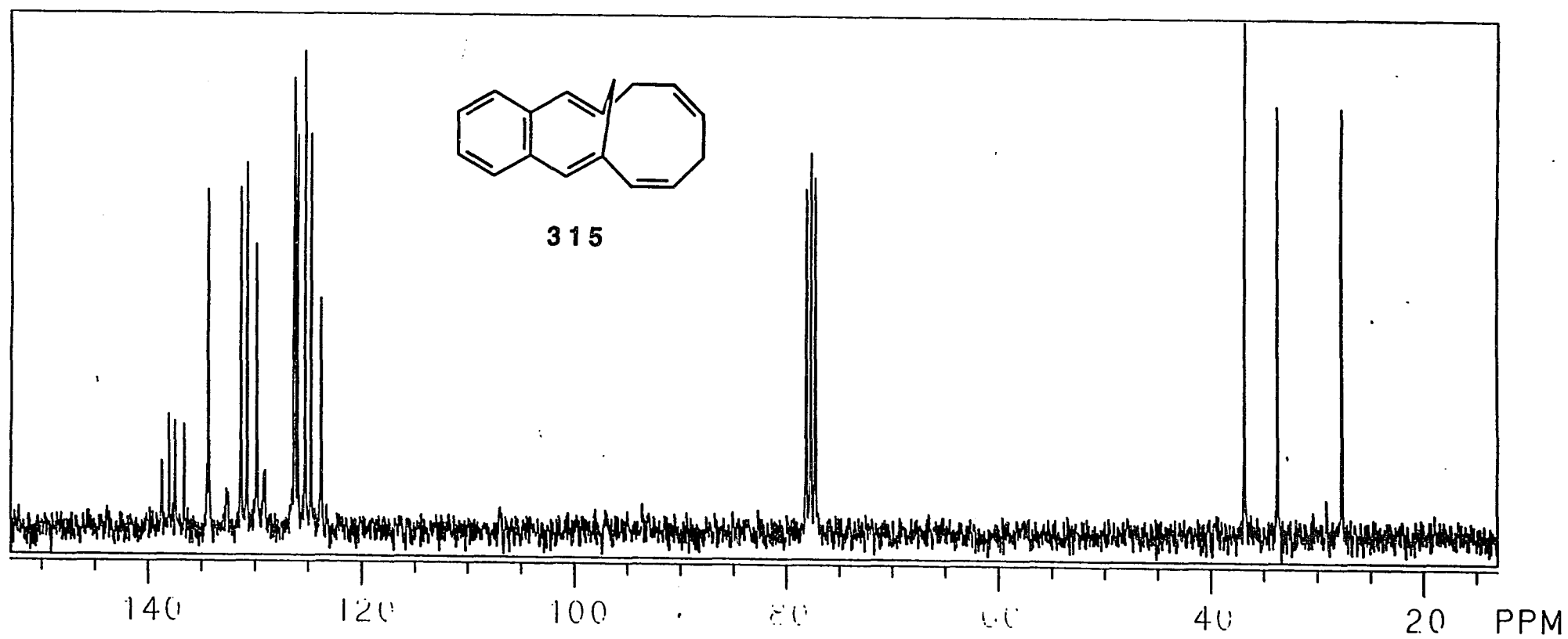


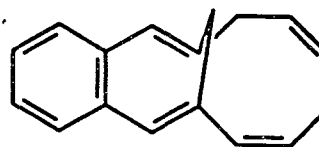
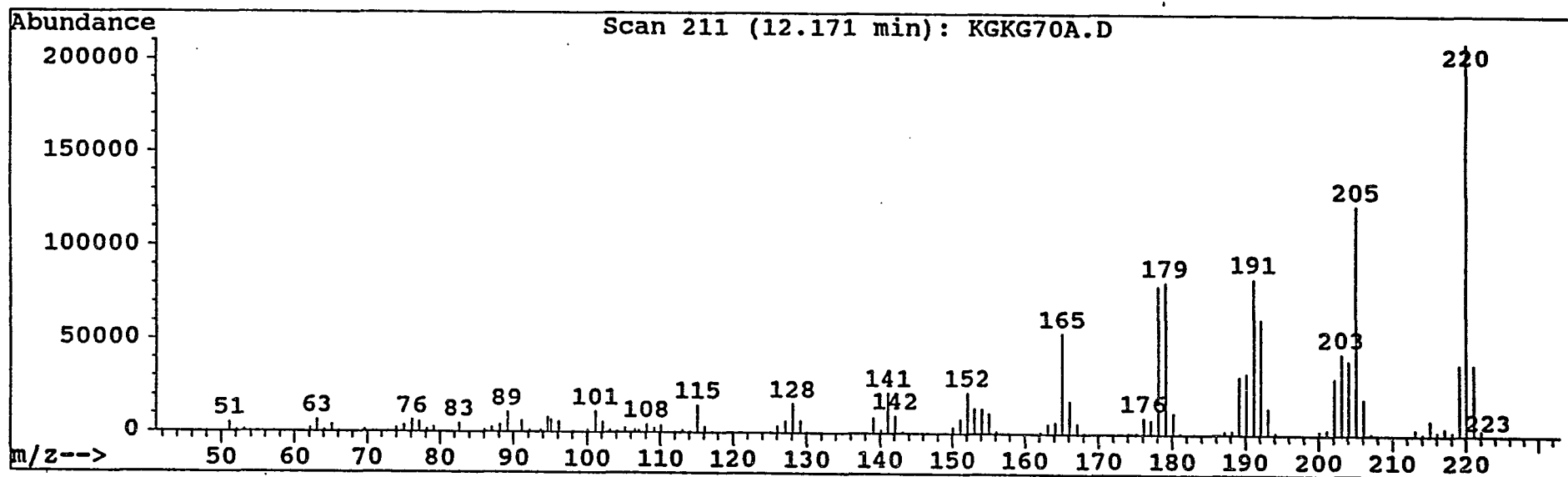
315



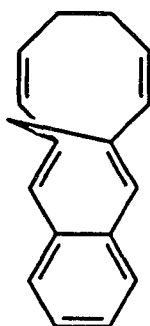


315

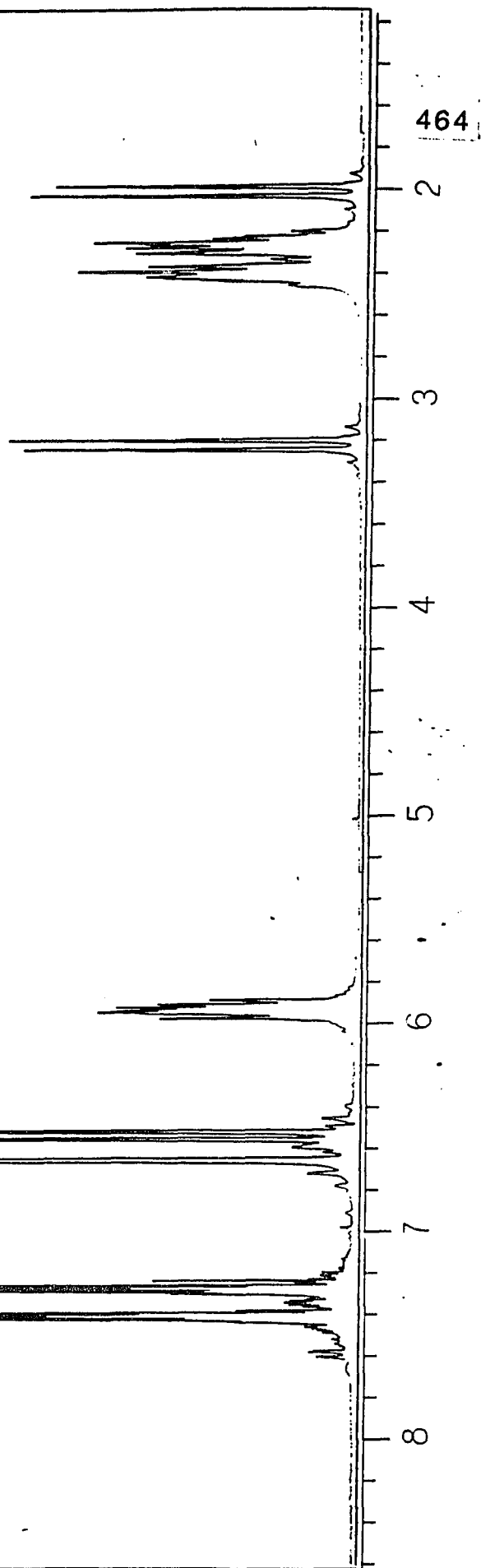


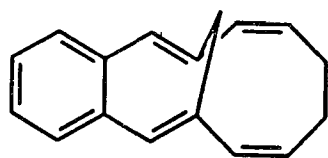


315

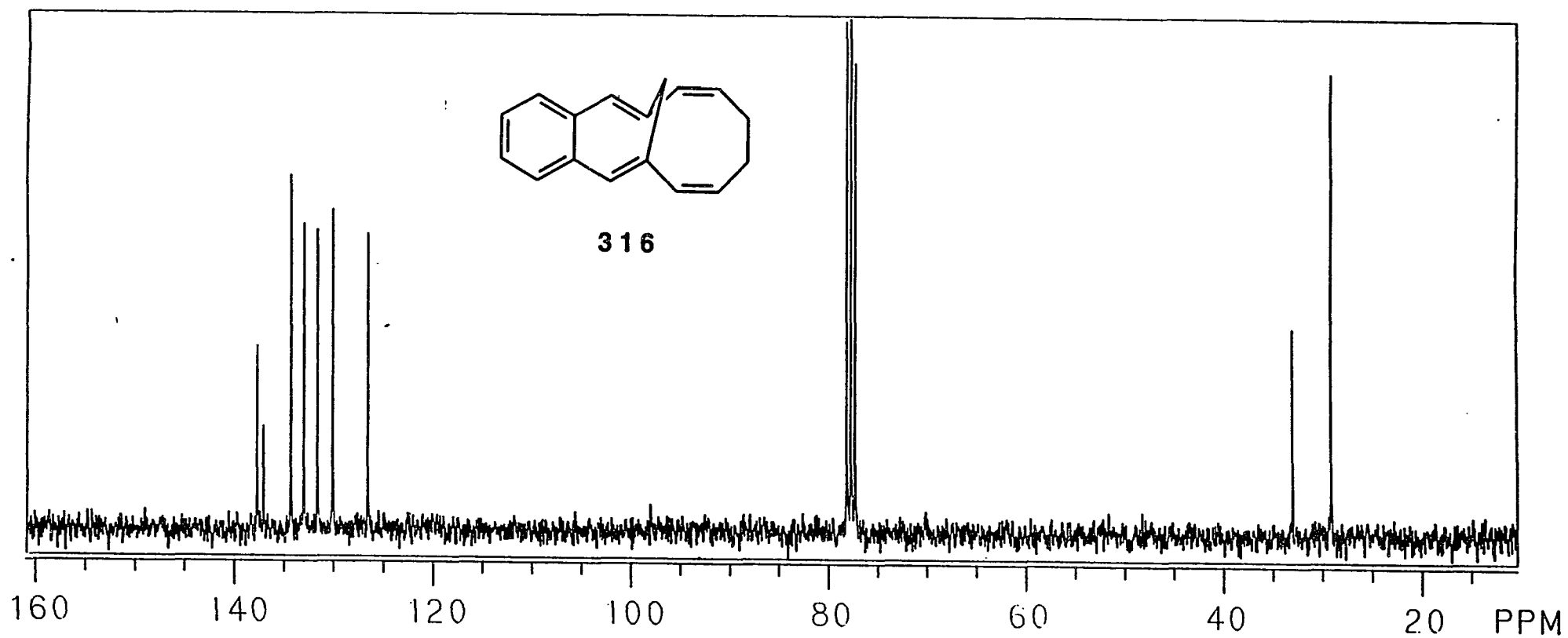


316

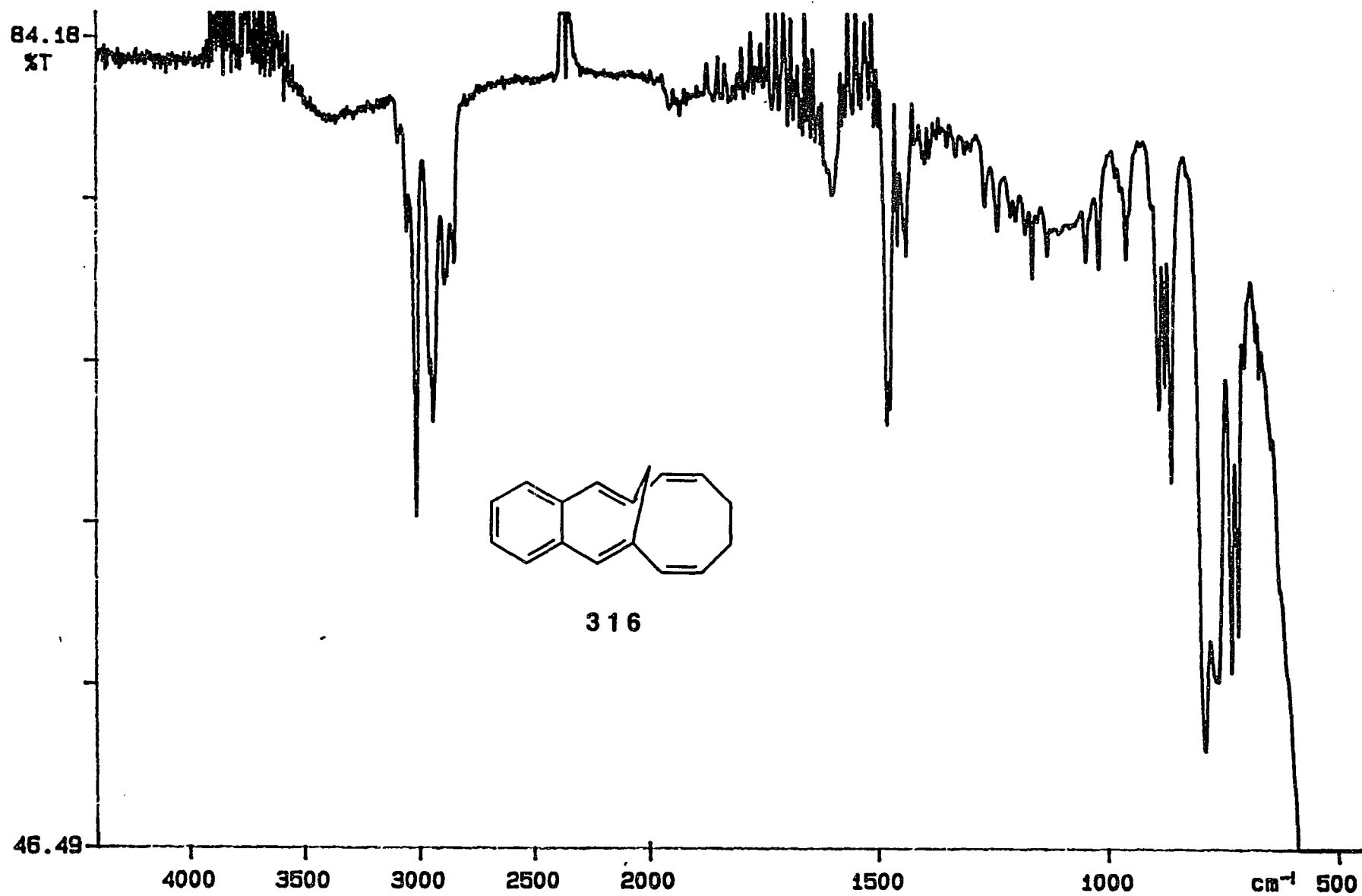




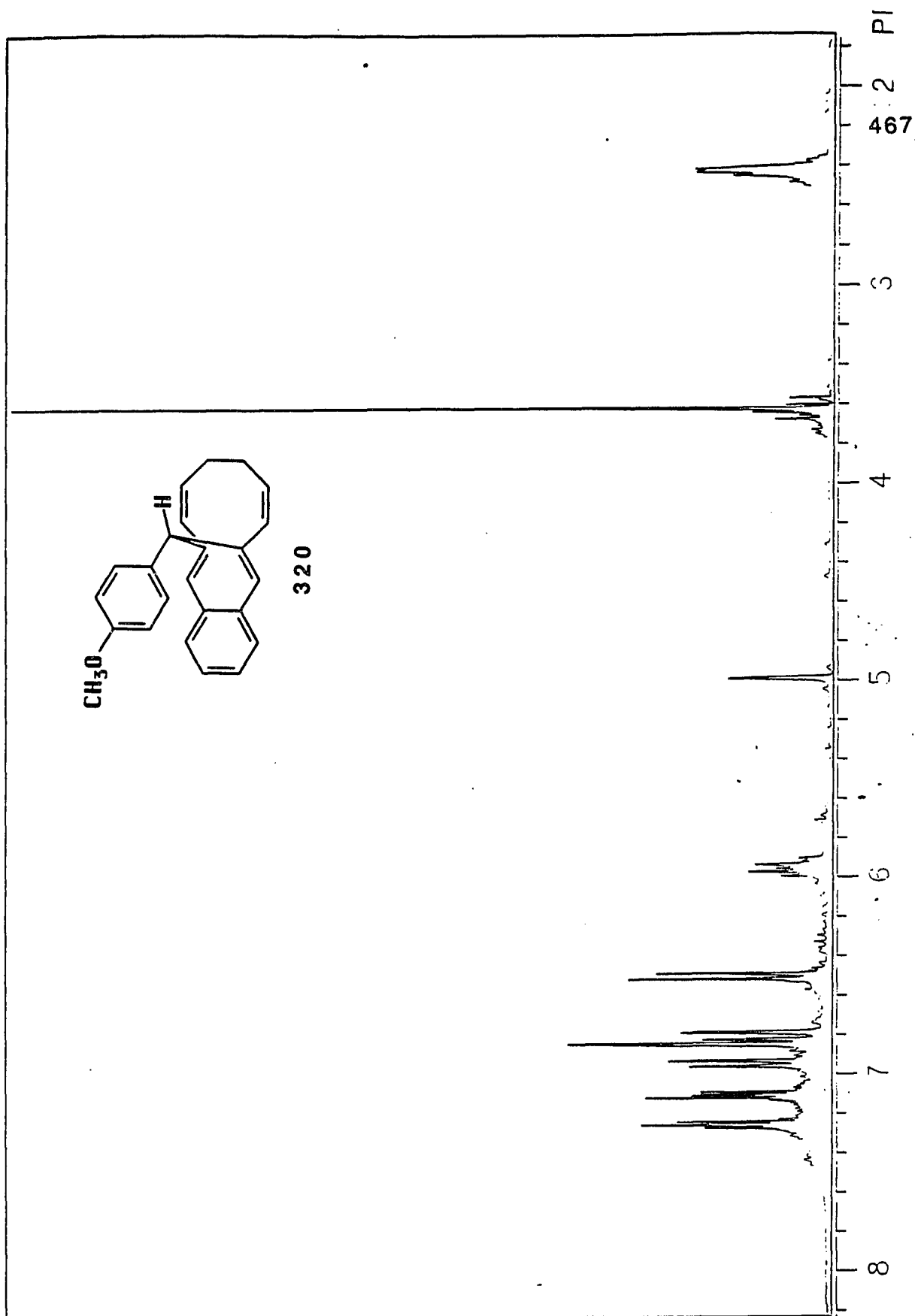
316

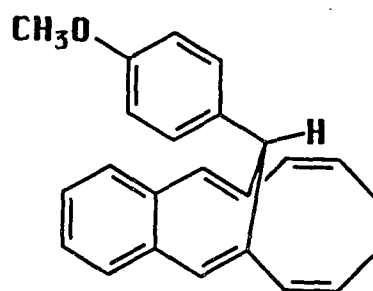


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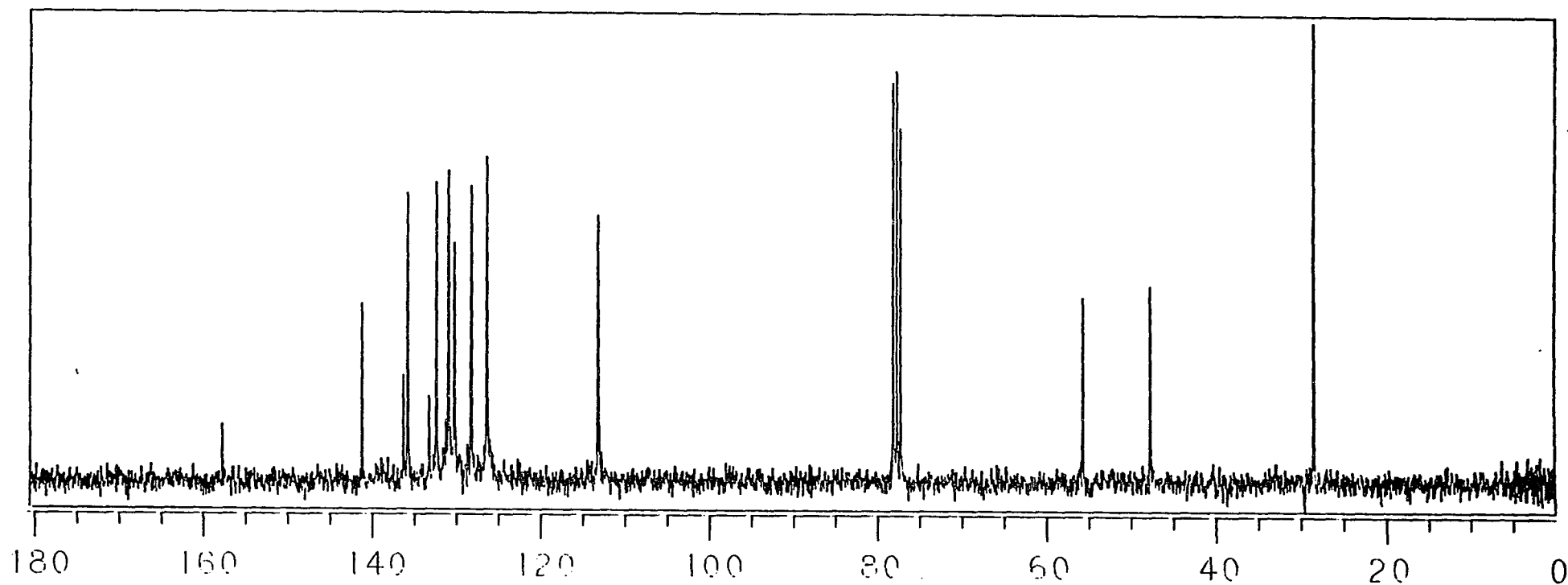


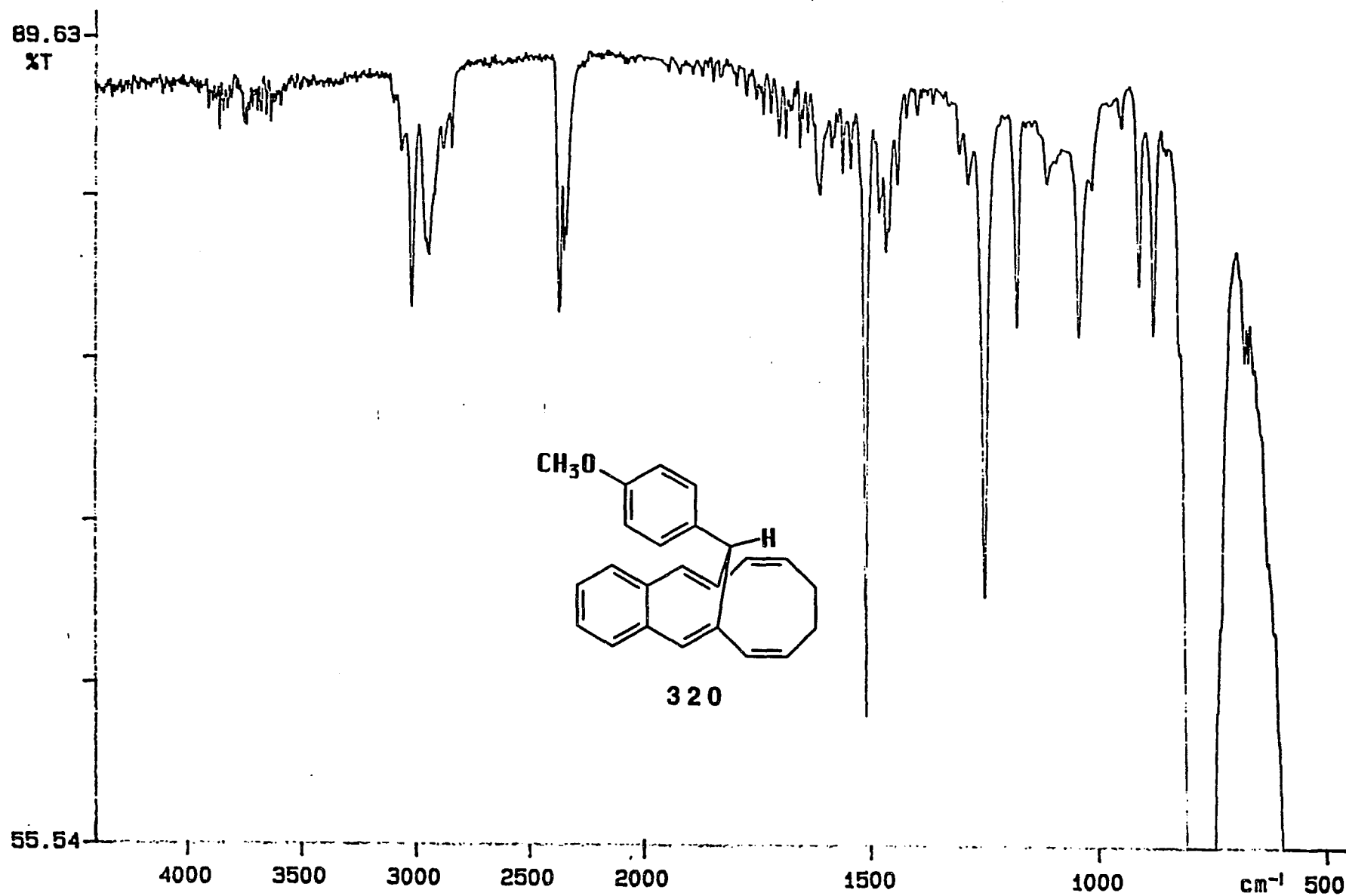
95/12/19 14:11
Y: 1 scan, 4.0cm⁻¹, flat



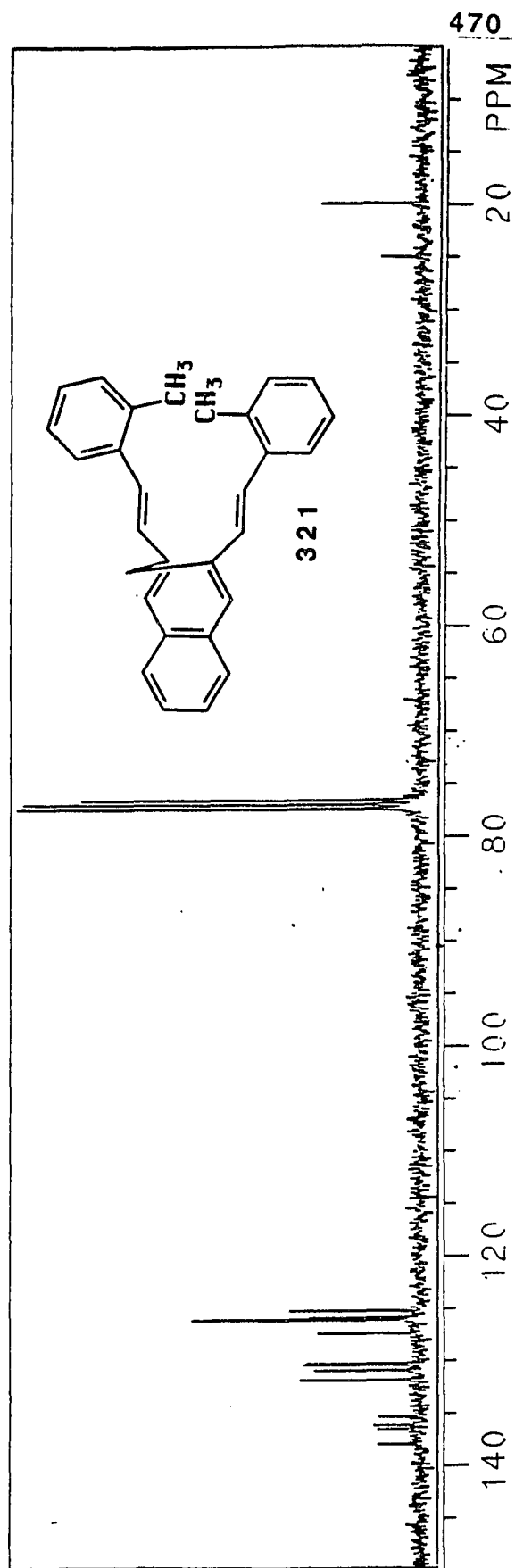
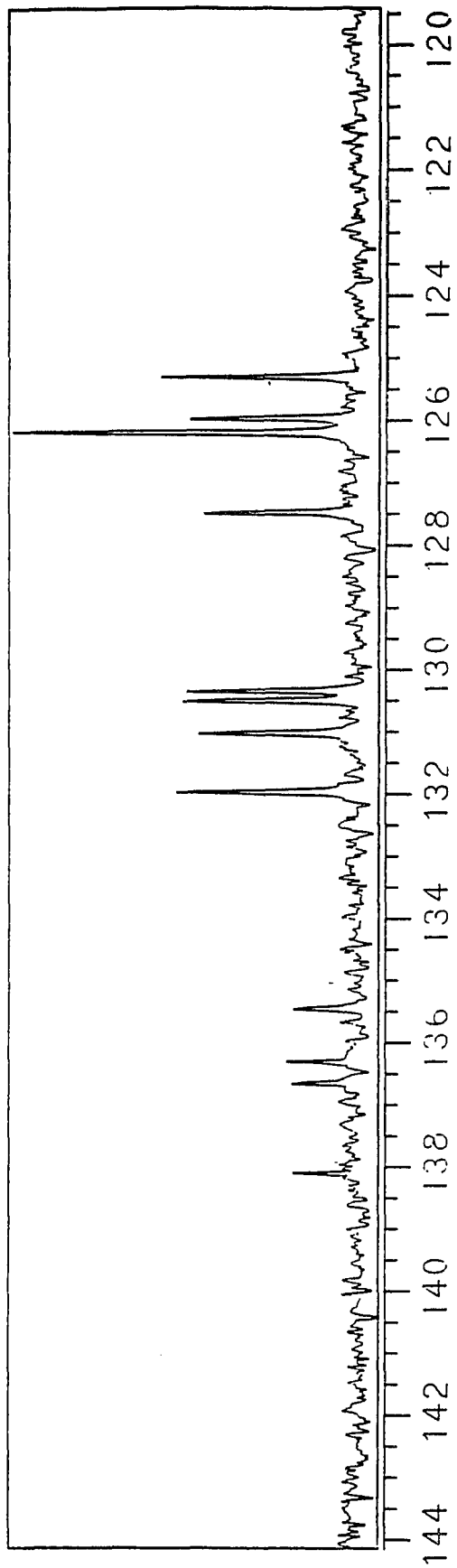


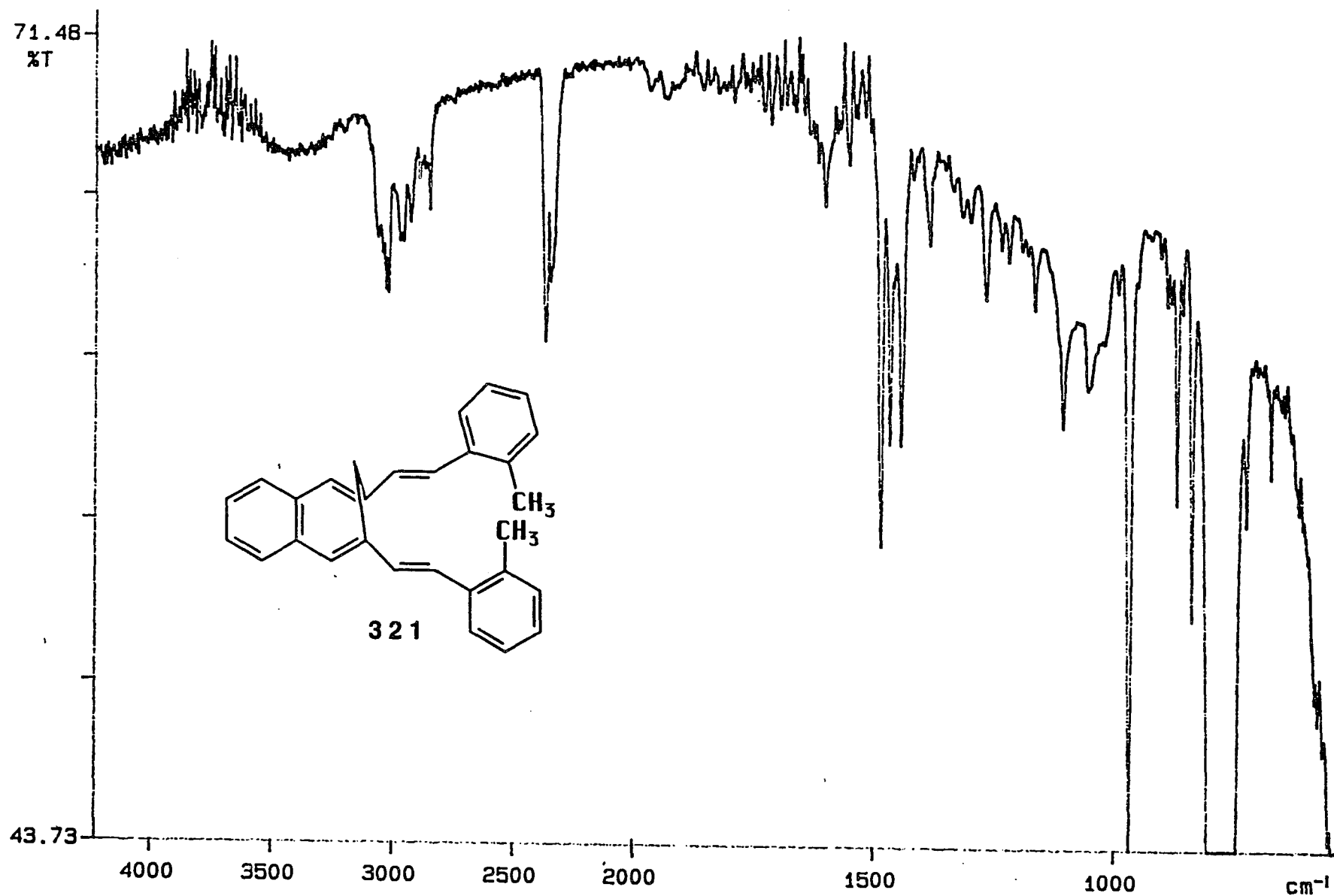
320





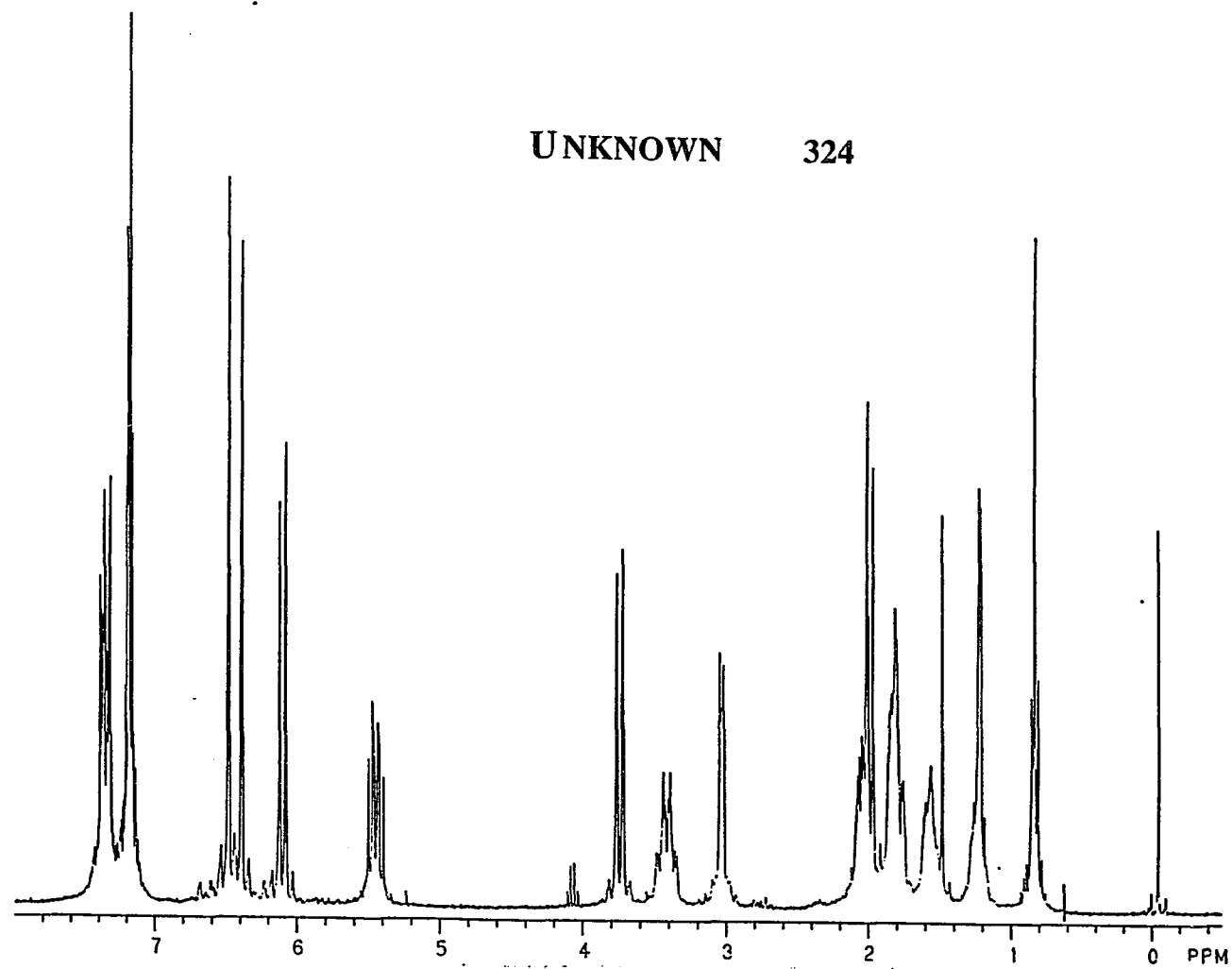
96/02/11 15:17
SCAN: 1 scan, 4.0cm⁻¹

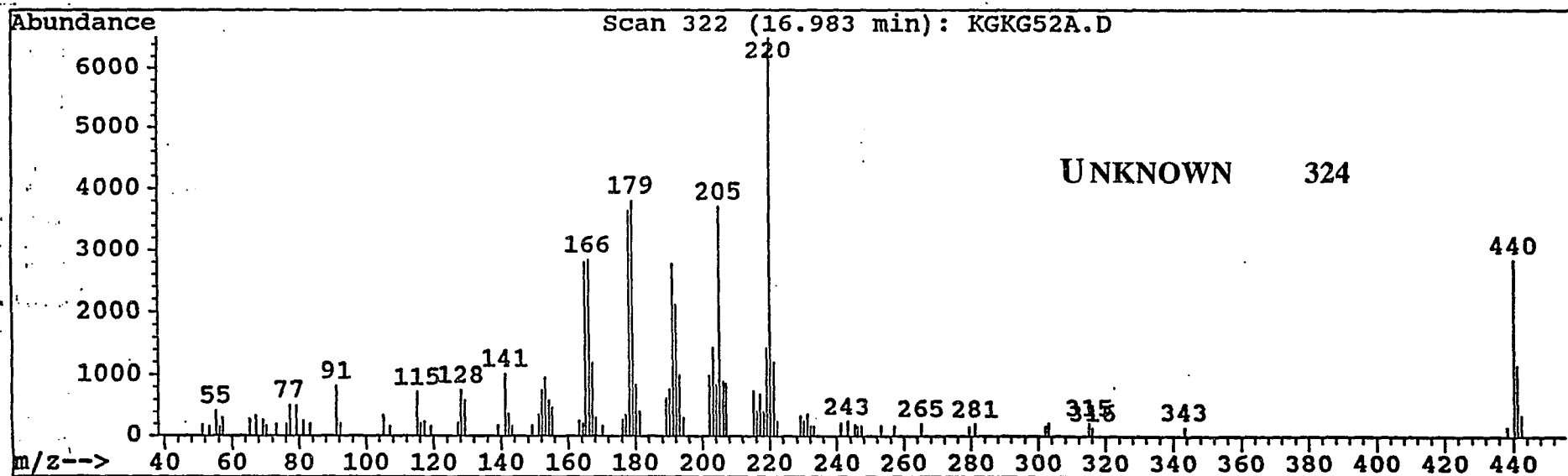


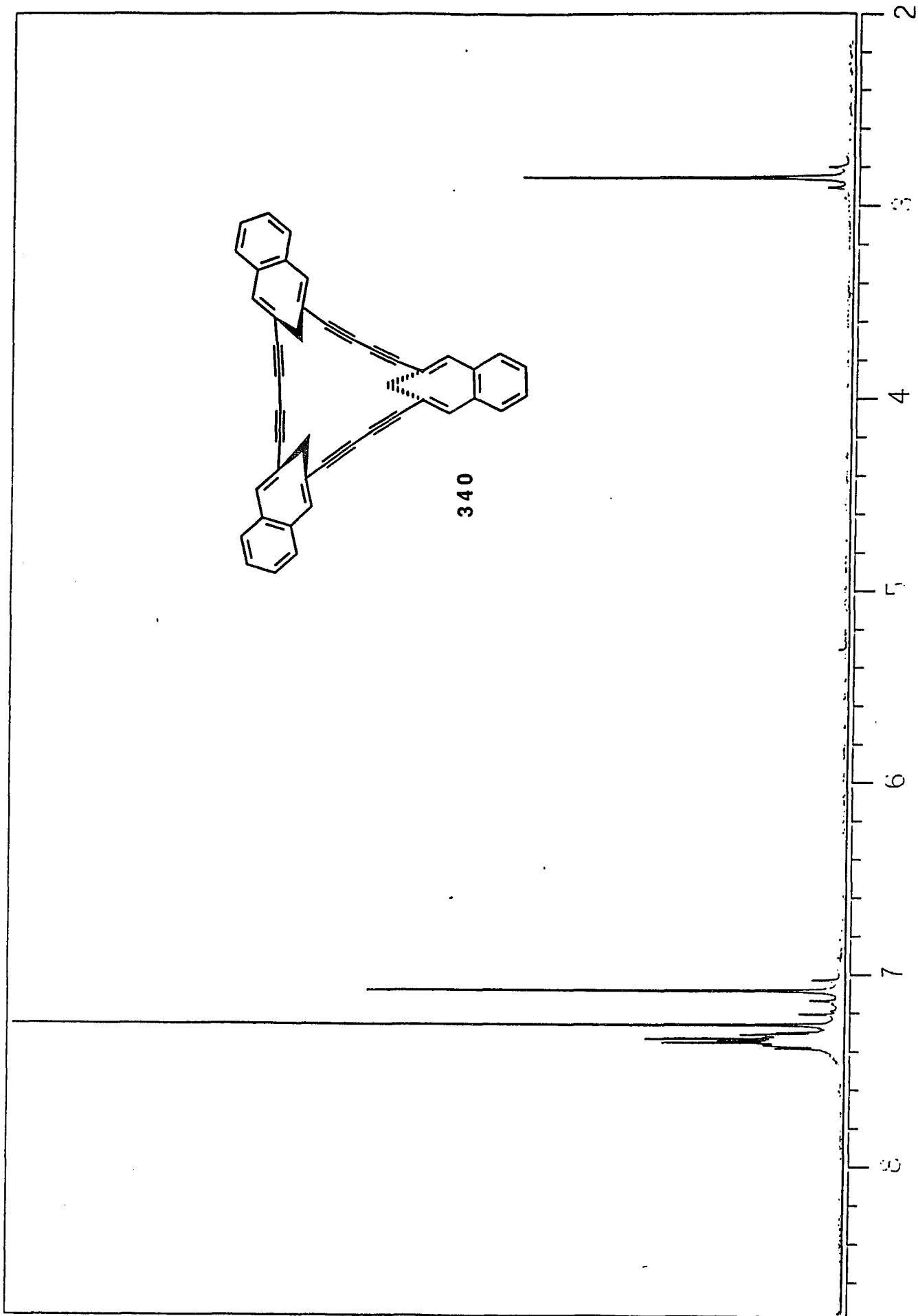
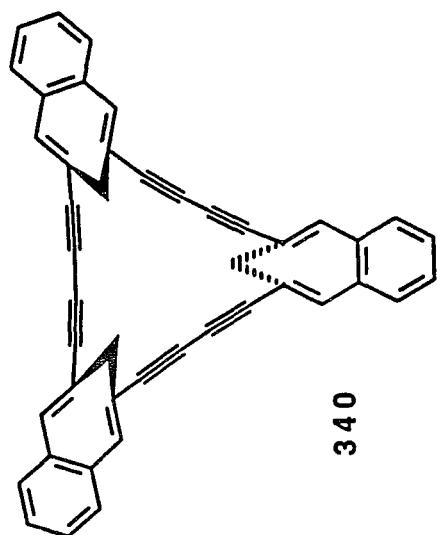


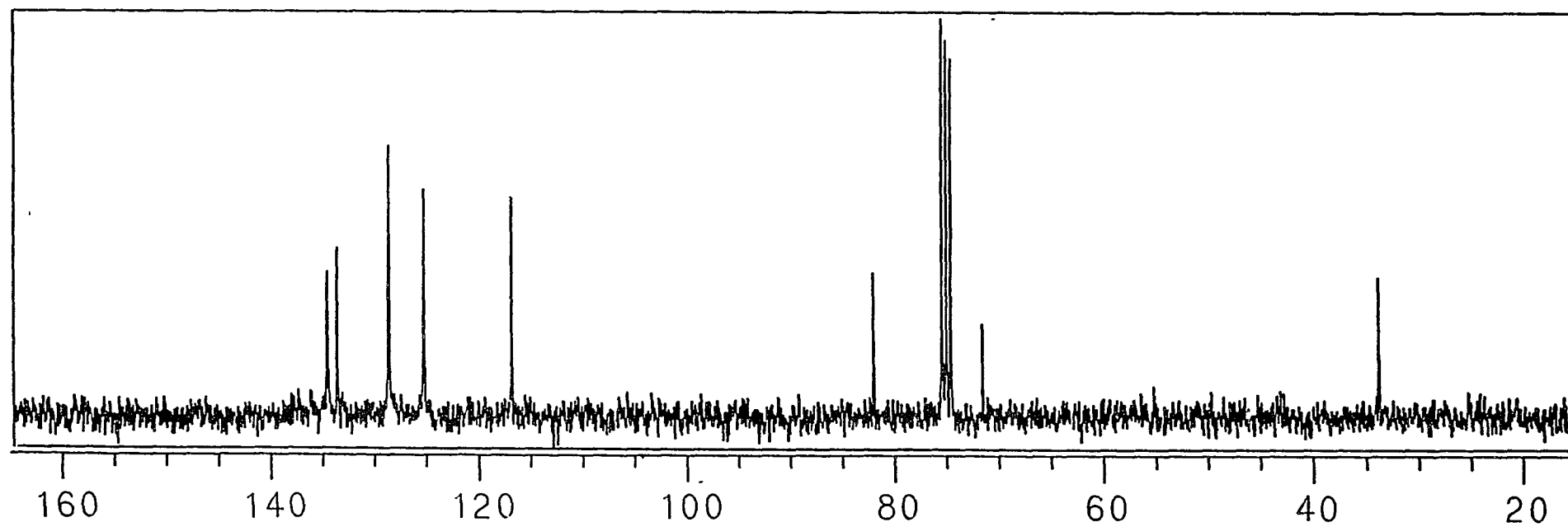
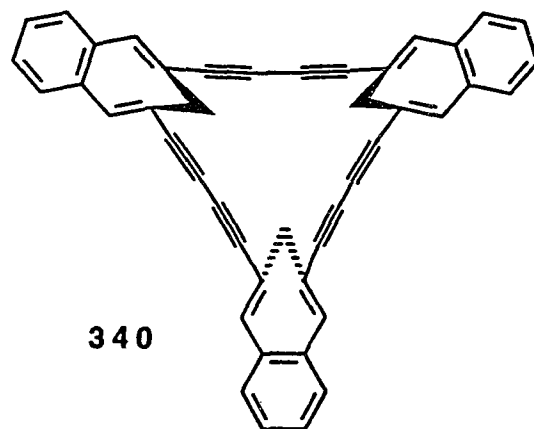
95/07/03 14:13
X: 1 scan, 4.0cm⁻¹, flat

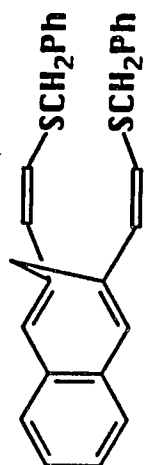
UNKNOWN 324





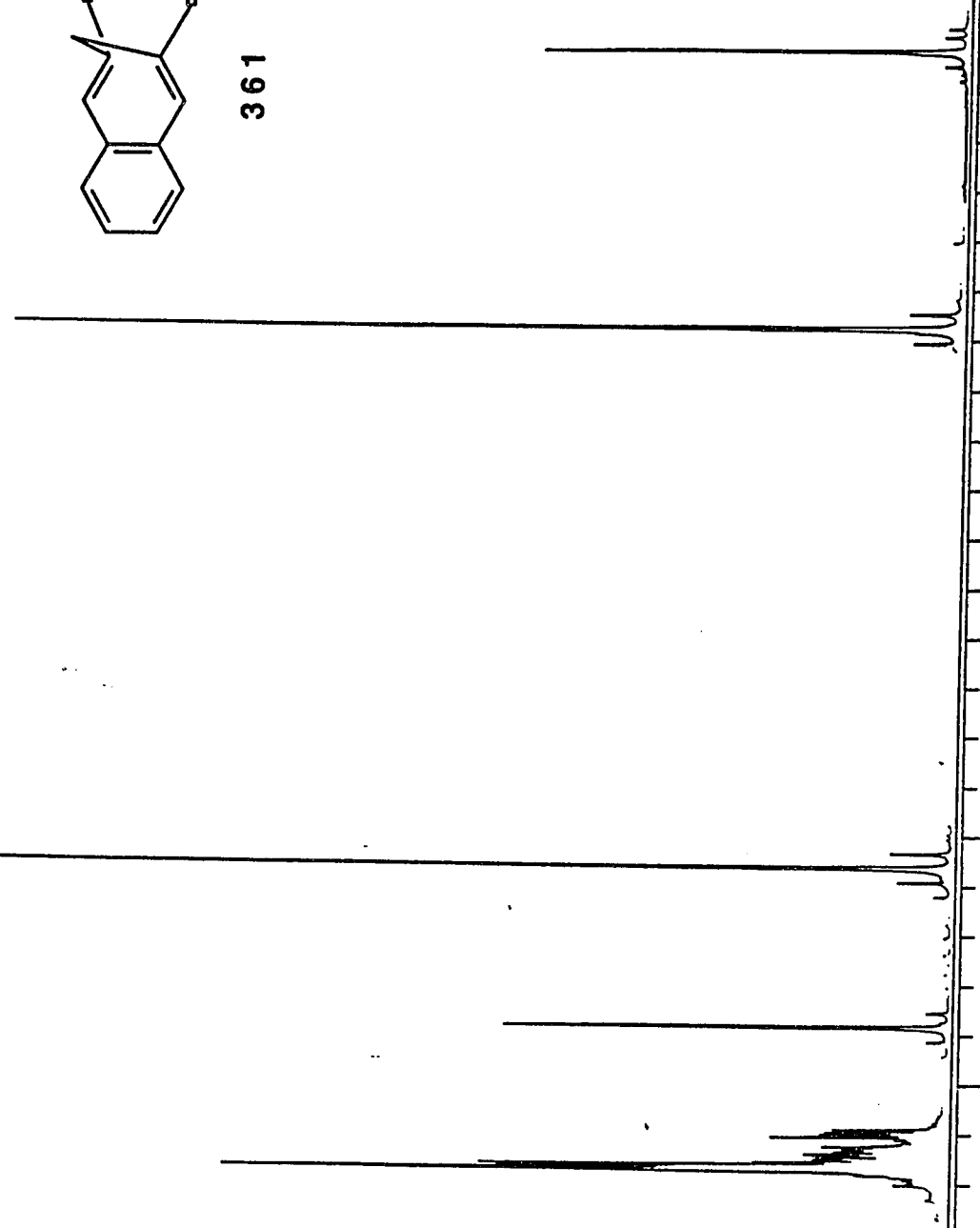


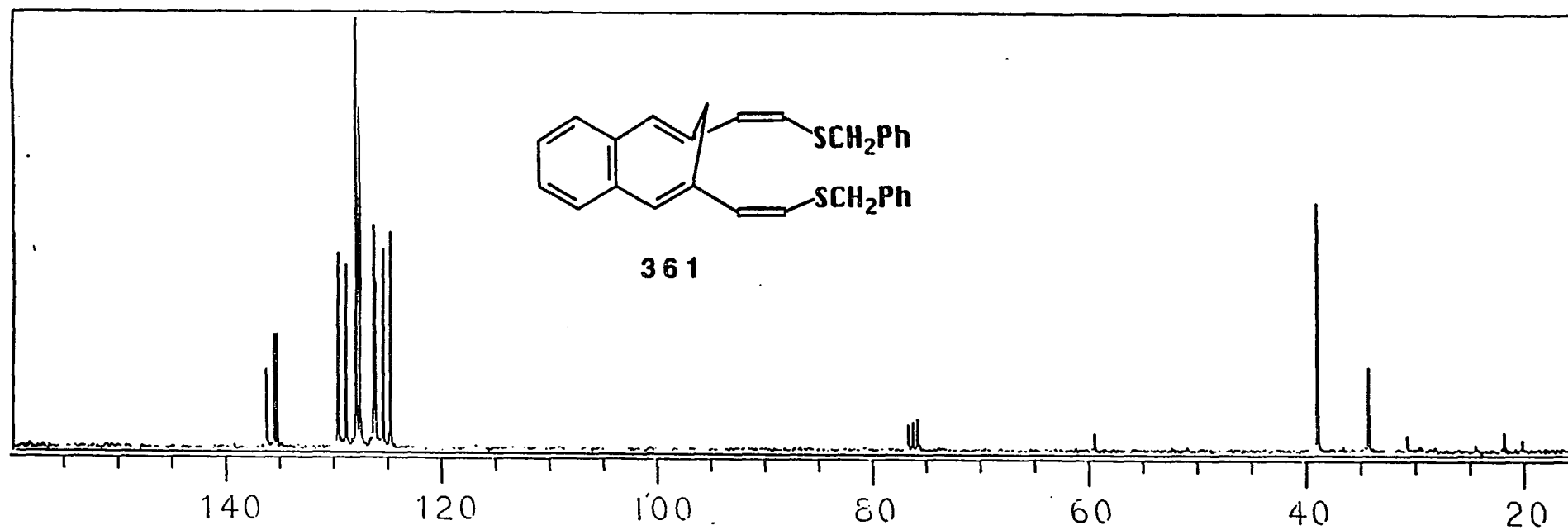


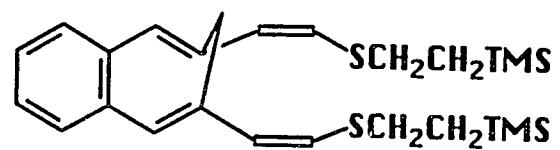


361

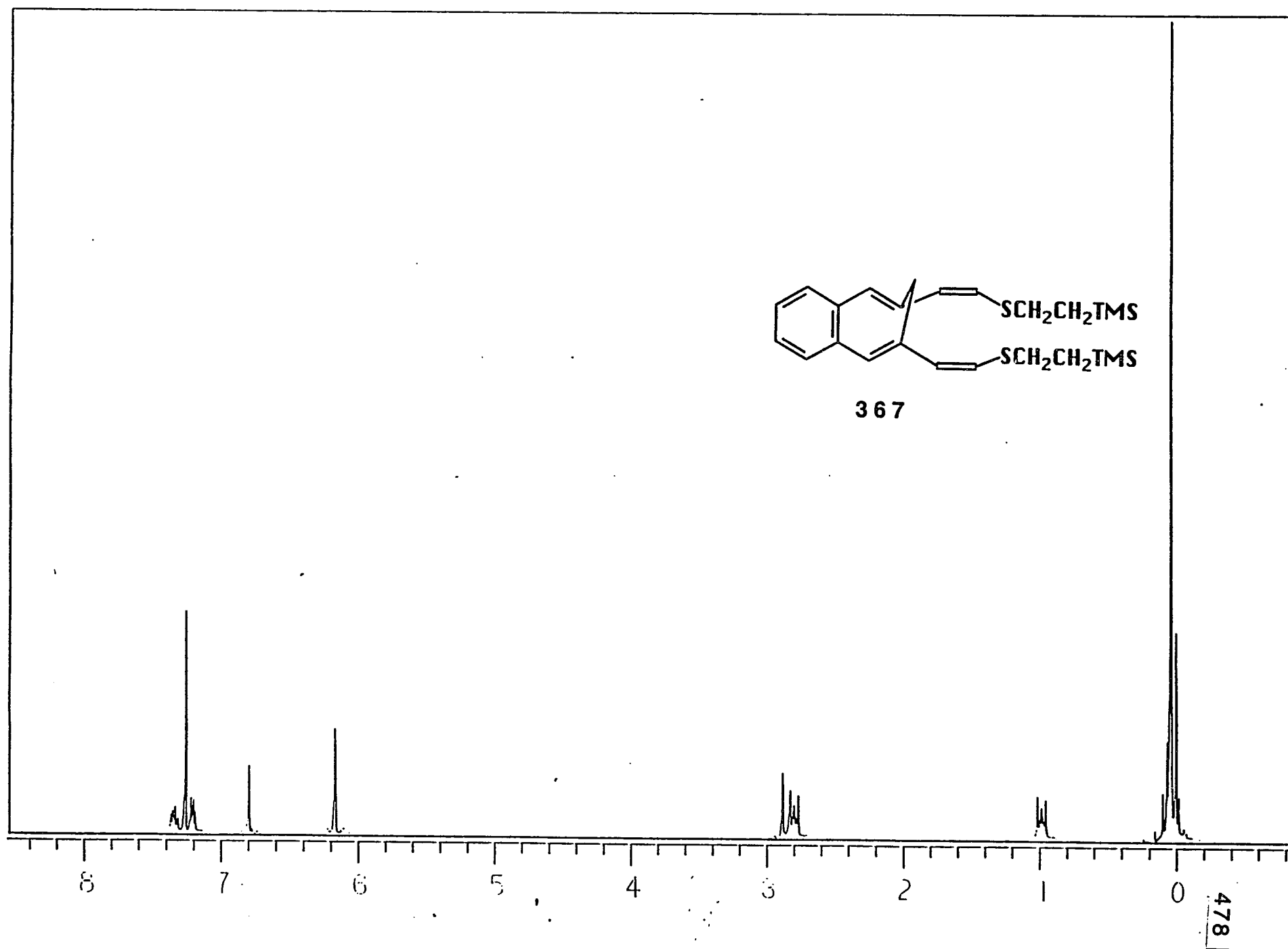
2 PPM
3
4
5
6
7
8

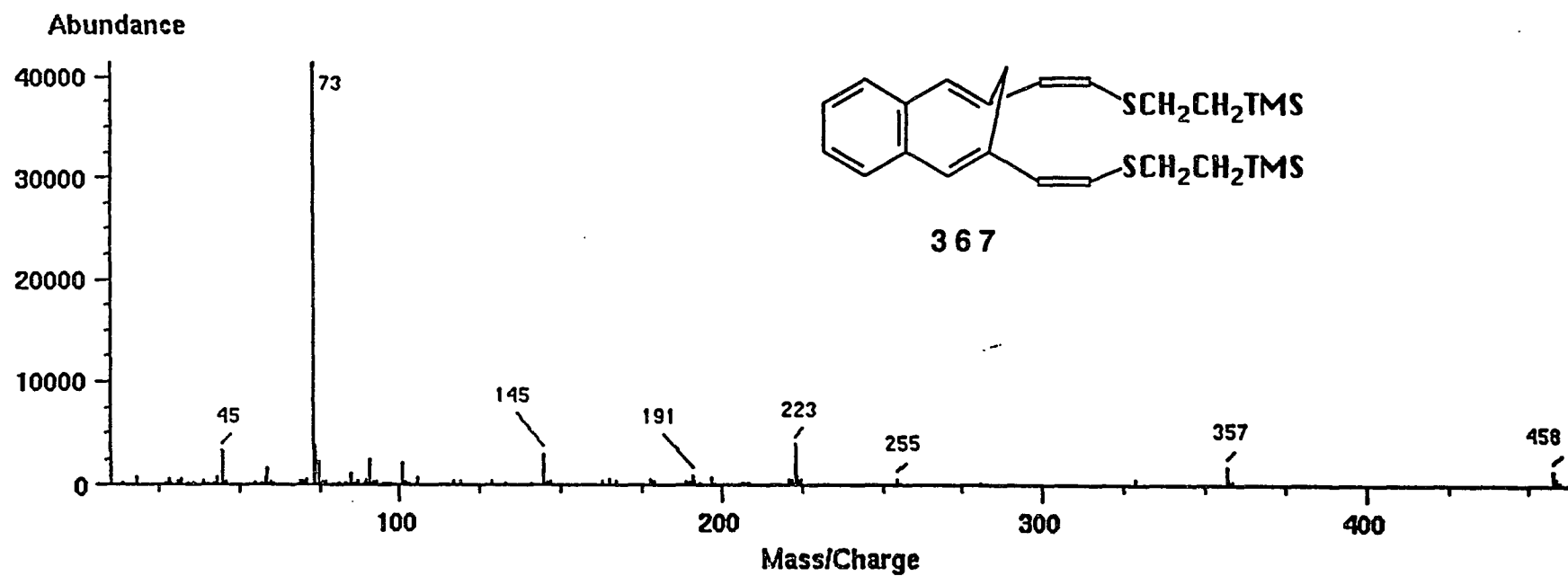




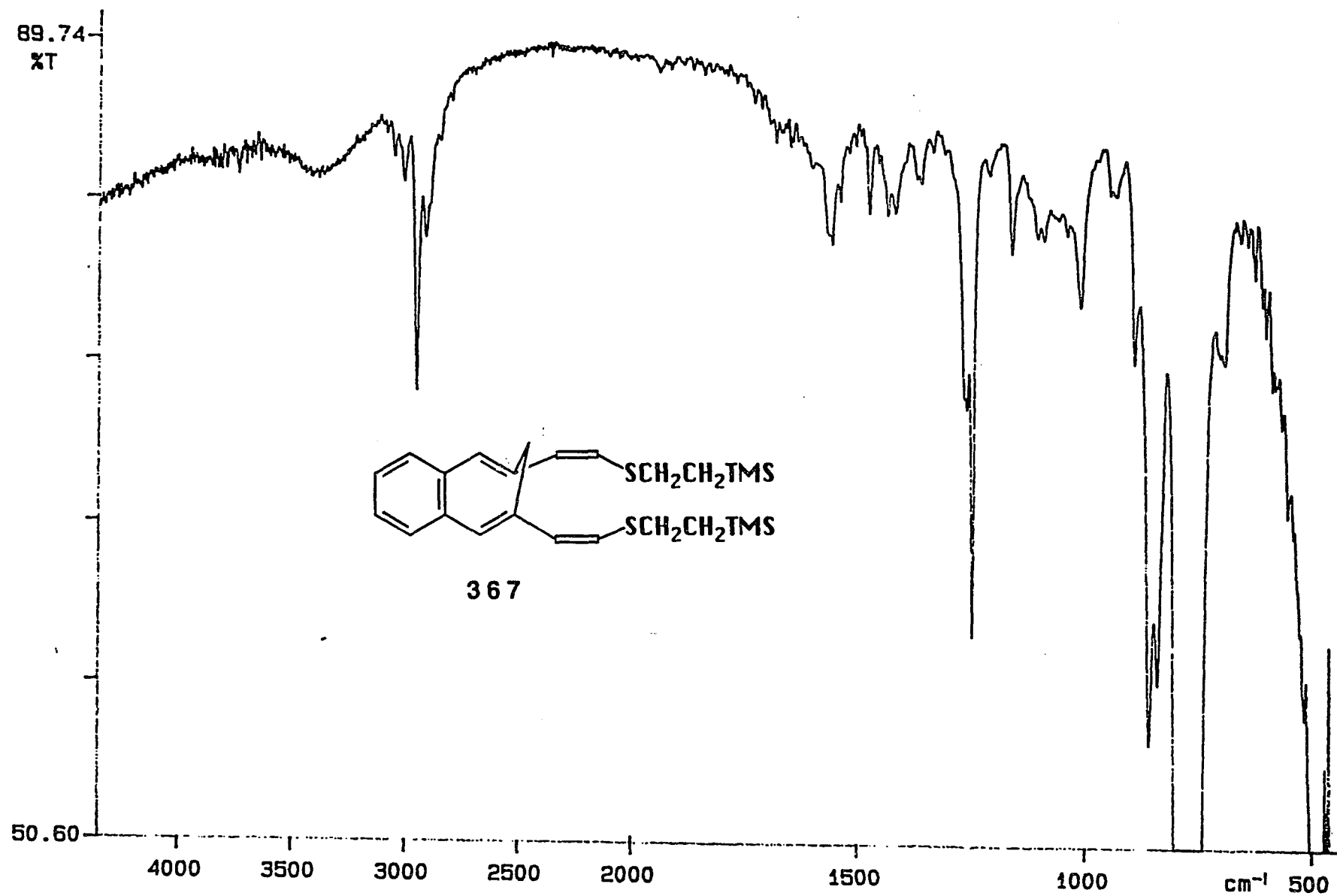


367



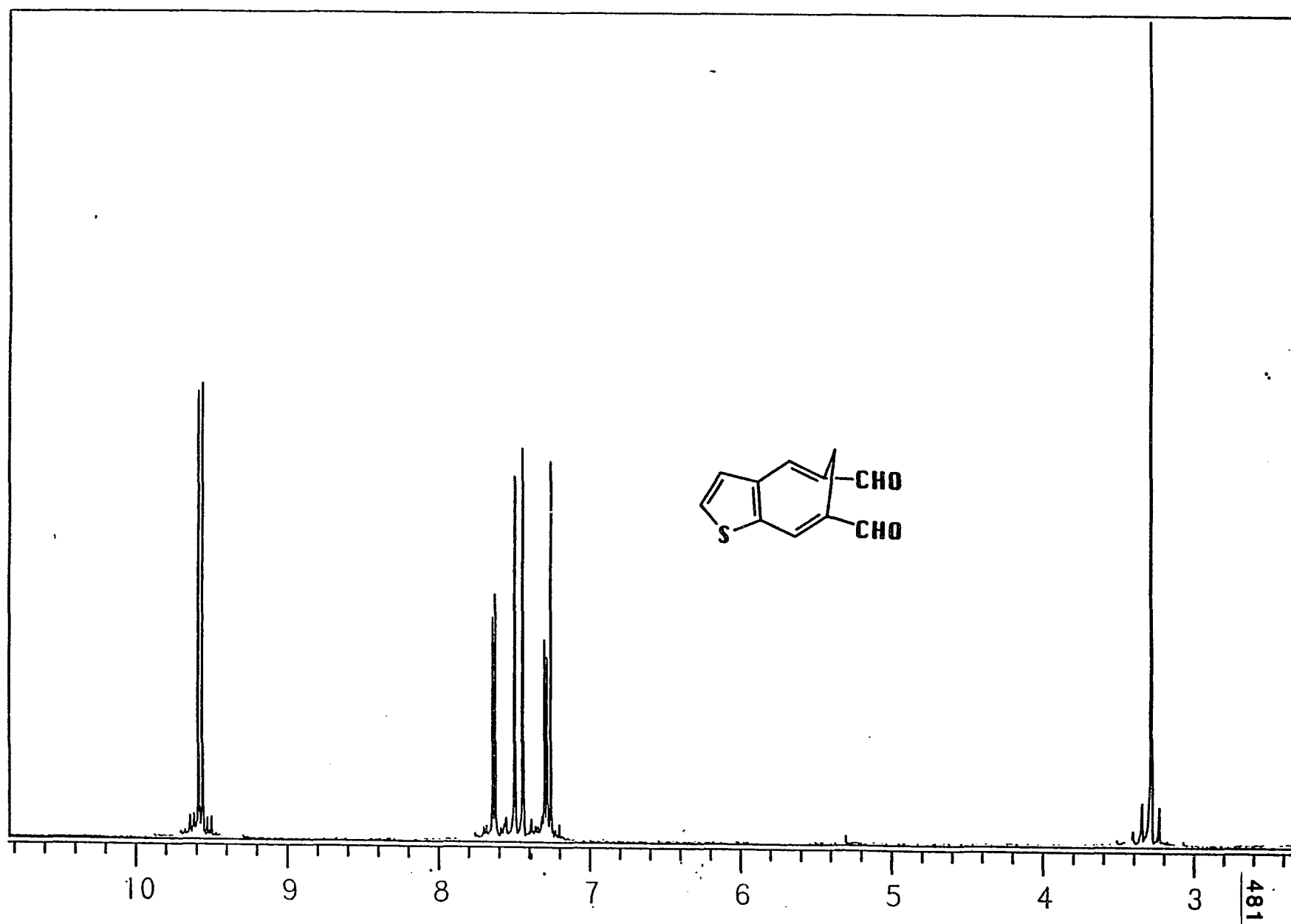


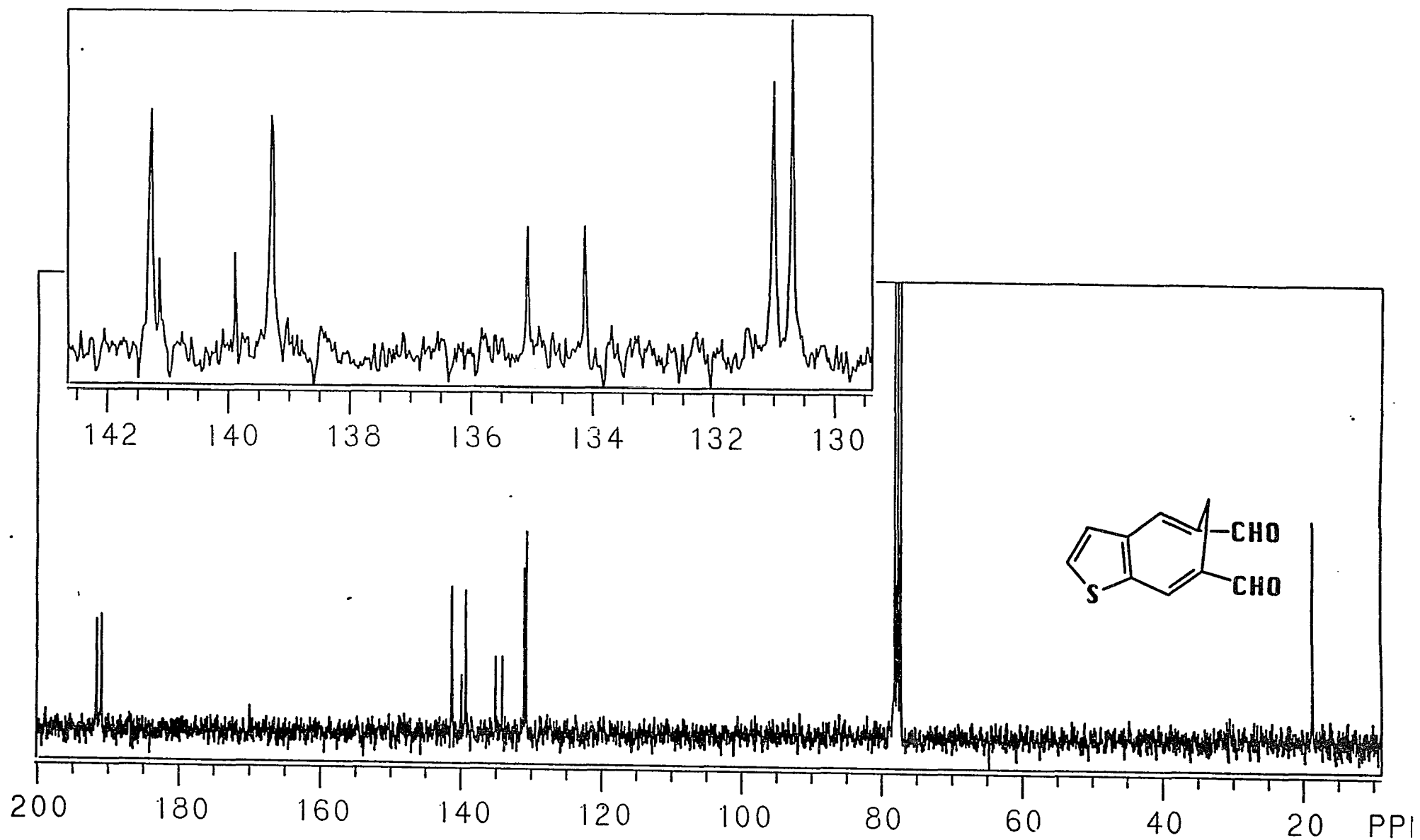
PERKIN ELMER

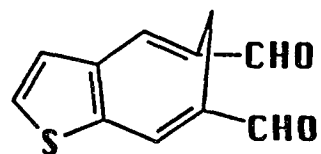
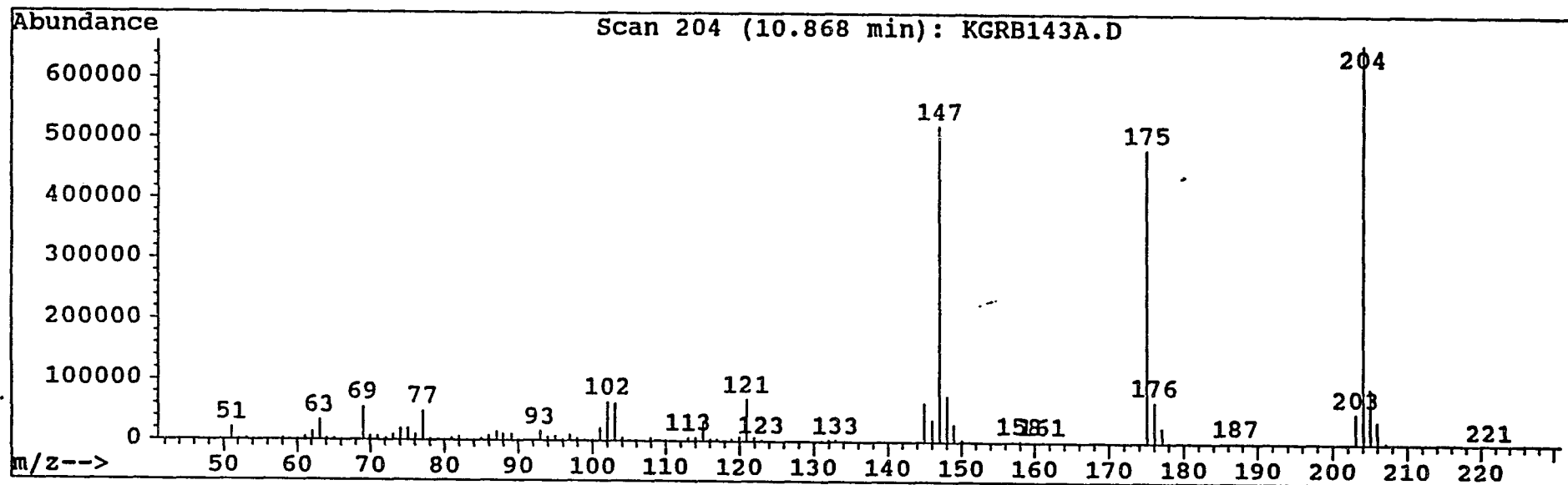


95/09/06 18:52

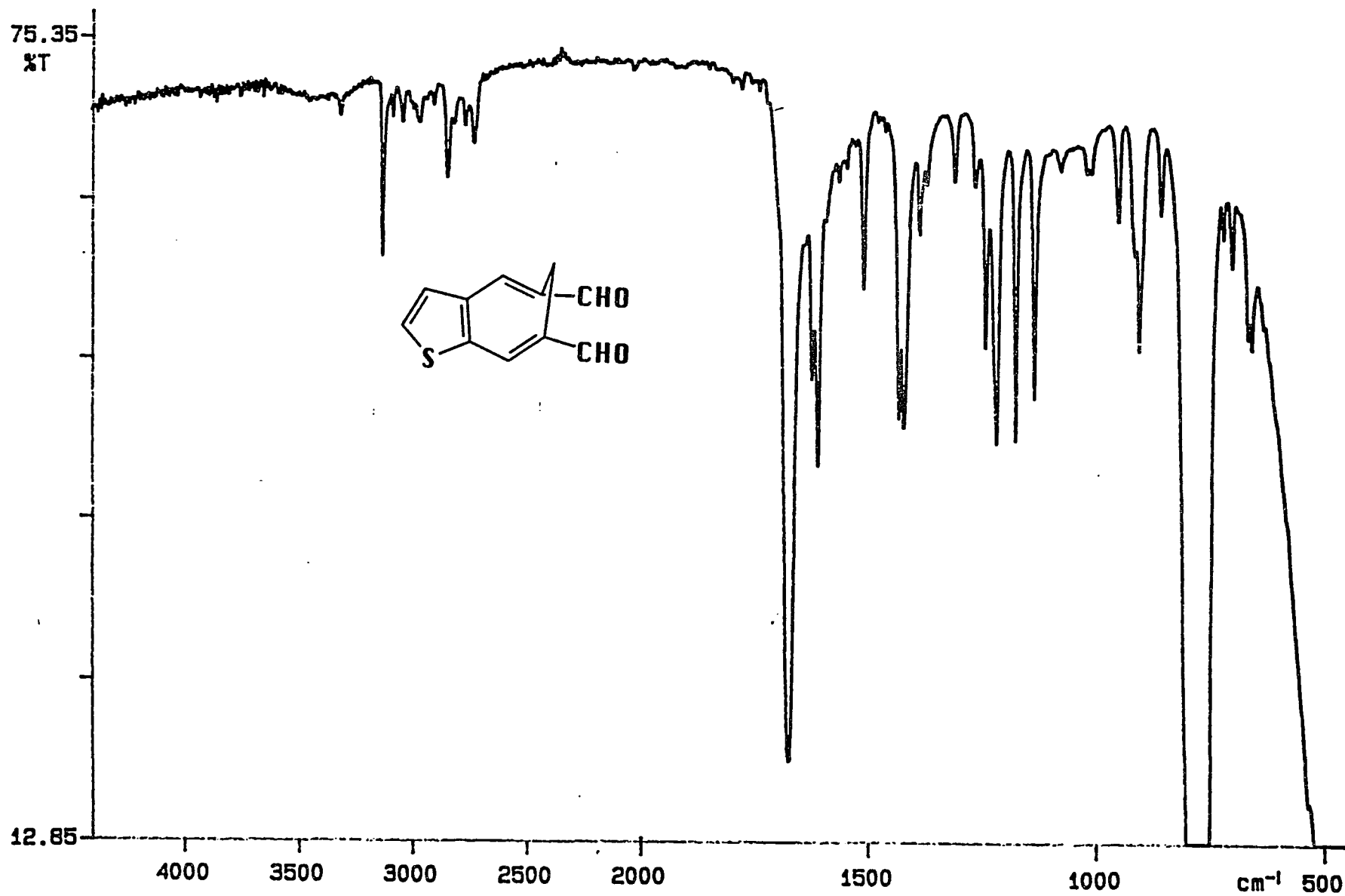
X: 1 scan, 4.0cm⁻¹, flat





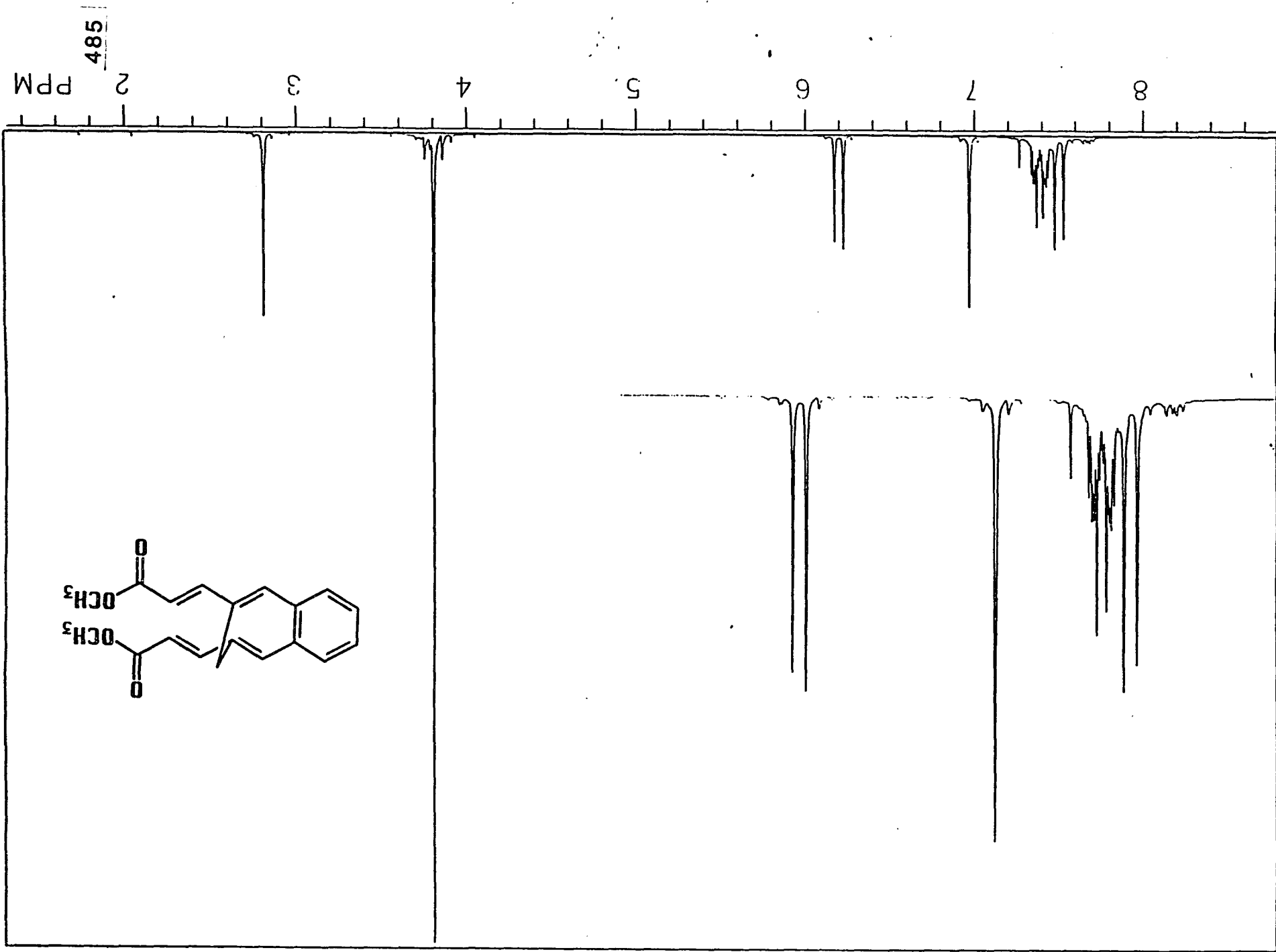


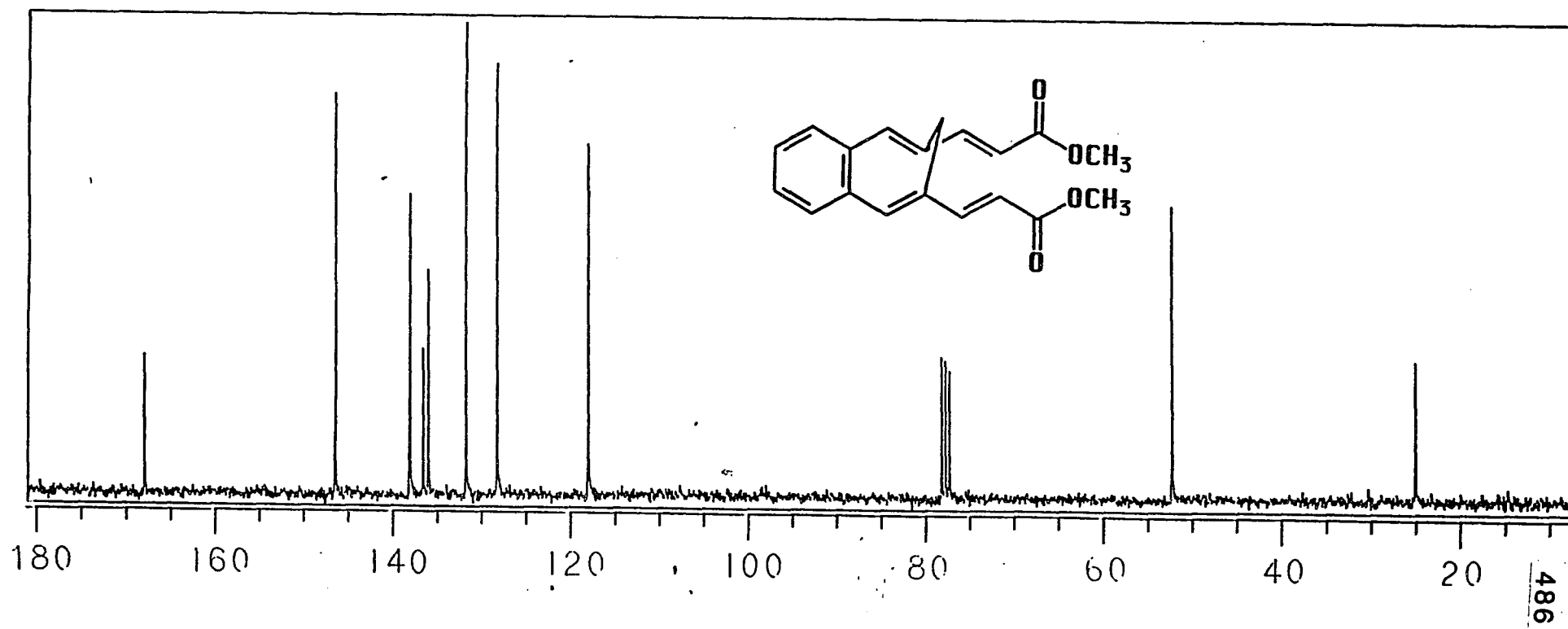
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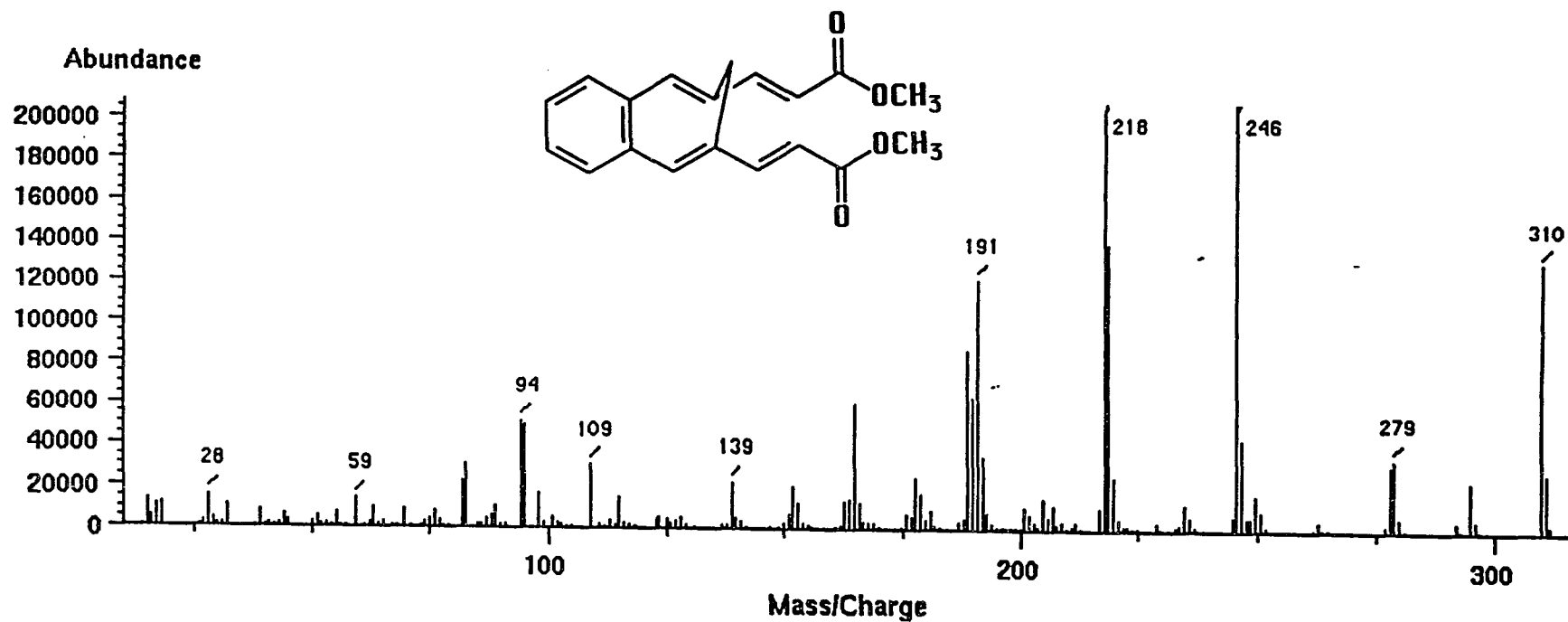


95/12/24 17:28

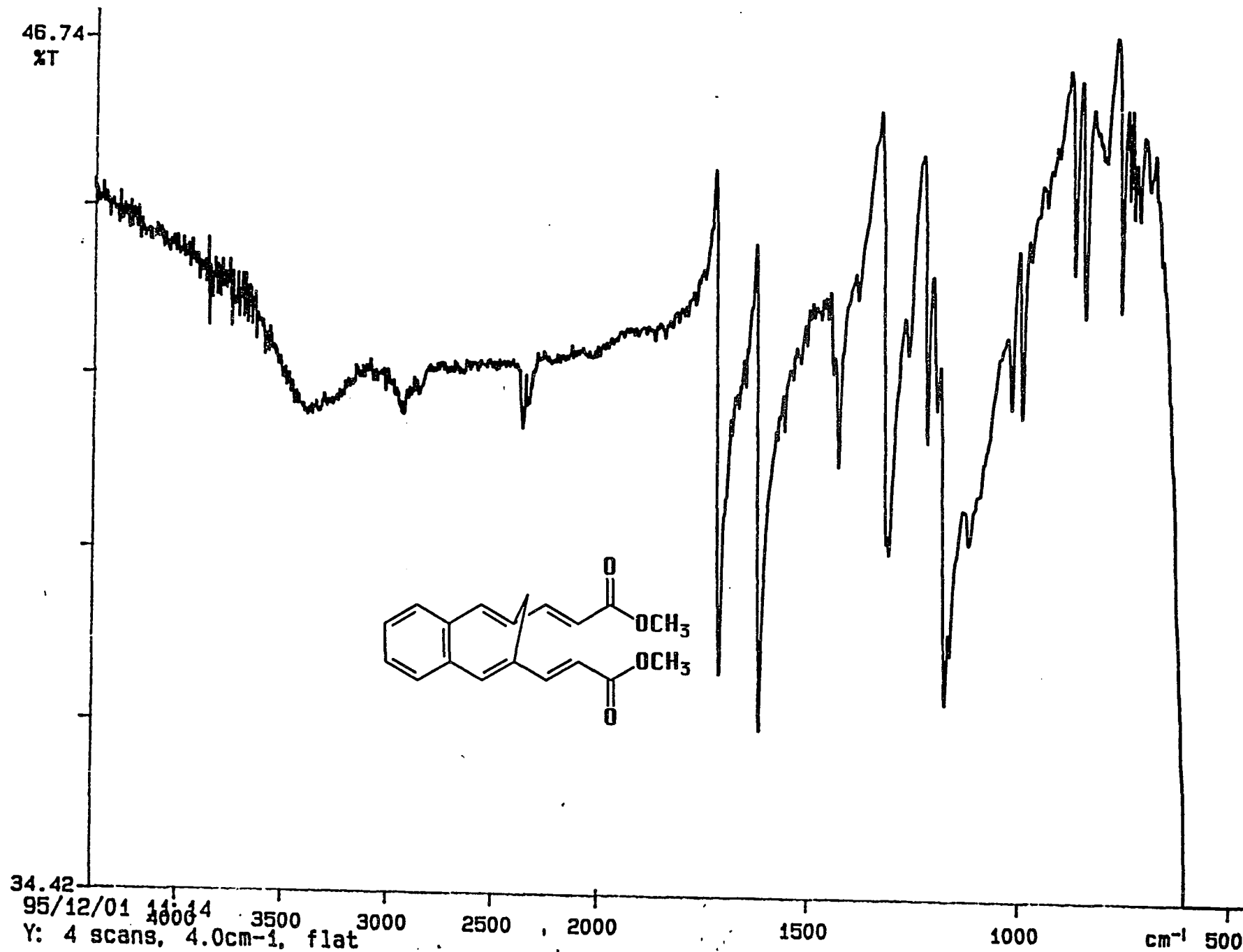
SCAN: 1 scan, 4.0cm⁻¹, flat

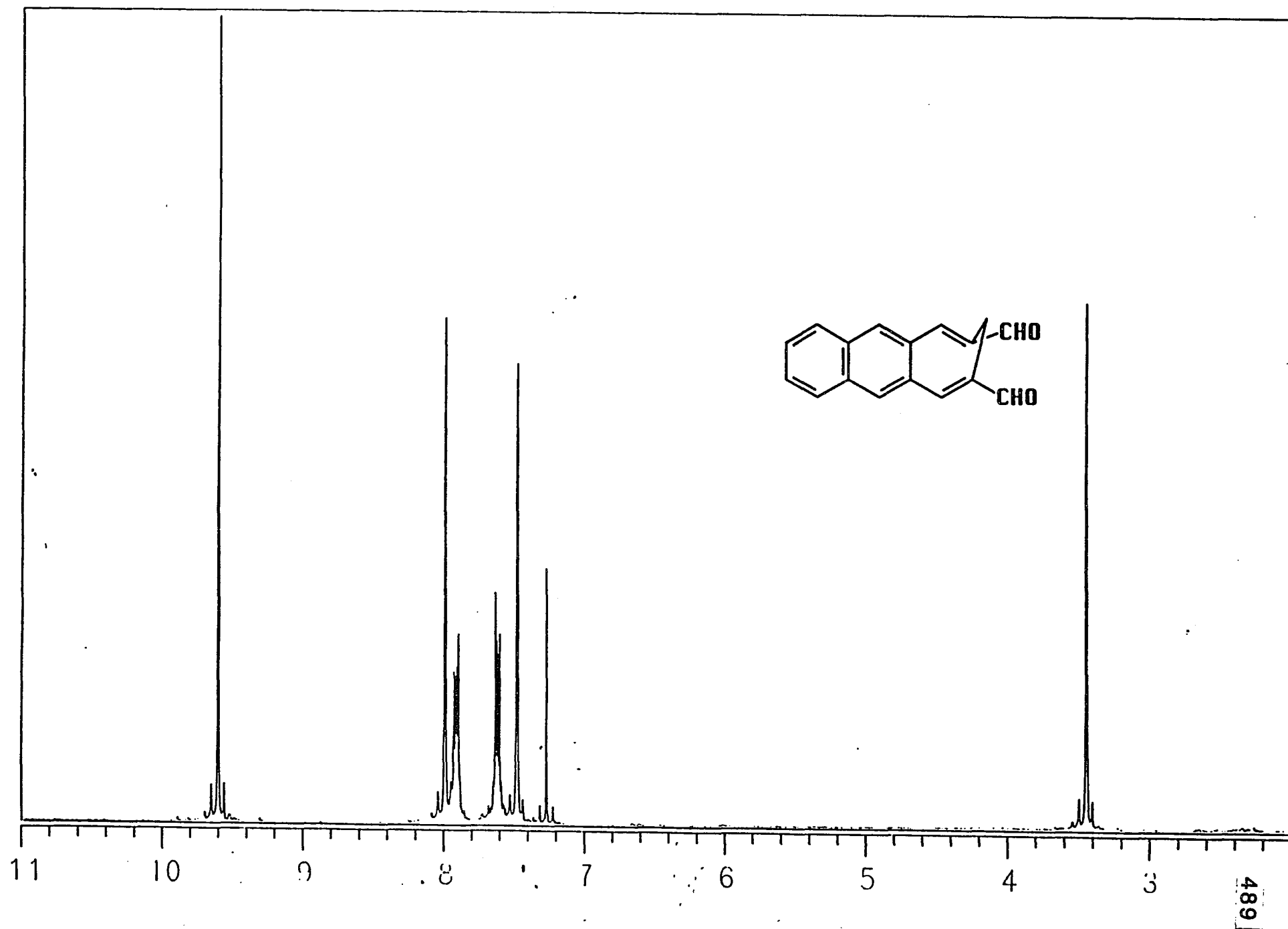


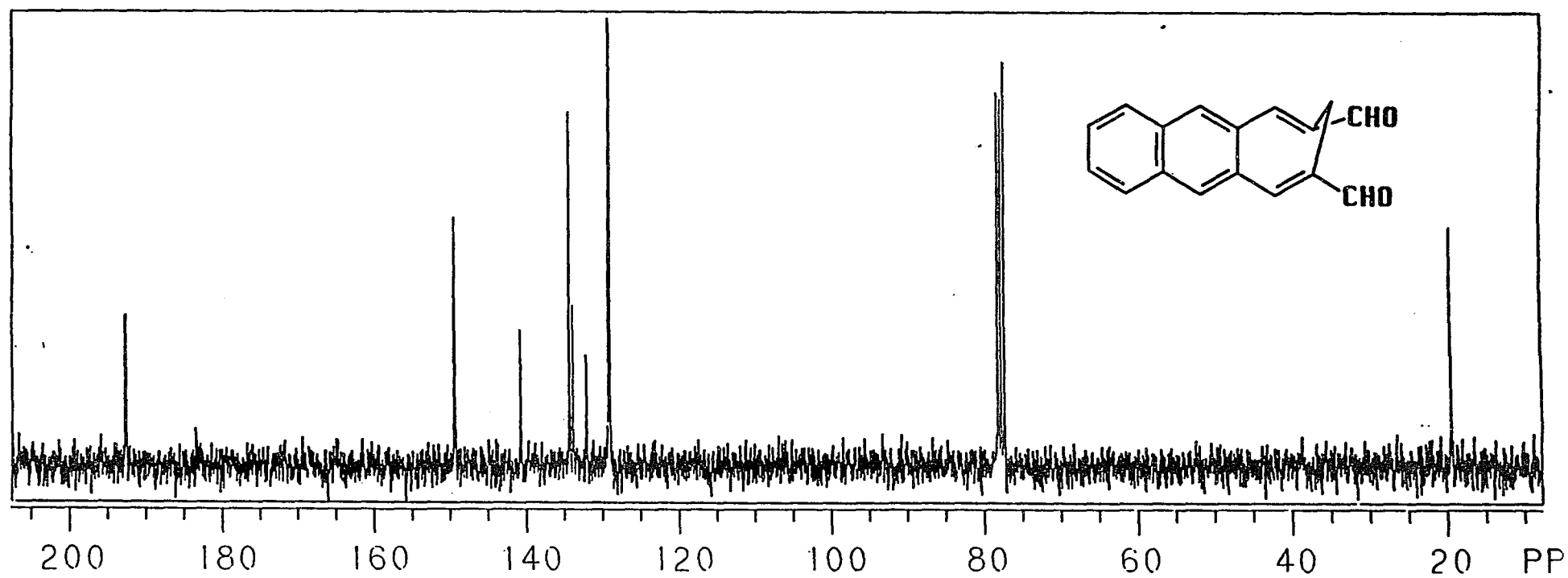
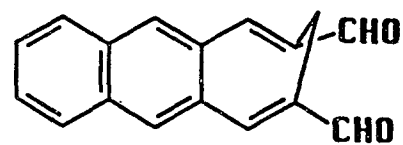


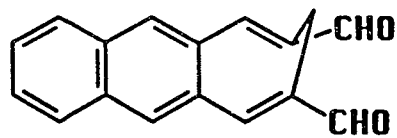
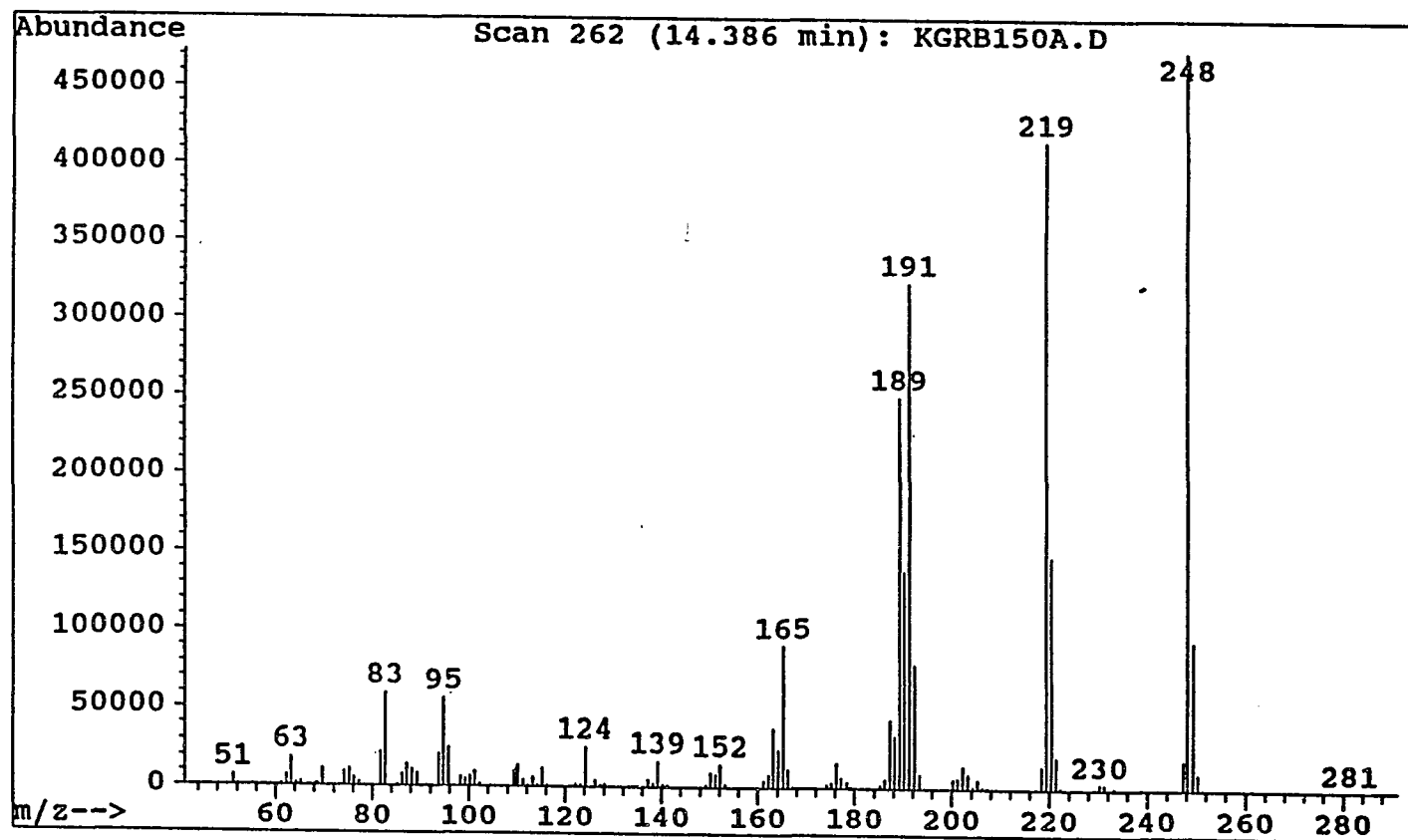


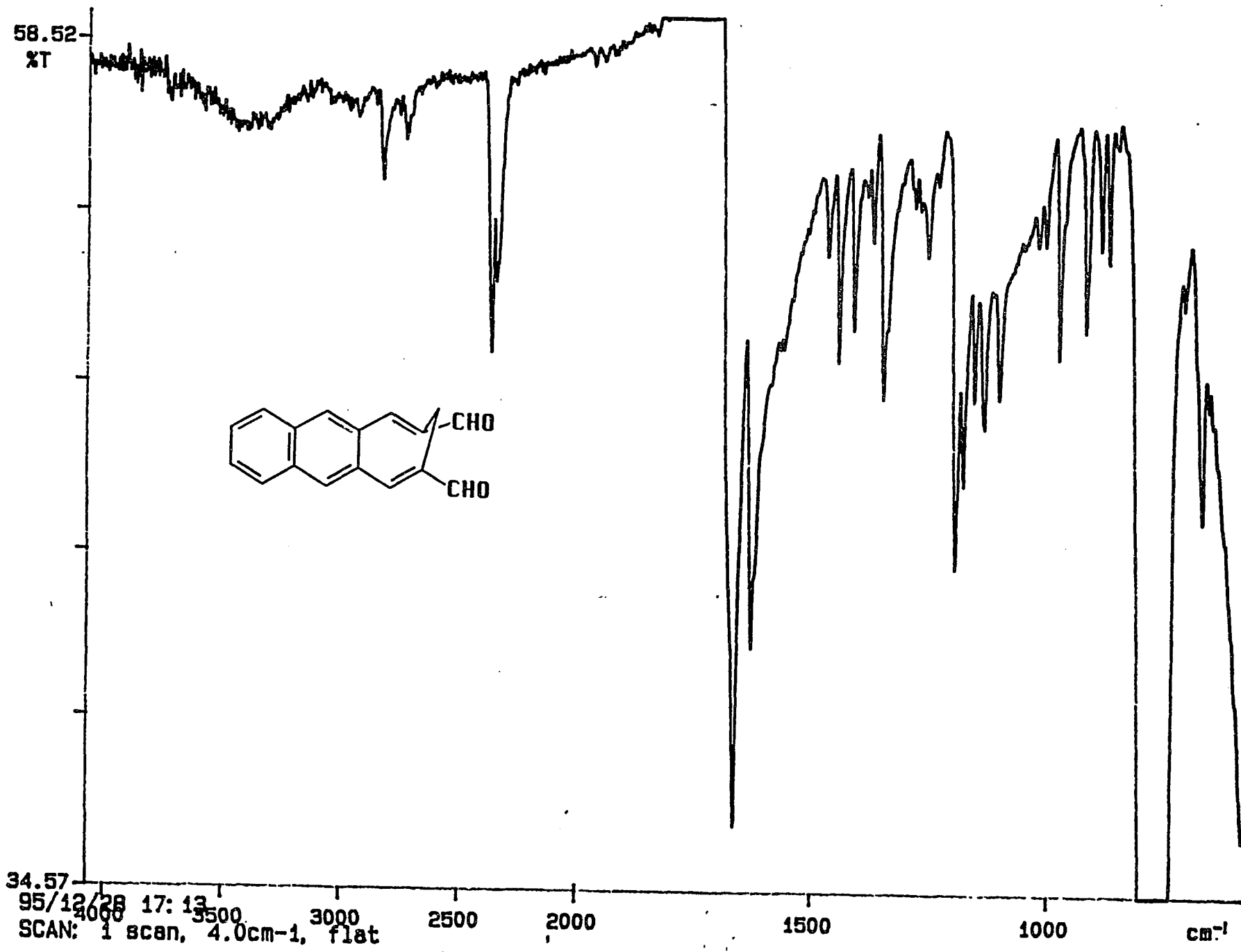
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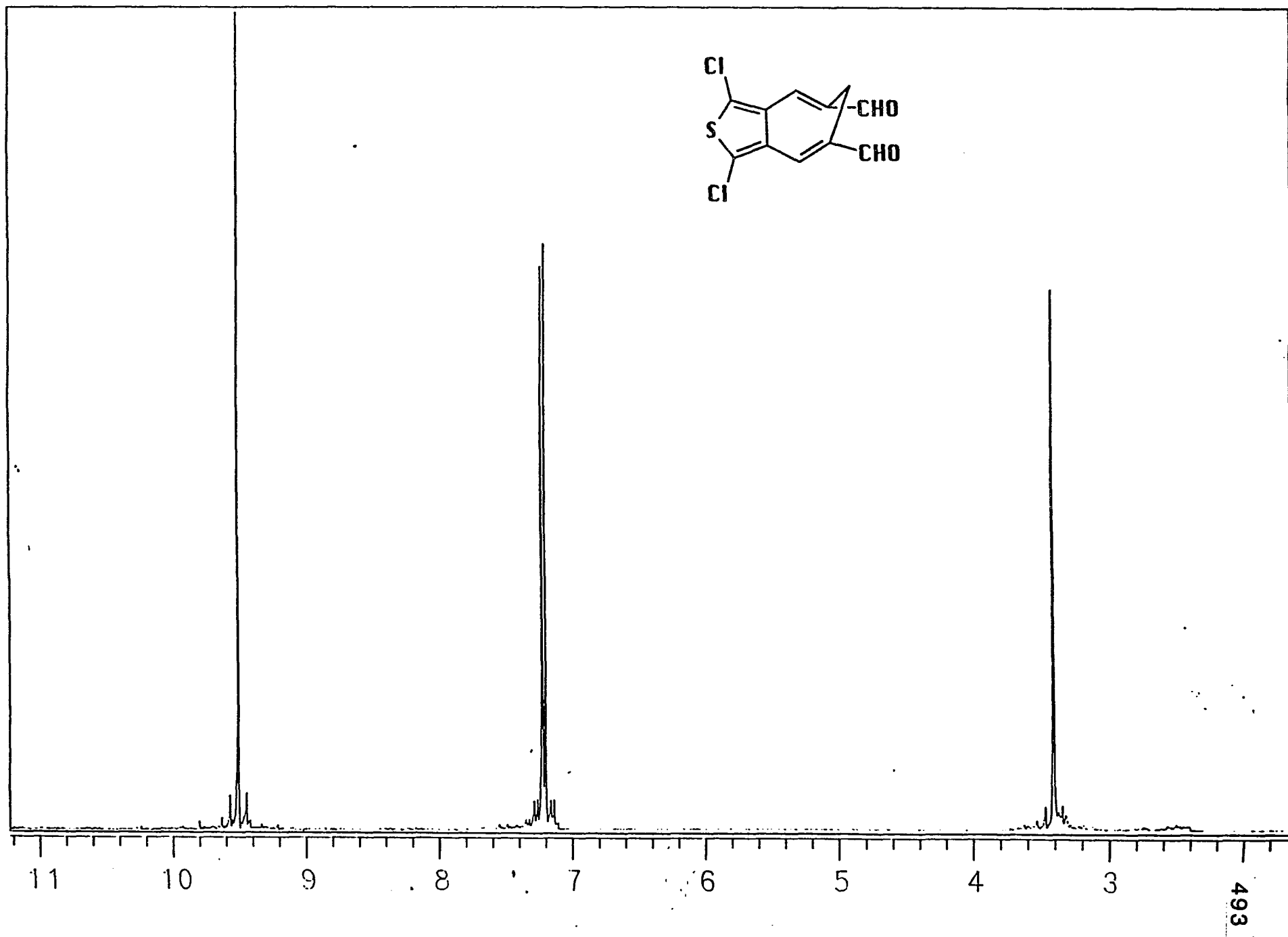
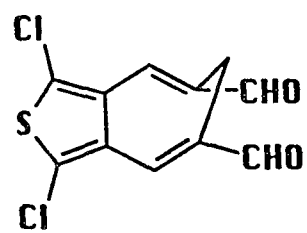


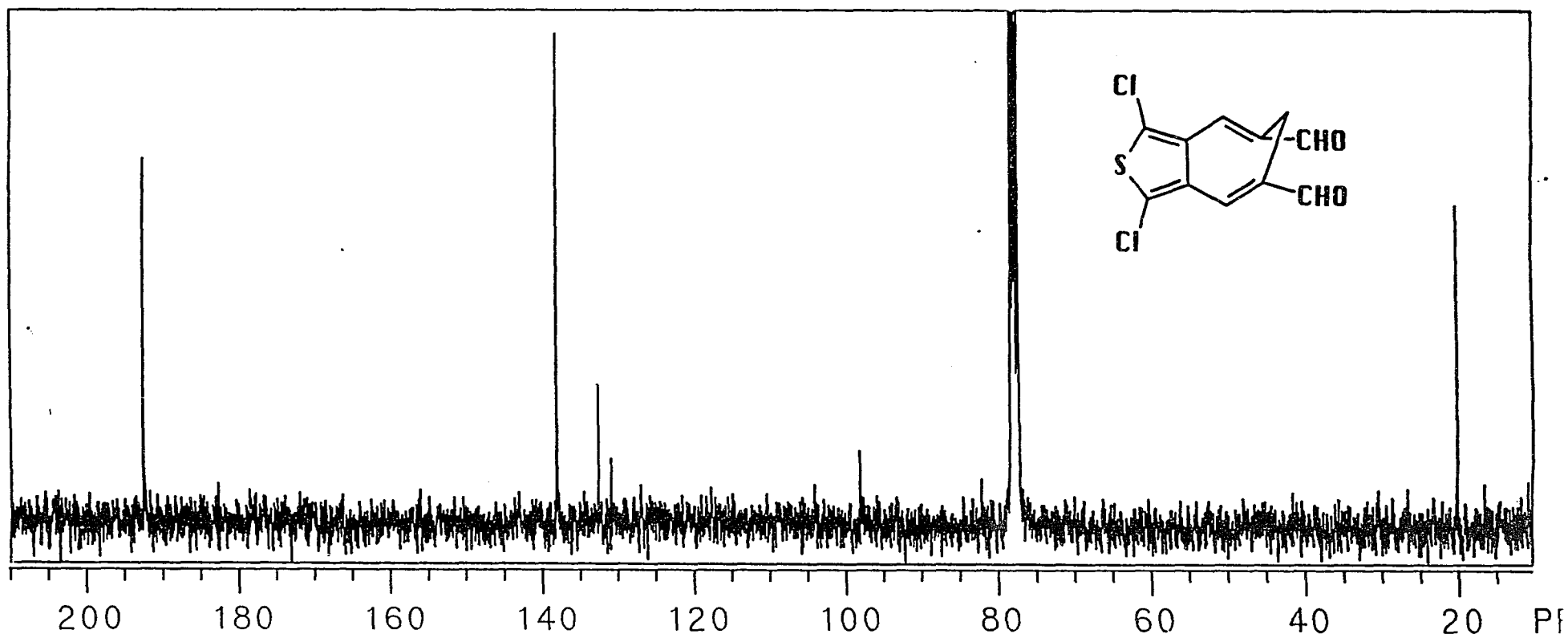


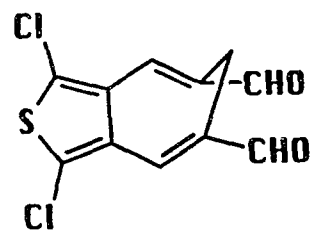
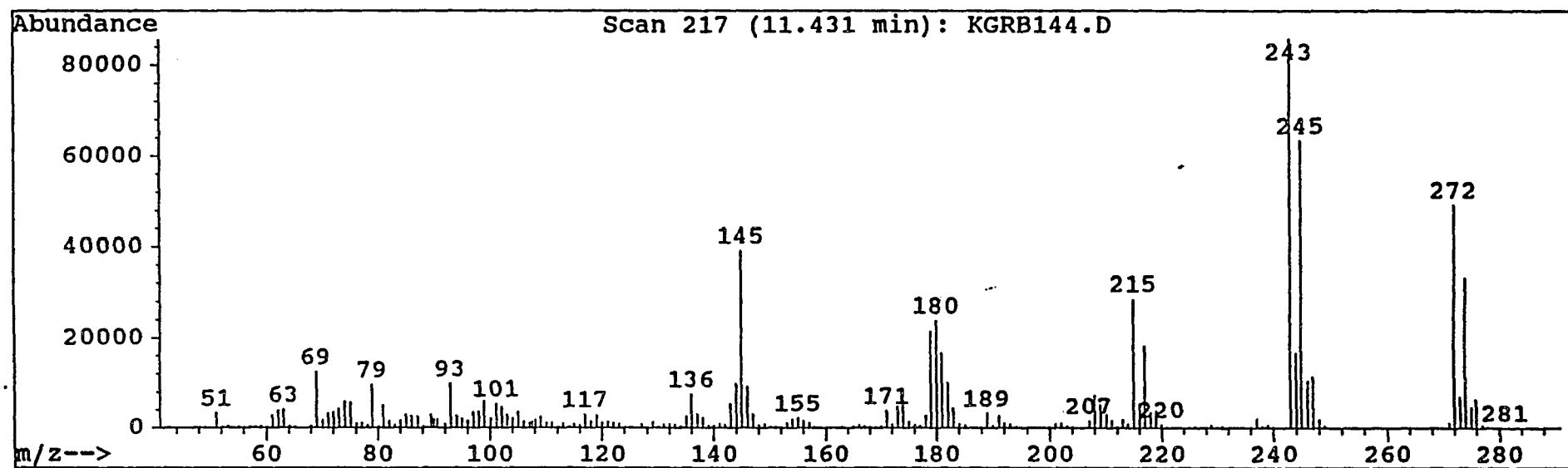


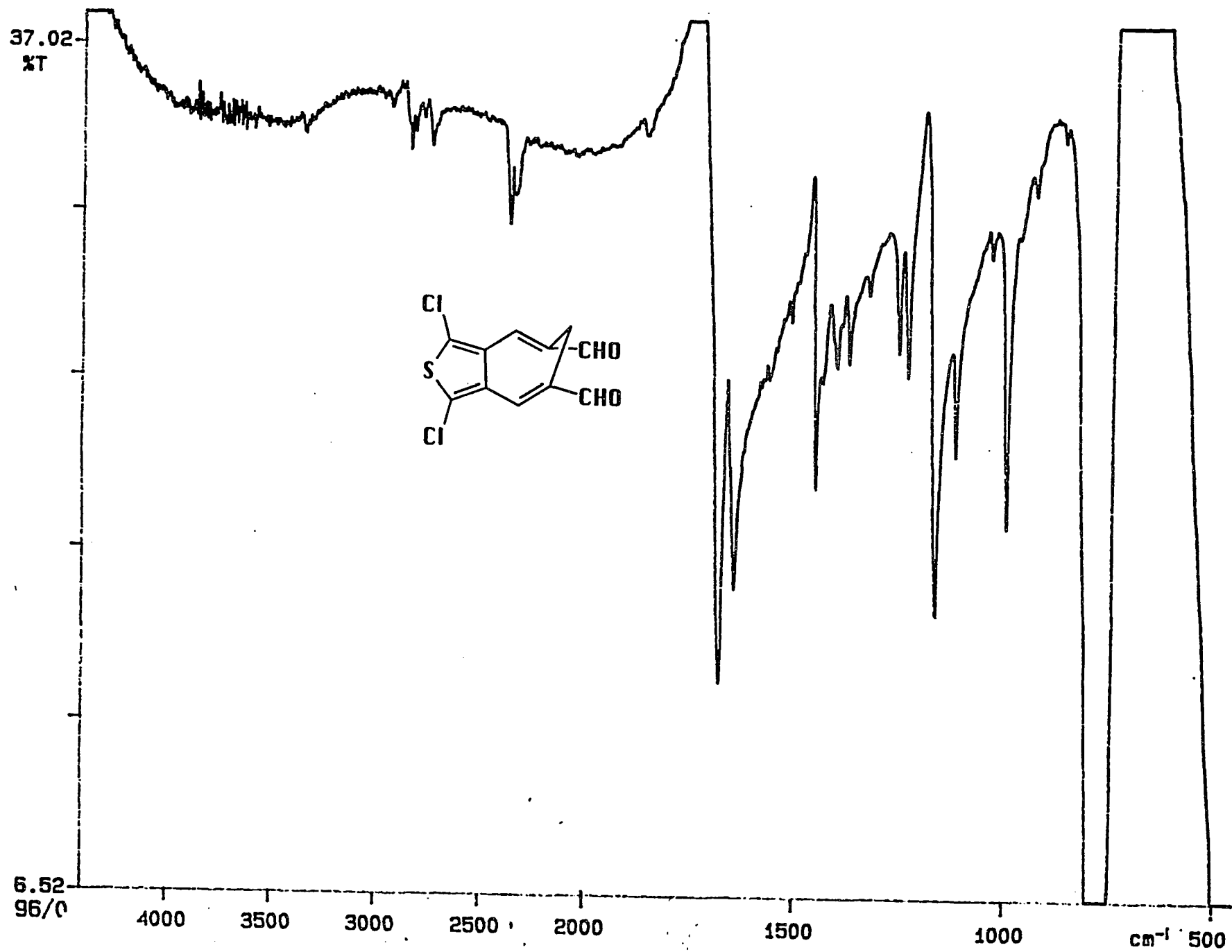












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