SYNTHESES AND STRUCTURES OF SUBSTITUTED POLYCYCLIC MOLECULES AND ANALYSIS OF THE TWO-DIMENSIONAL NMR SPECTRUM OF THIELE'S ESTER

THESIS

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By

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Diels-Alder cycloaddition of methylcyclopentadienes to 2,5-dibromo-p-benzoquinone was performed. A single, isomerically pure cycloadduct was isolated, whose structure was assigned via analysis of its 1-D and 2-D NMR spectra.

Diels-Alder cycloaddition of methylcyclopentadienes to 2-methoxy-p-benzoquinone was performed. A single, isomerically pure cycloadduct was isolated, whose structure was assigned via analysis of the 1-D and 2-D NMR spectra of this cycloadduct and its reduction product obtained via stereo-specific reduction with sodium borohydride in the presence of cerous chloride.

The structure of Thiele's ester was assigned via analysis of its 1-D and 2-D NMR spectra.

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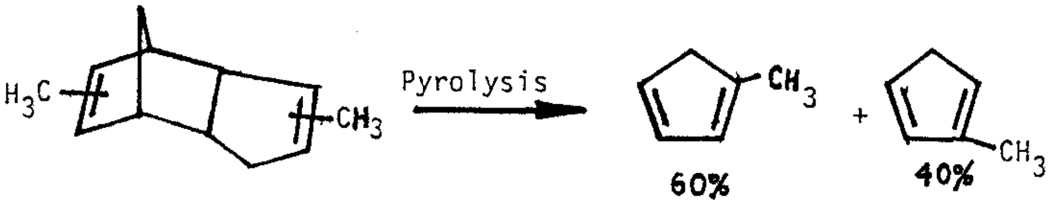
CHAPTER I

SYNTHESIS AND STRUCTURE OF A NEW BROMO-SUBSTITUTED POLYCYCLIC MOLECULE

Introduction

Diels-Alder cycloaddition of substituted cyclopentadienes to substituted-p-benzoquinones results in the tricyclic compounds which are of current interest as intermediates in the syntheses of novel polycyclic compounds. In the present work an investigation of Diels-Alder cycloaddition of methylcyclopentadienes to 2,5-dibromo-p-benzoquinone was undertaken as part of a continuing study of the chemistry of substituted pentacyclo[$5.4.0.0^{2,6}.0^{3,10}.^{5,9}$]undecanes.

Pyrolysis of the commercial methylcyclopentadiene dimer 1 (1) yields a mixture of 1-methylcyclopentadiene 2 and 2-methylcyclopentadiene 3. Diels-Alder cycloaddition of this diene mixture to 2,5-dibromo-p-benzoquinone 4 potentially could lead to a mixture of four endo isomeric cycloadducts, as shown below (2).



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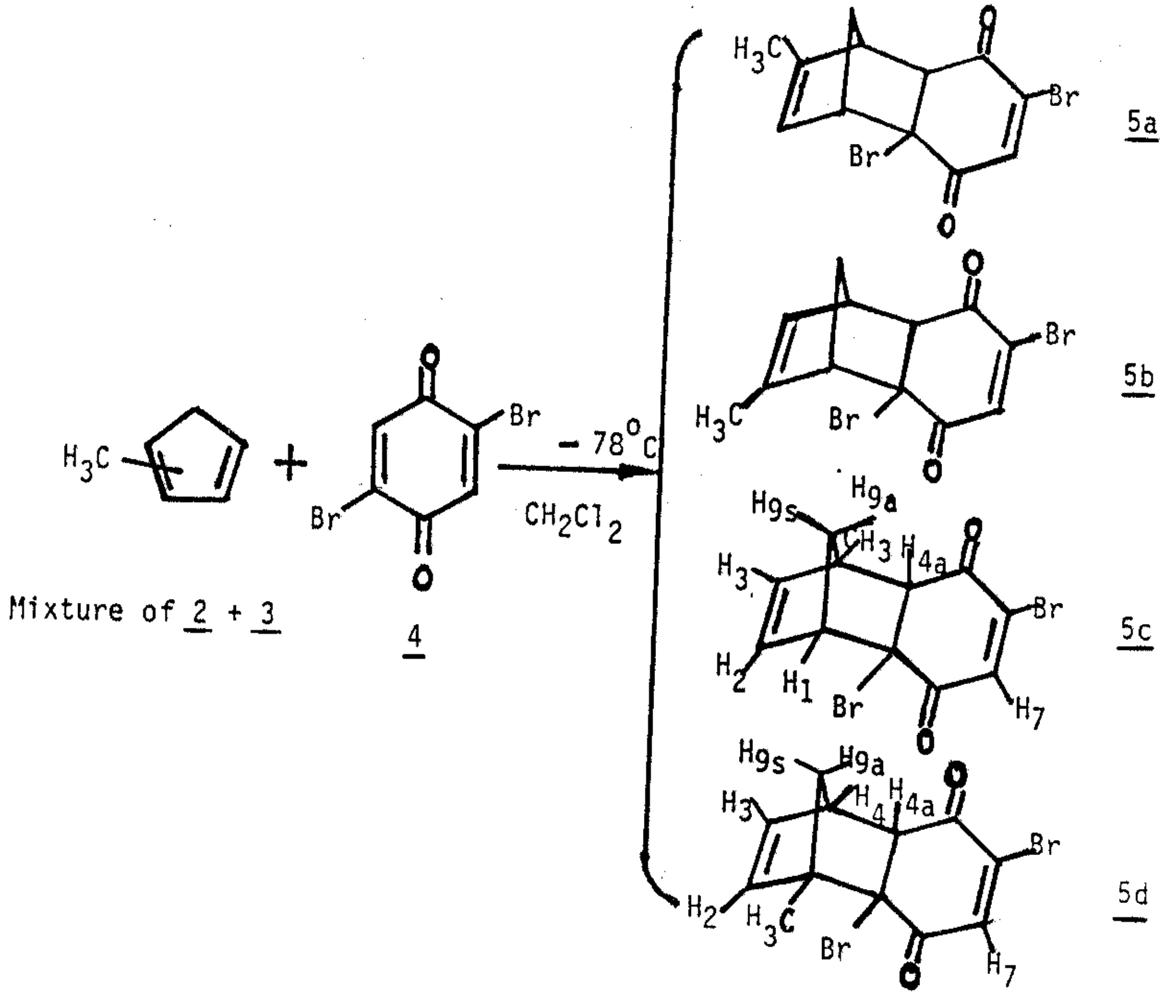
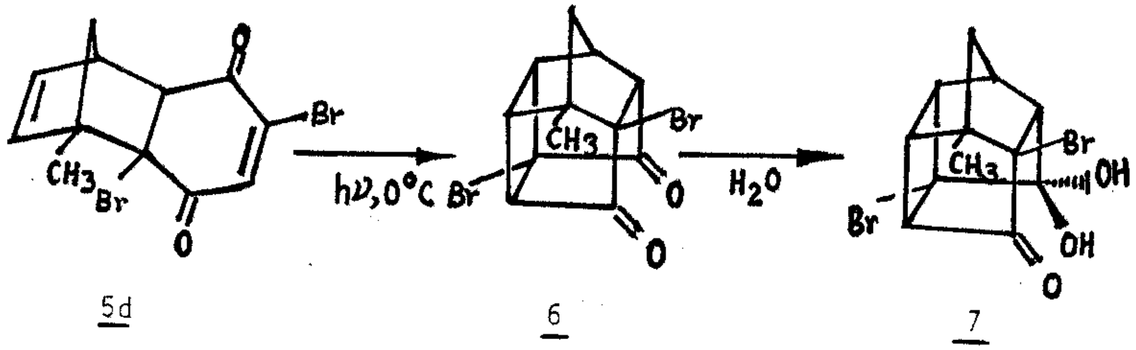




A single isomerically pure cycloadduct, 5, m.p. 96-97°C, was separated via fractional crystallization from hexane. The structure of this cycloadduct was assigned by analysis of its 1-dimmensional and 2-dimmensional NMR spectra. Its facial itramolecular [2+2] photochemical cyclization to a corresponding "cage" diketone demonstrated that this cycloadduct possesses the endo configuration.

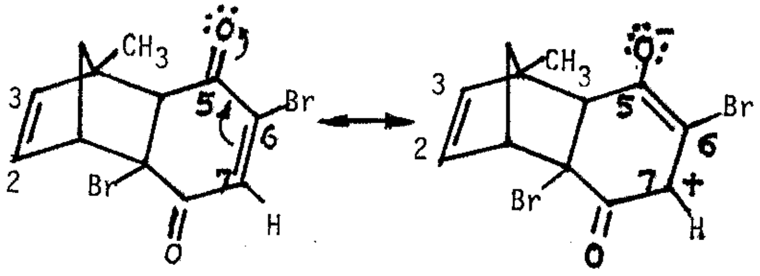
Results and Discussion

Diels-Alder cycloaddition of methycyclopentadiene, which is a mixture of 1-methyl and 2-methyl cyclopentadienes, to 2,5-dibromo-p-benzoquinone potentially could lead to the formation of four endo isomers. The proton NMR spectrum (Figure 1) of the cycloadduct separated via fractional crystallization from hexane reveals that there are three vinyl protons, and the simple integration of the proton NMR spectrum (Figure 1) and the HETCOR spectrum (Figure 2) of this adduct also reveal that no vinylic carbon atom bears a methyl group. Hence, of the four possible isomeric cycloadducts (5a-5d) that might have been formed, the material isolated must possess either structure 5c or 5d. This is confirmed by the fact that an attached proton test (APT) (Figure 3) reveals that only one of the four vinylic carbons in the spectral region δ136-δ143 is quaternary.

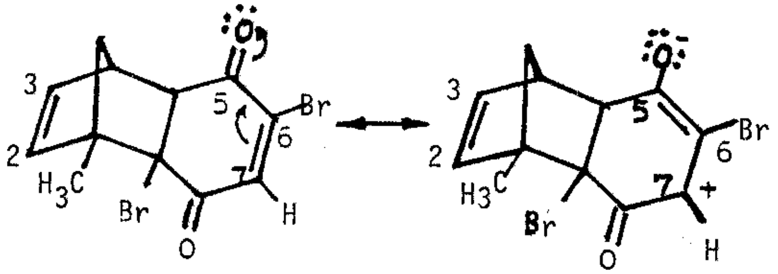
The absorption at δ1.70 in the proton NMR spectrum of this adduct can be readily assigned to the methyl group. The bridging methylene protons (H_{9s} and H_{9a}) can be assigned to the upfield AB pattern absorptions centered at δ1.89. The absorptions at δ3.9 and δ3.46 could be assigned to H_1 and

H_{4a} if the correct structure is 5c or assigned to H_4 and H_{4a} if the correct structure is 5d. The absorptions at $\delta 7.25$, $\delta 6.17$ and $\delta 5.87$ are due to H_7, H_2 and H_3, respectively, in either structure 5c or 5d.

Proton H_7 absorbs farthest downfield, compared to the other two vinyl protons (H_2 and H_3). This is probably a result of the deshielding resonance effect of the carbonyl groups, as shown below.



5c 5c

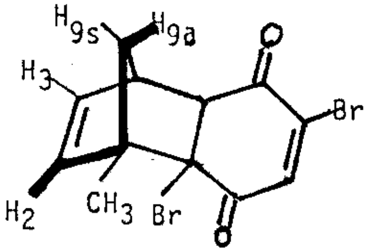


5d 5d

The carbon-13 NMR spectrum (Figure 3) of this adduct reveals twelve carbon resonances. An APT reveals the presence of five quaternary carbon atoms and one secondary carbon atom. There are two nonequivalent carbonyl carbon atoms that absorb at $\delta 188.9$. The four vinylic carbon resonances appear in the spectral region δ136-143. The absorption at the highest field δ16.77 could be due to the methyl carbon. The remaining highfield absorptions in the carbon-13 spectral region δ46.0-66.5 are due to the other aliphatic carbons.

Further structural information was made available via careful analysis of the 2-dimmensional COSY NMR spectrum (Figure 4) (3) and HETCOR spectrum (Figure 2) (3) of this adduct. The farthest downfield absorption at δ 7.25 can be assigned to H_7. This assignment is confirmed by the observed relatively intense off-diagonal responses in the COSY spectrum (Figure 4) that correlate H_3 with H_2. Now we can make use of the H_{4a} resonance to distinguish between structures <u>5c</u> and <u>5d</u>. If the correct structure is <u>5c</u>, it is unlikely that H_{4a} will exhibit intense responses due to its correlation with H_1. In the COSY spectrum of this adduct, there is a relative intense off-diagonal response that correlates H_{4a} with H_4 if the correct structure is <u>5d</u> or with H_1 if the correct structure is <u>5c</u>. The fact that this interaction is intense is consistent with structure <u>5d</u>, since in structure <u>5c</u> H_{4a} is separated from H_1 by four intervening bonds. Once structure <u>5d</u> has been assigned to this adduct, this fact can be used to complete assignment of the remaining proton and carbon-13 resonances.

The COSY spectrum contains one response that correlates the methy group protons to H_2. In contrast, the COSY spectrum does not contain information that establishes the connectivities between the methyl group protons and H_3. Therefore, the absorption at δ 5.87 is assigned to H_2 and the absorption at δ6.17 to H_3. A relatively intense response is observed that correlates H_3 with H_4 which absorbs at δ 3.16. Hence, the absorption at δ3.90 must be due to H_{4a}. The upfield AB pattern absorptions centered at δ3.46 are due to protons H_{9s} and H_{9a}. The question is which of the H_{9s} and H_{9a} corresponds to the upfield resonance and which to the downfield resonance. In order to answer this question a nuclear magnetic double resonance (4,5,6) experiment was performed in which H_2 or H_3 was irradiated. The aim of this technique is to remove the effect of spin coupling by applying a second R.F. field in addition to the one used for observation. The method consists of disturbing H_2 or H_3 nuclei with a strong R.F. field close to their resonance frequency. This leads to saturation and effectively decouples them from the remaining nuclei. In this case H_{9a} probably has a small W-shape long- range coupling to the vinyl protons H_2 and H_3, as shown below (7).



It is expected that irradiation of proton H_2 or H_3 could probably result in some change in the fine structure of H_{9a} resonance but no changes in H_{9s} resonance. It is also expected that irradiation of proton H_{9a} could probably result in some change in the fine structure of H_2 and H_3 resonances and irradiation of proton H_{9s} could not lead to any change in the fine structures of H_2 and H_3 resonances. The nuclear magnetic double resonance experiments were thereby performed, and they failed to distinguish between H_{9s} and H_{9a}. Figure 5 is one of the double resonance spectrum in which the proton at δ1.68 was irradiated.

The Nuclear Overhauser Effect (NOE) (3,8,9) experiment for studies of nonbonding nearest-neighbor interactions between protons in the molecule was performed for improving spectral resolution, assigning individual resonances, and charactering local spatial structure. The NOE experiment was performed in which H_{4a} signal at δ3.90 was saturated. Irradiation of the H_{4a} resulted in the intensity enhancement of the upfield resonance at δ1.68, but no significant intensity enhancement of the downfield resonance at δ2.08, as shown in Figure 6. As the Nuclear Overhauser Enhancement is inversely proportional to the sixth power of the distance between protons in the molecule and proton H_{9a} is much closer to H_{4a} than the proton H_{9s}, the intensity enhancement of the upfield resonance at δ1.68 when the H_{4a} is saturated is that of the H_{9a}. Hence the downfield resonance at δ2.08

can be assigned to proton H_{9s}.

The HETCOR spectrum (Figure 2) correlates directly bonded protons and carbons. Therefore, carbons can be assigned in a very straightforward fashion once the corresponding proton NMR assignments have been made with certainty, and vice versa.

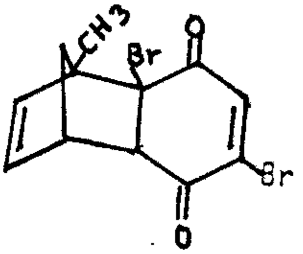
Intramolecular [2 + 2] photochemical cyclization of 5d afforded a "cage" diketone 6, thereby confirming the fact that 5d indeed possesses the endo configuration. The proton NMR spectrum (Figure 7) and carbon-13 NMR spectrum (Figure 8) of 6 are consistent with the structure suggested above. The proton spectrum of 6 displays a methy absorption at δ1.15. Its carbon-13 spectrum (with APT) reveals the presence of twelve carbon atoms. The HETCOR spectrum (Figure 9) of 6 in combination of its carbon-13 spectrum suggests that the two proton absorptions at δ1.85 and δ 2.19 in the proton spectrum (Figure 7) are due to the two bridging methylene protons and the proton absorptions in the spectra region δ2.9-3.5 are due to the remaining protons. There are no olefinic carbon absorptions in the carbon-13 spectrum (Figure 8) of 6 and the carbon resonances at δ199.2 and δ 199.8 are due to the two nonequivalent carbonyl carbon atoms. The carbon atom to which the methyl is attached resonanates at δ75.0 and the two carbon atoms bonded to the bromine atoms resonate at δ54.76 and δ56.0, respectively.

Single-crystal X-ray analyses confirmed the suggested structures of 5d and 7, as shown in Figure 10 and Figure 11, respectively.

Experimental

Melting points are uncorrected. Proton and carbon-13 NMR spectra were acquired by using a Varian VXR-300 NMR spectrometer that operates at 300 MHz. In all cases, signals were reported in parts per million (δ) downfield from internal tetramethylsilane. Infrared spectra were obtained by using a Perkin-Elmer Moder 1330 infrared spectrophotometer. Mass spectra were acquired by using a Hewlett-Packward Model 5970 A GC/MS system that operates at 70 eV. Elemental microanalyses were performed by Galbraith Laboratories, Inc. Knocvillr, TN.

1. 4,7-Dibromo-8-methyltricyclo[6.2.1.0^{2,7}]undeca-4,9-diene-3,6-diones, 5d.

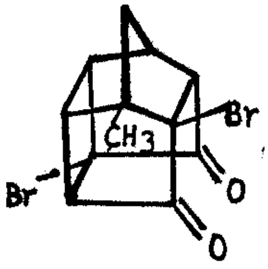


A solution of 2,5-dibromo-p-benzoquinone (10.0 g, 26.9 mmol.) in methylene chloride (400 ml) was cooled to -78°C via application of an external dry ice/acetone bath. To this solution was added with stirring freshly cracked methylcyclopentadienes (2.6 g, 32.5 mmol.) The reaction mixture was stirred at -78°C for 6 hours, and was then concentrated in vacuo. The residue, a mixture of isomeric Diels-Alder cycloadducts, was obtained as a light yellow oil (9.7 g, 80%). This oil was purified via fractional crystalization from hexane. A single isomer was thereby obtained as pale yellow needles: m.p. 96-97°C.

IR (KBr) 3045 (s), 2945 (s), 1676 (vs), 1665 (vs), 1592 (s), 1455 (s), 1385 (s), 1340 (s), 1320 (s), 1252 (vs), 1204 (s), 1165 (s), 1095 (s), 1075 (m), 1015 (s), 1000 (m), 978 (m), 962 (m) (cm^{-1}); ^1H NMR ($CDCl_3$) δ 1.68 (d, 1H), 1.72 (s, 3H), 2.08 (d, 1H), 3.46 (m,1H), 3.90 (d, 1H), 5.87 (d, 1H), 6.17 (m, H), 7.25 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 16.77 (q), 47.84 (d), 52.95 (t), 59.52 (s), 64.08 (d), 66.29 (s), 137.9 (d), 138.5 (d), 142.6 (s), 142.8 (d), 188.9 (s); mass spectrum (70 eV.) m/e (relative intensity) 265 (90.0), 238 (22.3), 187 (9.3), 159 (43.5), 157 (42.8), 134 (23.1), 131 (24.3), 106 (25.9), 104 (24.6), 81 (6.5), 79 (7.8), 53 (100), 50 (21.5), 49 (15.7);

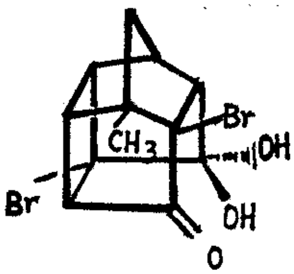
Anal. Calcd. for $C_{12}H_{10}O_2B_{r2}$: C, 41.79; H, 2.97; Found: C, 41.65; H, 2.91.

2. 7,10-Dibromo-3-methylpentacyclo[$5.4.0.0^{2,6}.0^{3,10}.0^{5,9}$]undecane-8,11-diones, 6.



A solution of 5d (0.35 g, 0.77 mmol.) in ethyl acetate (300 ml) was irradiated for 30 minutes under sunlight in an ice-cooled round-bottomed flask filled with nitrogen. The reaction mixture was then concentrated in vacuo, thereby affording a white solid (0.345 g, 98%): IR (KBr) 3490 (s), 3290 (w), 2940 (s), 2916 (s), 2850 (m), 1720 (vs), 1455 (s), 1380 (s), 1330 (m), 1300 (m), 1270 (s), 1240 (m), 1225 (m), 1180 (s), 1150 (s), 1135 (s), 1100 (s), 1070 (s), 1045 (m), 1020 (s), 995 (m), 980 (s), 930 (m) (cm^{-1}) ^1H NMR ($CDCl_3$) δ1.15 (s, 3H), 1.85 (d, 1H), 2.19 (d, 1H), 3.00 (m, 1H), 3.20 (m, 3H), 3.48 (m, 1H); ^{13}C NMR ($CDCl_3$) δ15.81 (q), 42.08 (d), 44.06 (t), 44.69 (d), 50.08 (d), 50.98 (d), 54.69 (s), 56.00 (s), 63.90 (d), 75.00 (d), 50.98 (d), 54.69 (s), 56.00 (s), 63.90 (d), 75.00 (s), 199.2 (s), 199.8(s); mass spectrum (70 eV.) m/e (relative intensity) 347 (16.7), 267 (100.0), 265 (98.4), 158 (28.9), 130 (31.0), 129 (22.0), 115 (17.2), 80 (44.7), 79 (25.3), 77 (18.9), 51 (24.8).

The white solid could be recrystallized from ethyl acetate-hexane mixed solvent to afford a colorless crystal, m.p. 138-139°C. Elemental microanalysis of this solid suggested that it is a monohydrate (*10*) of compound 6. A single-crystal X-ray crystallographic study (Figure 11) afforded the structure of this material 7, as shown below.



Elemental microanalysis was performed on 7.

Anal. Calcd. for $C_{12}H_{12}Br_2O_3$: C, 39.59; H, 3.32. Found: C, 39.85; H, 3.32.

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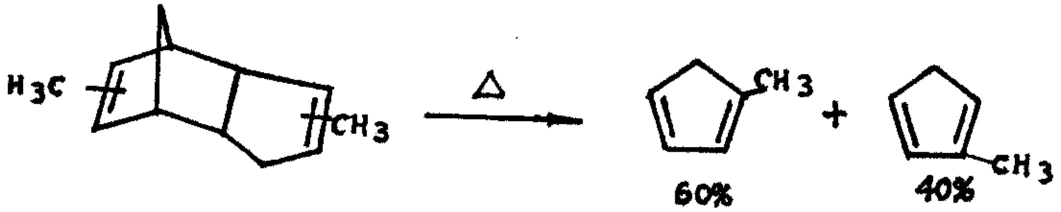
CHAPTER II

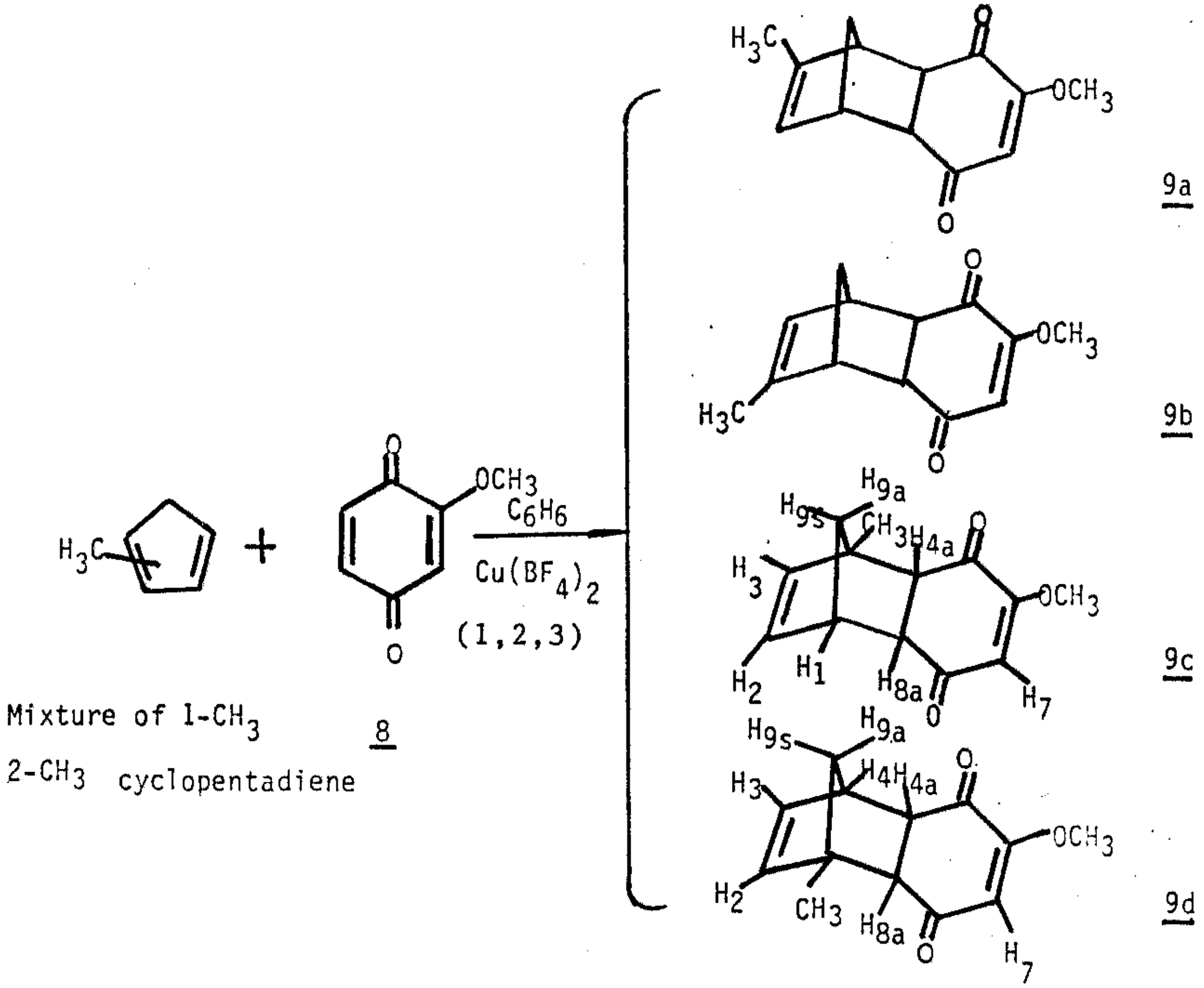
SYNTHESIS AND STRUCTURE OF A NEW METHOXY-SUBSTITUTED POLYCYCLIC MOLECULE

Introduction

As described above, tricyclic compounds that result via Diels-Alder cycloaddition of substituted cyclopentadienes to substituted p-benzoquinones are of current interest as intermediates in the syntheses of novel polycyclic compounds. Therefore, it is desirable to further study the stereochemistry of this system and its full NMR spectral characterization. Diels-Alder cycloaddition of methylcyclopentadienes to 2-methoxy-p-benzoquinone has been chosen for this study.

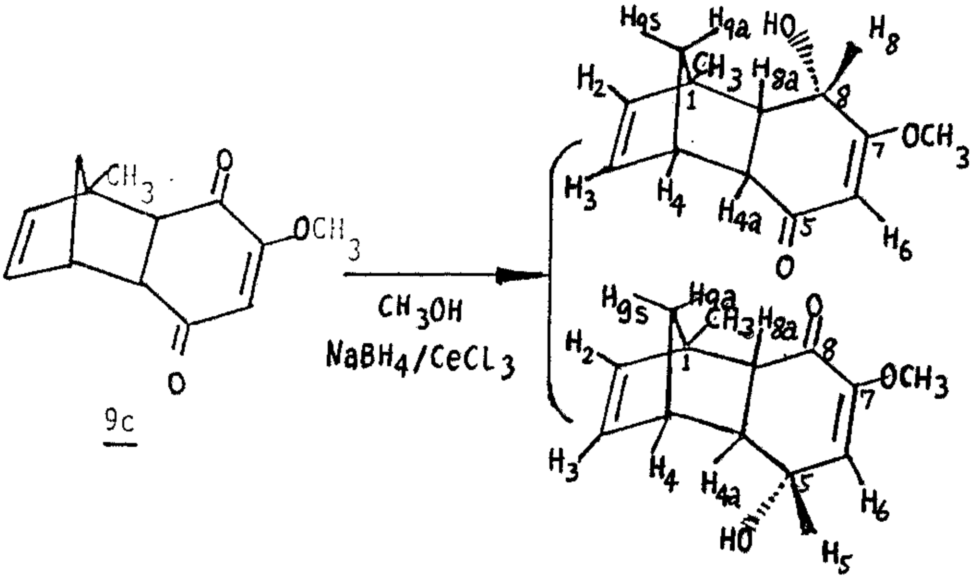
Pyrolysis of the commercial methylcyclopentadiene dimer yields a mixture of 1-methyl and 2-methyl cyclopentadienes. Diels-Alder cycloaddition of this diene mixture to 2-methoxy-p-benzoquinone 8 potentially could lead to a mixture of four isomeric endo cycloadducts 9a-9d, as shown below.





A single isomerically pure cycloadduct, 9, m.p. 133-134°C, was separated via fractional crystallization from ethyl acetate-hexane mixed solvent. Analysis of the 1-D and 2-D NMR spectra of this cycloadduct 9 suggested that it must possess either structure 9c or 9d.

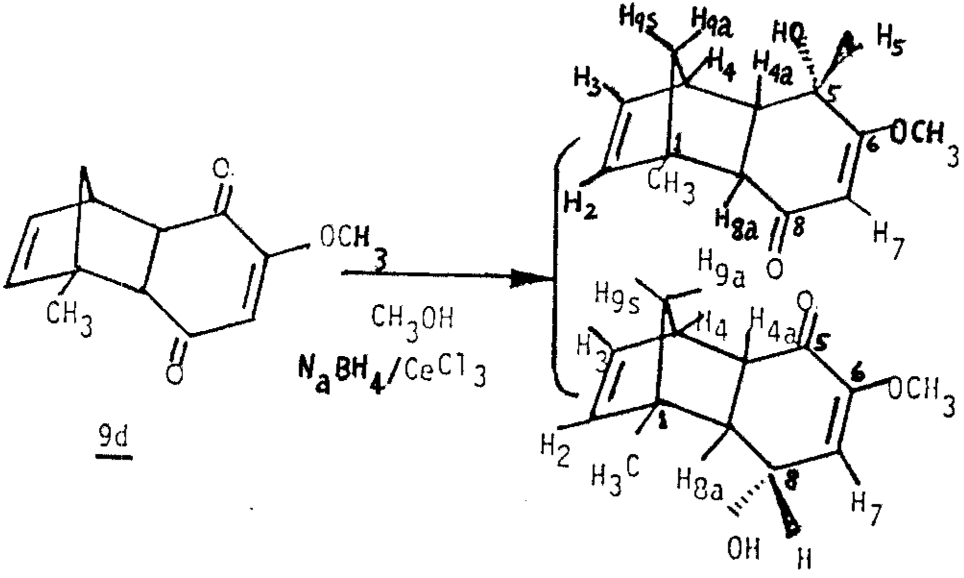
Stereo-specific reduction of this cycloadduct 9 with sodium borohydride in the presence of cerous chloride (4) afforded a corresponding tricyclic alcohol 10, which must possess one of the four possible structures 10a-10d, as shown below.



9c

10a

10b



9d

10c

10d

This reduction product could be purified via flash colum chromatography. A single isomerically pure tricyclic alcohol, 10, m.p. 128-129°C, was thereby obtained (see

Experimental Section). Further structural information was made available via careful analysis of the 1-D and 2-D NMR spectra of this tricyclic alcohol 10.

Results and Discussion

Diels-Alder cycloaddition of methylcyclopentadienes which is a mixture of 1-methyl and 2-methylcyclopentadienes, to 2-methoxy-p-benzoquinone potentially could lead to the formation of four isomeric endo cycloadducts. A single isomerically pure cycloadduct 9 was separated via careful fractional crystallization from ethyl acetate-hexane mixed solvent. The proton NMR spectrum (Figure 12) of this adduct 9 reveals that there are three vinyl protons, and the simple integration of the proton NMR spectrum and the HETCOR spectrum (Figure 13) of this adduct also suggest that no vinylic carbon atom bears a methyl group. Hence, of the four possible isomeric cycloadducts 9a-9d that might have been formed, the material isolated must possess either structure 9c or 9d. This is confirmed by the fact that an attached proton test (APT) (Figure 14) reveals that only one of the four vinylic carbons in the spectral region 115-163 is quaternary. The absorption at δ 1.44 in the proton NMR spectrum (Figure 12) of this adduct can be assigned to the methyl group and the absorption at δ 3.60 to the methoxy group. The bridging methylene protons H_{9s} and H_{9a} can be assigned to the farthest upfield AB partern absorption centered at δ 1.30. The absorptions at δ5.72, δ5.74 and δ5.88 are due to the three vinyl protons and the absorptions in the proton NMR spectral region δ2.70-δ3.40 are due to the tertiary protons. The carbon-13 NMR spectrum (Figure 14) of this adduct reveals thirteen carbon resonances. An APT reveals the presence of one secondary carbon atom and four quaternary carbon atoms. The two carbonyl carbon atoms absorb at δ194.0 and δ198.1, respectively. The four vinylic carbon resonances appear in the carbon-13 spectral region δ114-δ163. The absorption at the highest field δ17.64 could be assigned to the methyl carbon. The remaining highfield absorptions in the carbon-13 spectral δ49.8-δ57.5 are due to the the other aliphatic carbons and the methoxy carbon.

The intense off-diagonal responses in the COSY spectrum (Figure 15) of this adduct correlate H_2 with H_3. Therefore the absorption at δ5.72 in the proton NMR spectrum (Figure 12) could be assigned to H_7. Careful analysis of this COSY spectrum suggests that the absorptions at δ5.88, δ 5.74, δ5.72, δ 3.32, δ3.25, and δ 2.75 could be assigned to H_2, H_3, H_1, H_{8a} and H_{4a} respectively if the correct structure is <u>9c</u> or assigned to H_3, H_2, H_4, H_{4a} and H_{8a} respectively if the correct structure is <u>9d</u>.

The Nuclear Overhauser Effect (NOE) (5,6,7) experiment for studies of nonbonding nearest-neighbor interactions between protons in the molecule was performed in order to assign the bridging methylene protons, H_{9s} and H_{9a}.

The NOE experiment in which the signal at δ 2.75 (which could be due to either H_{4a} or H_{8a}) was saturated. Irradiation of this proton at δ 2.75 resulted in the intensity enhancement of the upfield resonance at δ 1.27, but no intensity enhancement of the downfield resonance at δ 1.32, as shown in Figure 16. As proton H_{9a} is much closer to H_{4a} (or H_{8a}) than the proton H_{9s}, the intensity enhancement of the upfield resonance at δ 1.27 when the signal at δ 2.75 is irradiated is that of the H_{9a}. Hence the downfield resonance at δ 1.32 can be assigned to proton H_{9s}. Further structural information was made available via analysis of the 1-D and 2-D NMR spectra of the tricyclic alcohol, 10.

The proton NMR spectrum (Figure 17,18,19,20) of the tricyclic alcohol 10 reveals that there are three vinyl protons. The farthest upfield AB pattern absorption centered at δ 1.30 could be assigned to the bridging methylene protons H_{9s} and H_{9a}, and the absorption at δ 1.50 to the methyl group. The absorption at δ 3.71 could be assigned to the methoxy group. The carbon-13 spectrum (Figure 21) of the reduction product 10 reveals only one carbonyl carbon atom which absorbs at δ 199.1. Therefore, only one carbonyl of the cycloadduct 9 was reduced to $\supset\underline{\mathrm{C}}\mathrm{H(OH)}$ whose carbon atom absorbs at δ 65.62 in the carbon-13 spectrum (Figure 21) of the tricyclic alcohol 10. Attempts to differentiate among structures 10a, 10b, 10c and 10d just by the normal HETCOR (Figure 22) and COSY (Figure 23) of the tricyclic alcohol have been made and are inconclusive.

The carbon-13 spectrum (with APT) (Figure 21), in combination with normal HETCOR spectrum (Figure 22) reveals that the absorptions at δ 54.68, δ 58.35, δ 172.8 and δ 199.1 are due to C_9, C_1, carbonyl carbon and the carbon attached to the $-OCH_3$.

The two vinyl protons at δ 5.59 and δ 6.06 are strongly coupled (J=5.5 Hz), which must be H_2 and H_3. The absorption at δ 5.59 appears as a simple doublet in the proton spectrum (Fingure 20), however, it collapses to a doublet (J=1.4 Hz) when the proton at δ 6.06 is irradiated. Thus, the signal is a double doublet (dd) with the smaller coupling constant J being typical of an allylic ($^4J_{H2,H4}$) coupling in norbornene systems *(8)*. Therefore, the proton at δ 5.59 must be H_2. The proton at δ 6.06 is H_3 (dd, J=5.5, 2.8 Hz) with the smaller coupling being a typical vicinal $J_{H3,H4}$ in norbornenes. The assignments of H_2 and H_3 are confirmed by the correlation between H_3 and H_4 in the COSY spectrum (Figure 23). In the delayed COSY spectrum (Figure 24), only H_3 reveals a correlation with H_4. However, both H_3 and H_2 correlate with H_4 in the RELAY COSY spectrum (Figure 25). H_4 appears to absorb at approximately δ 3.19 and is not amenable to first-order interpretation. The normal HETCOR spectrum (Figure 22) correlates directly bonded protons and carbons. Thus, the absorptions at δ 140.0, δ 134.9 and δ 45.39 can be assigned to C_2, C_3 and C_4 respectively.

Normally, the two vinylic carbons (C_2 and C_3) would give a $^3J_{CH}$ correlation only with H_{9a} in the long-range HETCOR; and C_{4a} and C_{8a} would correlate only with H_{9s}. However, the long-range HETCOR spectrum (Figure 26) is not well resolved and the protons at C_9 are fairly close (δ1.35, δ1.25). It appears that C_2 (δ140.0) correlates more closely with the higher field H_9 at δ 1.25, thus the proton at δ 1.25 can be assigned to H_{9a}. However, the correlation for C_3 (δ 134.9) is broad and seems to appear between the two shifts for H_9. The carbon at δ 41.78 (which will be assigned below to C_{4a}) appears to correlate closer to the proton at δ 1.35 and this would be consistent if that proton were H_{9s}. The absorption at δ 1.35 is a dd (J=8.4, 1.8 Hz) and the 1.8 Hz coupling is with H_4. The absorption at δ 1.25 is actually a dddd (J=8.4, 1.2 Hz, ?? small), which collapses to a dd (J=8.4, 1.2 Hz) when H_2 (δ5.59) or H_3 (δ6.06) is irradiated. The 1.2 Hz coupling is with H_4. This coupling information is also consistent with the assignment of H_{9s} at δ 1.35 since its J with H_4 in other norbornenes is usually larger than that of the anti H with H_4.

In the long-range HETCOR spectrum (Figure 26) the bridgehead methyl carbon at δ 18.12 correlates with the proton doublet at δ2.68 (J=8.9 Hz). The same doublet also correlates with C_2 (δ140.0). Thus, the proton at δ 2.68 must be on C_{8a}, which comes at δ 53.71. The vinylic carbon C_3 (δ 134.9) correlates with a complex proton absorption at

δ3.13, which must be H_{4a}, and the associated carbon (C_{4a}) would be the one at δ41.78.

The proton H_{8a} (δ2.68) has only one large coupling, which is a coupling with H_{4a}. Therefore C_{8a} must be attached to the carbonyl carbon. If C_{8a} were attached to a protonated carbon (C_5), there would certainly be two large couplings. Actually, H_{8a} is coupled to two other protons (H_4 and H_5) but the coupling constants are so small that only a slight broadening of the lines for the H_{8a} doublet is seen. H_5 appears as a double doublet (J=9.3, 1.4 Hz) at δ4.67 and is <u>not</u> coupled <u>vicinally</u> to H_{8a} whose large coupling constant J is 8.9 Hz, not 9.3 Hz. Irradiation of the signal at δ4.67 (H_5) causes the doublet at δ5.14 to collapse to a singlet but does not decouple the doublet at δ2.68 other than to narrow the two lines slightly. Irradiation at δ3.17 with enough decoupling power to decouple both H_4 and H_{4a} causes collapse of both the signal at δ2.68 to a broadened singlet and the signal at δ4.67 to a doublet (J=1.4 Hz). This could be consistent only with structures <u>10c</u> and <u>10b</u>. Structures <u>10a</u> and <u>10d</u> could be ruled out.

The vinyl proton at δ5.14 is a clean doublet, J=1.4 Hz. The magnitude of the smaller coupling constant J for H_5 is 1.4 Hz, which is in the range of allylic coupling , and this immediately suggests <u>10c</u> as the correct structure for the tricyclic alcohol. In the long-range HETCOR spectrum (Figure 26), the expected ^3J's support the structure <u>10c</u> for the tricyclic alcohol. C_5 (65.62) correlates with H_7 (5.14) and C_7 (δ102.6) correlates with H_5 (δ4.67). The remaining carbons are C_8 (δ199.1), C_6 (δ172.8) and OCH_3 (δ56.26, H's at 3.71). Once structure 10c has been assigned to the reduction product 10, this fact can be used to assign the structure 9d to the cycloadduct 9 obtained via fractional crystallization of that Diels-Alder reaction mixture.

Now that structure 9d has been assigned to the cycloadduct 9, the absorptions at δ2.75, δ3.25 and δ3.32 in the proton NMR spectrum (Figure 12) of 9d could be assigned to H_{8a}, H_{4a} and H_4, respectively.

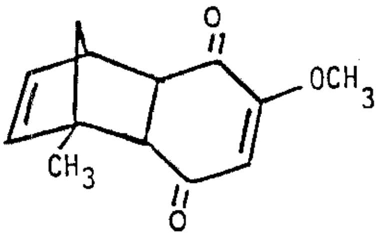
The HETCOR spectrum (Figure 13) of 9d correlates directly bonded protons and carbons. Therefore, carbons can be assigned in a very straightforward fashion once the corresponding proton NMR assignments have been made with certainty, and vice versa.

The assignments of structure 9d for the cycloadduct 9 and structure 10c for the tricyclic alcohol 10 have been confirmed by the results of single-crystal X-ray analyses, as shown in Figure 27 and Figure 28, respectively.

Experimental

Melting points are uncorrected. Proton and carbon-13 NMR spectra were acquired by using a Varian VXR-300 NMR spectrometer that operates at 300 MHz. In all cases, signals were reported in parts per million (δ) downfield from internal tetramethylsilane. Infrared spectra were obtained by using a Perkin-Elmer Moder 1330 infrared spectrophotometer. Mass spectra were acquired by using a Hewlett-Packward Model 5970 A GC/MS system that operates at 70 eV. Elemental microanalyses were performed by Galbraith Laboratories, Inc. Knoxville, TN.

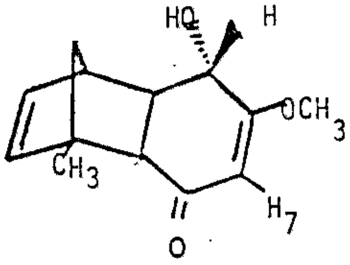
1. 4-Methoxy-8-methyltricyclo[6.2.1.$0^{2,7}$]undeca-4,9-diene-3,6-dione, 9d.



A solution of 2-methoxy-p-benzoquinone (3.0 g, 21.7 mmol.) in benzene (70 ml) was cooled to 0-5°C via application of an external ice/water bath, and 1.6 g, 6.5 mmol. of dry cupric fluoroborate was added. To this solution was added with stirring freshly cracked methylcyclopentadienes (2.1 g, 26.1 mmol.). The reaction mixture was stirred at 0-5°C for 5 hours, and was then concentrated in vacuo. The residue, a mixture of isomeric Diels-Alder cycloadducts, was obtained as a white solid (4.74 g, 93%). Careful fractional crystallization of this solid from ethyl acetate-hexane mixed solvent afforded a single isometrically pure cycloadduct 9d as a colorless crystal: m.p. 143-144°C; IR (KBr) 3035 (m), 2950 (w), 2865 (m), 1654 (vs), 1620 (vs), 1586 (vs), 1450 (m), 1435 (m), 1360 (m), 1330 (m), 1290 (m), 1280 (m), 1230 (vs), 1200 (s), 1170 (vs), 1135 (m), 1070 (m), 1054 (m), 1040 (m), 990 (s), 880 (m) (cm^{-1}); ^1H NMR ($CDCl_3$) AB pattern, δ_A1.27, δ_B1.32 (2H methylene bridge protons), 1.44 (s, 3H), 2.75 (d, 1H), 3.25 (m, 1H), 3.32 (m, 1H), 3.60 (s, 3H), 5.72 (s, 1H), 5.74 (m, 1H), 5.88 (m, 1H); ^{13}C NMR ($CDCl_3$) 17.64 (q), 49.80 (d), 50.81 (d), 53.34 (d), 55.81 (t), 56.23 (q), 57.47 (s), 114.8 (d), 134.3 (d), 139.7 (d), 162.7 (s), 194.0 (s), 198.1 (s); mass spectrum (70 eV.), m/e (relative intensity) 138 (30.4), 123 (6.7), 110 (42.7), 108 (36.6), 95 (23.87), 82 (30.2), 68 (100.0), 55 (15.7), 54 (46.0), 53 (38.7), 52 (29.9), 41 (24.5), 39 (31.1).

Anal. Calcd for $C_{13}H_{14}O_3$: C, 71.54; H, 6.47. Found : C, 71.27; H, 6.42.

2. 4-Methoxy-8-methyltricyclo[6.2.1.$0^{2,7}$]undeca-4,9-diene-3-endo-ol-6-one, 10c.



Cycloadduct 9d (162 g, 0.74 mmol.) was dissolved in a 0.6 M solution of cerium (III) chloride heptahydrate in methanol (5 ml, 2.0 mmol.). The resulting solution was cooled to 0°C by external application of an ice bath. Sodium borohydride (112 mg, 3.0 mmol.) was then added at such a rate that the temperature of the reaction mixture did not rise significantly above 0°C. After addition of the sodium borohydride had been completed, the reaction mixture was stirred at room temperature for 18 hours. The reaction mixture was analyzed by TLC, this examination revealed that no starting material 9d remained unchanged. The reaction was then quenched via addition of distilled water (10 ml), and the resulting mixture was then extracted with methylene chloride. The combined organic layers were dried (anhydrous magnesium sulfate) and filtered. The filtrate was concentrated in vacuo. Crude product 10c (160 mg, 98%) was thereby obtained, which could be purified via flash column chromatography. Recrystallization from ethyl acetate-hexane mixed solvent afforded a colorless crystal: m.p. 128-129°C; IR KBr) 3450 (w), 2990 (w), 1620 (w), 1480 (m), 1370 (w), 1260 (w), 1170 (m), 1105 (m), 1075 (m), 1040 (m), 880 (m), 850 (m), 810 (m) (cm^{-1}); ^1H NMR ($CDCl_3$) AB pattern δ_A1.25, δ_B1.35 (2H methylene bridge protons), 1.50 (s, 3H), 2.68 (d, 1H), 3.13 (m, 1H), 3.19 (m, 1H), 3.71 (s, 3H), 4.67 (m, 1H), 5.14 (d, 1H), 5.59(m, 1H), 6.06(m, 1H); ^{13}C NMR ($CDCl_3$) δ 18.12 (q), 41.78 (d), 45.39 (d), 53.71 (d), 54.68 (t), 56.27 (q), 58.35 (s), 65.62 (d), 102.6 (d), 134.9 (d), 140.0 (d), 172.8 (s), 199.1 (s); mass spectrum (70 eV.) m/e (relative intensity) 140 (100.0), 125 (93.7), 111 (4.7), 97 (92.0), 79 (10.5), 69 (19.0), 55 (12.6), 52 (22.0), 51 (13.8), 50 (7.3), 43 (7.3), 42 (9.9), 41 (19.9), 39 (18.2).

Anal. Calcd for $C_{13}H_{16}O_3$: C, 70.89; H, 7.32. Found : C, 71.29; H, 7.39.

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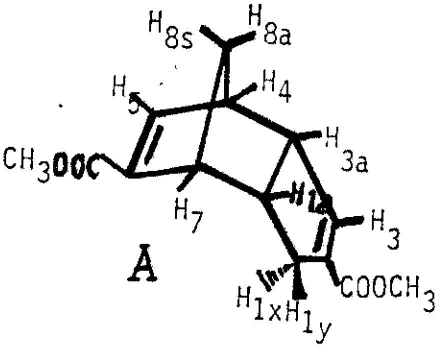
CHAPTER III

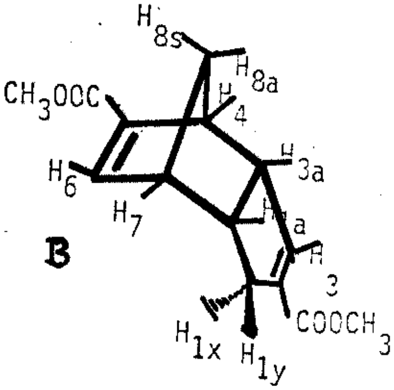
ANALYSIS OF THE 2-D NMR SPECTRUM OF THIELE'S ESTER

Introduction

In 1901 Thiele first prepared (*1*) a dicyclopentadiene-dicarboxylic acid (Thiele's acid) from the carbonation of cyclopentadienyl potassium, and he prepared also a crystalline dimethyl ester (Thiele's ester) through acid-catalyzed esterification of this acid. Earlier structures postulated by Alder (*2*) in 1954 were discarded when more recent spectroscopic and proton magnetic resonance data established. In 1959 Peters obtained (*3*) ultraviolet data of Thiele's acid and concluded that both carboxylic groups were conjugated with the double bonds, however, his subsequent structural assignment of Thiele's acid was then proved to be a mistake. In 1964 Finnegan and McNees assigned (*4*) the structure B to Thiele's ester on the basis of Peters' structural assignment of Thiele's acid and a series of chemical and spectroscopic investigations, and their misinterpretation of the NMR spectrum of Thiele's ester was then inevitable. The upfield vinyl proton absorption at δ6.51 (J3.53) was assigned to H_2 (H_b, using their designation) in structure B, which should be H_3 in structure A.



A



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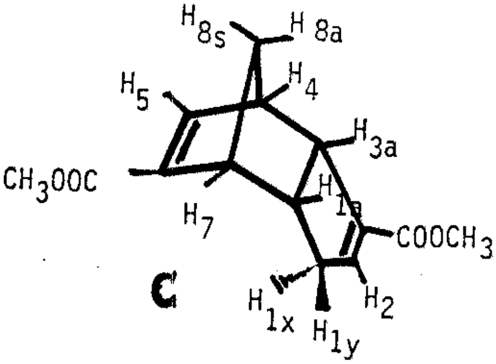

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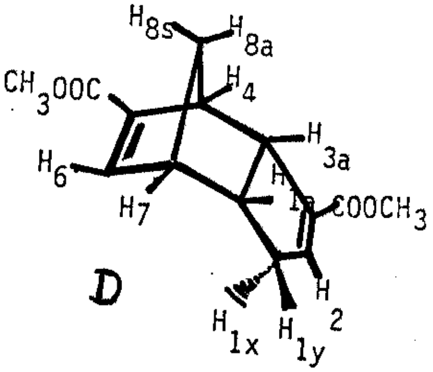
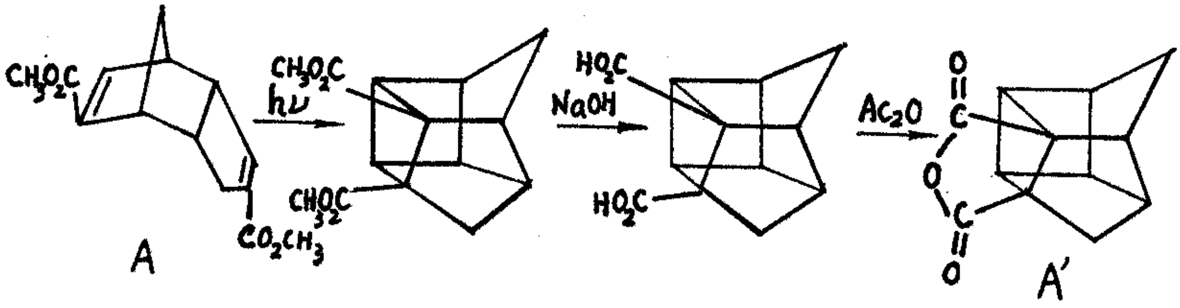


D

In 1968 Dunn prepared (5) a saturated ester from the facial intramolecular [2 + 2] photochemical cyclization of Thiele's ester. Hydrolysis of this saturated ester gave the pentacyclodecane diacid, which then was heated in refluxing acetic anhydride to give an anhydride. This is shown as below: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A
CO$_2$CH$_3$
CH$_3$O$_2$C
hν
CH$_3$O$_2$C
HO$_2$C
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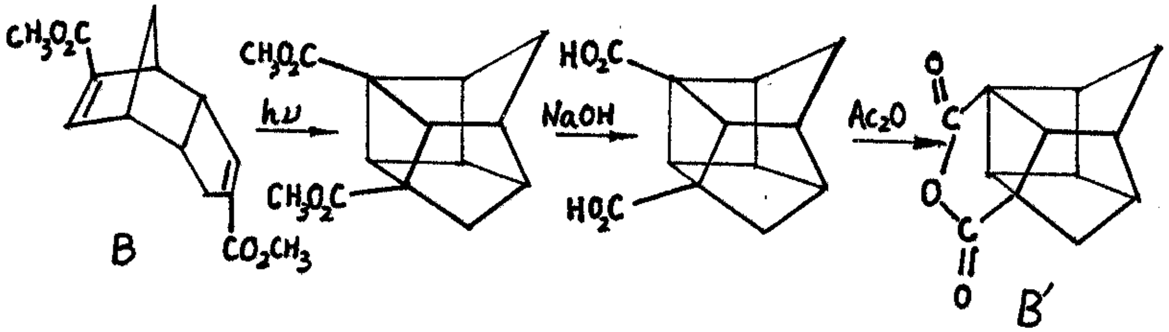
O
C
O
C
O
A′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B
CO$_2$CH$_3$
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hν
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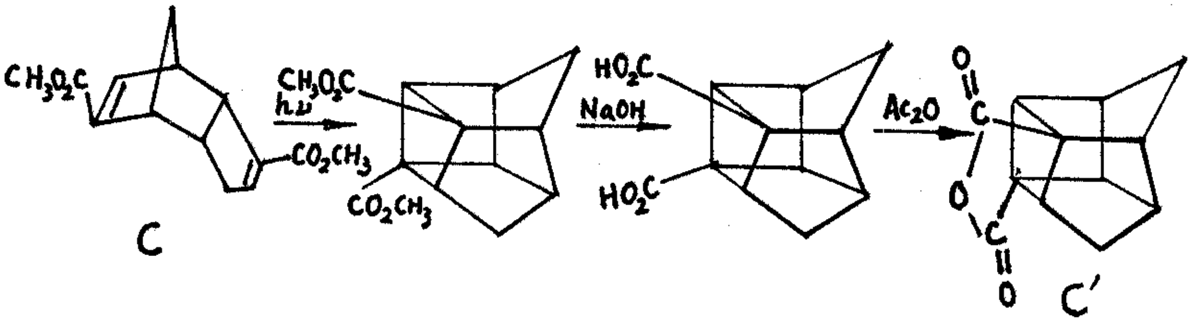
O
C
O
C
O
B′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C
CO$_2$CH$_3$
CH$_3$O$_2$C
hν
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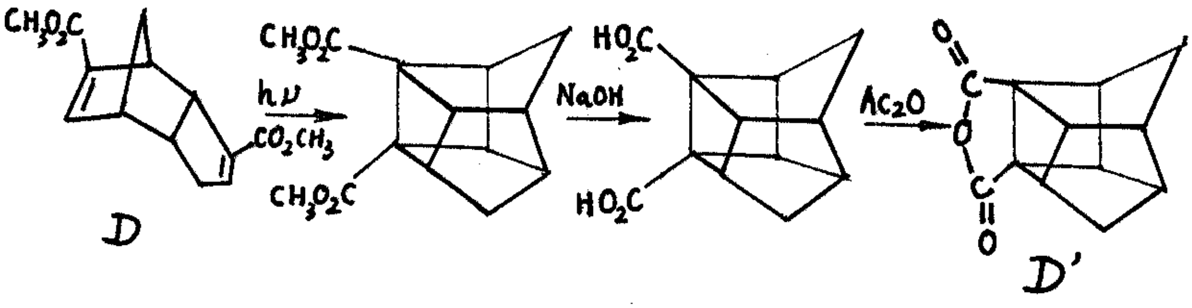
Ac$_2$O
O
C
O
C
O
C′


CH$_3$O$_2$C
D
CH$_3$O$_2$C
hν
CO$_2$CH$_3$
CH$_3$O$_2$C
HO$_2$C
NaOH
HO$_2$C
Ac$_2$O
O
C
O
C
O
D′

The infrared spectrum (CCl_4) of the anhydride revealed peaks at 1854 and 1787 cm^{-1} (anhydried C=0), which are indicative of a 5-membered cyclic anhydride, while 1,3-cyclobutanedicarboxylic anhydrides (6-membered) (6) generally absorb at about 1815 and 1765 cm^{-1}. Therefore Dunn confirmed the endo configuration of Thiele's ester and ruled out B and C as the possible structure of Thiele's ester. Dunn assigned structure A to Thiele ester on the basis of a series of chemical and spectroscopic investigations.

The present work is concerned with the structural assignment of Thiele's ester via analysis of its two dimensional NMR spectra.

Results and Discussion

In the proton NMR spectrum (Figure 29, 30, 31) of Thiele's ester there are two vinyl protons, which absorb at δ6.51 and δ 6.85, respectively. Hence, two vinylic carbon atoms bear carboxylate groups. The upfield portion of this spectrum contains resonances for four protons exhibiting two AB patterns: the first at δ1.43 and δ1.68 with an AB coupling of 8.6 Hz, and the other at δ2.01 and δ2.47 with an AB coupling of 17.9 Hz ($CDCl_3$ solvent). For the first AB pattern absorption, the magnitude of couplings is analogous to those reported for the methylene bridge protons of norborne (7,8) and cyclopentadiene dimer (9,10). Therefore, protons H_{8a} and H_{8s} can be assigned to the resonances at

δ1.43 and δ1.68. The remaining components in the upfield portion exhibit an AB coupling of 17.9 Hz which is indicative of a methylene group. Therefore the absorptions at δ2.01 and δ2.47 can be assigned to the two methylene protons H_{1x} and H_{1y}. The absorptions at δ3.66 and δ 3.71 can be readily assigned to the two methyl protons. The remaining absorptions in the spectral region δ2.9-δ3.6 are due to the four tertiary protons.

The carbon-13 NMR spectrum (Figure 32) of Thiele's ester reveals fourteen carbon resonances. An attached proton test (APT) reveals the presence of two secondary carbon atoms and four quaternary carbon atoms. The two nonequivalent carbonyl carbon atoms absorb at δ165.0 and δ165.2, respectively. The four vinylic carbon absorptions appear in the spectral region δ136-148. The remaining highfield absorptions in the spectral region δ32-56 are due to the other aliphatic carbons.

The normal HETCOR spectrum (Figure 33) of Thiele's ester contains responses that correlates H_{8s} and H_{8a} (δ1.68 and δ1.43) with C_8 (δ50.4). Further structural assignment of Thiele's ester below is based on the above conclusion that the bridging methylene carbon C_8 is the one at δ 50.4 with attached H_{8s} and H_{8a} at δ 1.68 and δ1.43.

The longe-range HETCOR spectrum I (Figure 34) of Thiele's ester shows a strong $^3J_{CH}$ which correlates both the protonated vinyl carbon at δ146.9 and the unprotonated vinyl carbon at δ138.4 with the proton at δ1.43. This establishes the shifts for C_5 and C_6 in the norbornene system and also the proton at δ1.43 as H_{8a}. The structures B and C can be ruled out as Thiele's ester according to Dunn's work discussed above. If the correct structure is A, H_5 must be the one that absorbs at δ6.85. The long-range HETCOR spectrum I (Figure 34) also reveals two correlations for H_5. One is a residual $^1J_{CH}$ with C_5, but the other is a $^3J_{CH}$ with the carbonyl carbon at δ164.9. This carbonyl carbon also correlates ($^3J_{CH}$) with the methyl (m) protons at δ3.71 (s). Since the normal HETCOR spectrum (Figure 33) establishes the carbon shift for this methyl (m) at δ51.0, then the carbomethoxy group at C_6 has a carbonyl at δ164.9, a methyl (m) carbon at 51.0, and methyl (m) protons at δ3.71. Therefore the other carbomethoxy group attached to the five membered ring has a carbonyl at δ164.7, a methyl (n) carbon at δ50.8, and methyl (n) protons at δ3.66. These assignments are supported by the appropriate 3-bond couplings in the long-range HETCOE spectrum I (Figure 34).

In the long-range HETCOR spectrum II (Figure 35), the proton at δ1.68, which must be H_{8s}, shows three correlations. One is a residual 1-bond J; but the others correlate H_{8s} with carbons at δ40.6 and δ54.0, and these carbons must be C_{1a} and C_{3a}. The COSY spectrum (Figure 36) of Thiele's ester establishes a vicinal relationship between H_5 and the proton at δ3.14, which must be H_4. Then C_4 must be the carbon at δ46.9. The proton at δ3.14 (H_4) is also coupled to one at δ3.51, which must be H_{3a}. Thus, C_{3a} absorbs at δ54.0 and C_{1a} must absorb at δ40.6. The remaining bridgehead carbon C_7 must be at δ46.2 and its attached proton at δ3.35. The long-range HETCOR spectrum II (Figure 35) reveals the proper $^3J_{CH}$ correlation between C_7 and H_5. This spectrum also shows a correct $^3J_{C4,H7}$ but not a $^3J_{C7,H4}$. The COSY spectrum (Figure 36) reveals the expected correlations of H_7 with H_{8a} and H_{8s} and also with a proton at δ2.97, which must be H_{1a}.

The methylene group (C_1 at δ32.6, H_{1y} at δ2.47 and H_{1x} at δ2.01) must be attached to C_{1a}. In the COSY spectrum (Figure 36), H_{1a} correlates with both H_{1x} and H_{1y} and vicinal coupling constants J's are large (4.0 and 10.4 Hz) and typical. H_{3a} is also coupled to H_{1x} and H_{1y}, but the coupling constants are much smaller (4.0 and 1.9 Hz). It seems that the $^5J_{H3a,H1x}$ is abnormally large. The $^5J_{H3a,H1y}$ is also abnormally large. The $^5J_{H3a,H1y}$ is 1.9 Hz.

The long-range HETCOR spectra I and II helps to differentiate between the structure A and D. The long-range HETCOR spectrum I (Figure 34) reveals a ^3J between the vinyl proton at δ6.51 and the carbonyl carbon at δ164.7, but this should be seen regardless of whether the structure is A or D. This HETCOR spectrum also shows a ^3J between H_{1y} and the vinyl carbon at δ142.3. The complementary correlation between C_1 at δ32.6 and the vinyl proton at δ6.51 is seen in the long-range HETCOR spectrum II (Figure 35) and this is all consistent with structure A. Thus, the structure of Thiele's ester is A.

The $^2J_{CH}$ between C_2 (δ137.5) and H_{1y} in the long-range HETCOR spectrum I (Figure 34) is firmly believed to be ^2J, not a ^3J. Obviously, if it were a ^3J, then structure D would be possible. However, this would require that both of the other correlations metioned above be ^2J's. The problem comes from the fact that the ^2J for this type of linkage is almost the same magnitude as the ^3J. This makes it impossible to choose a JNXH parameter which will suppress the ^2J.

Double resonance experiments were made in which protons at δ3.35 and δ6.48 were irradiated. Two spectra (Figure 37, 38) were thus obtained. All coupling constants obtained are listed in Table 1.

The multiples of protons H_{1x} and H_{1y} are complicated (Figure 30), however they exhibit quite different vicinal couplings with the proton H_{1a}. The dihedral angles between protons H_{1a} and H_{1y} and H_{1x} can be estimated from Dreiding models to be 10 and 110°C, respectively. Based on the angular dependence (*11,12*) one can deduce that J(1Y, 1a) > J(1X, 1a). The COSY spectrum of Thiele's ester contains a relatively intense response that correlates H_{1a} with H_{1y} and a relatively weak response that correlates H_{1a} with H_{1x}. Therefore the absorption at δ2.47 could be assigned to H_{1y} and the absorption at δ2.01 to H_{1x}. This is consistent with the structural assignments discussed above.

The farthest upfield AB pattern absorptions are due to the methylene bridge protons H_{8s} and H_{8a}. Furthermore, from the generalization based on norbornene derivatives (7,8), J (8s, 4) and J (8s, 7) should be slightly larger than J (8a, 4) and J (8a, 7). On this basis the upfield resonance at δ1.43 was assigned to proton H_{8a} and the downfield resonance at δ1.68 to H_{8s}. The difference between the vicinal couplings of H_{8s} and H_{8a} with H_4 and H_7 is, however, very small; consequently, the use of this inequality to differentiate between H_{8s} and H_{8a} may be questioned. Nevertheless, this assignment has been confirmed by a nuclear magnetic double resonance experiment in which proton H_5 (δ6.85) is irradiated. The method consists of disturbing H_5 nucleus with a strong R.F. field close to its resonance frequency. This leads to saturation and effectively decouples it from the remaining nuclei. Irradiation of H_5 leads to some change in the fine structure of the upfield resonance but no change in the downfield resonance, as shown in Figure 39. H_{8a} is expected to exhibit a small W-shape long range coupling to H_5 but H_{8s} is not, therefore, the upfield absorption at δ 1.43 is confirmed to be H_{8a} and the downfield absorption at δ1.68 to be H_{8s}.

Experimental

The NMR spectra were obtained using a Varian VXR-300

NMR spectrometer that operates at 300 MHz. $CDCl_3$ was used as a solvent and tetramethylsilane (TMS) was included as an internal reference and field locking signal. In all cases, signal were reported in parts per million (δ) downfield from the internal TMS.

Thiele's ester, A, was prepared according to the method of J. Thiele (*1*).

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APPENDIX

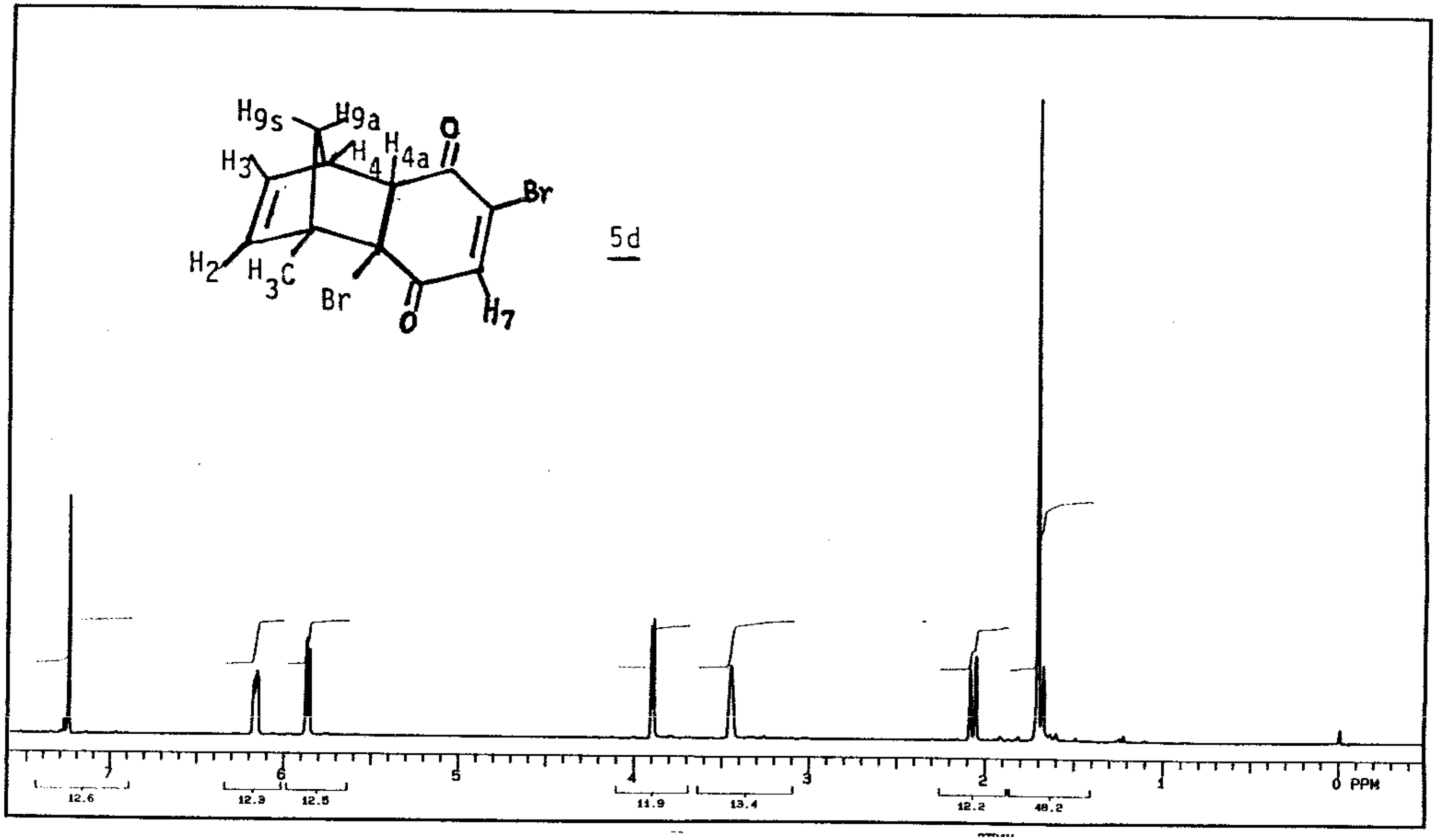


Figure 1 The ^{1}H NMR Spectrum of 5d.

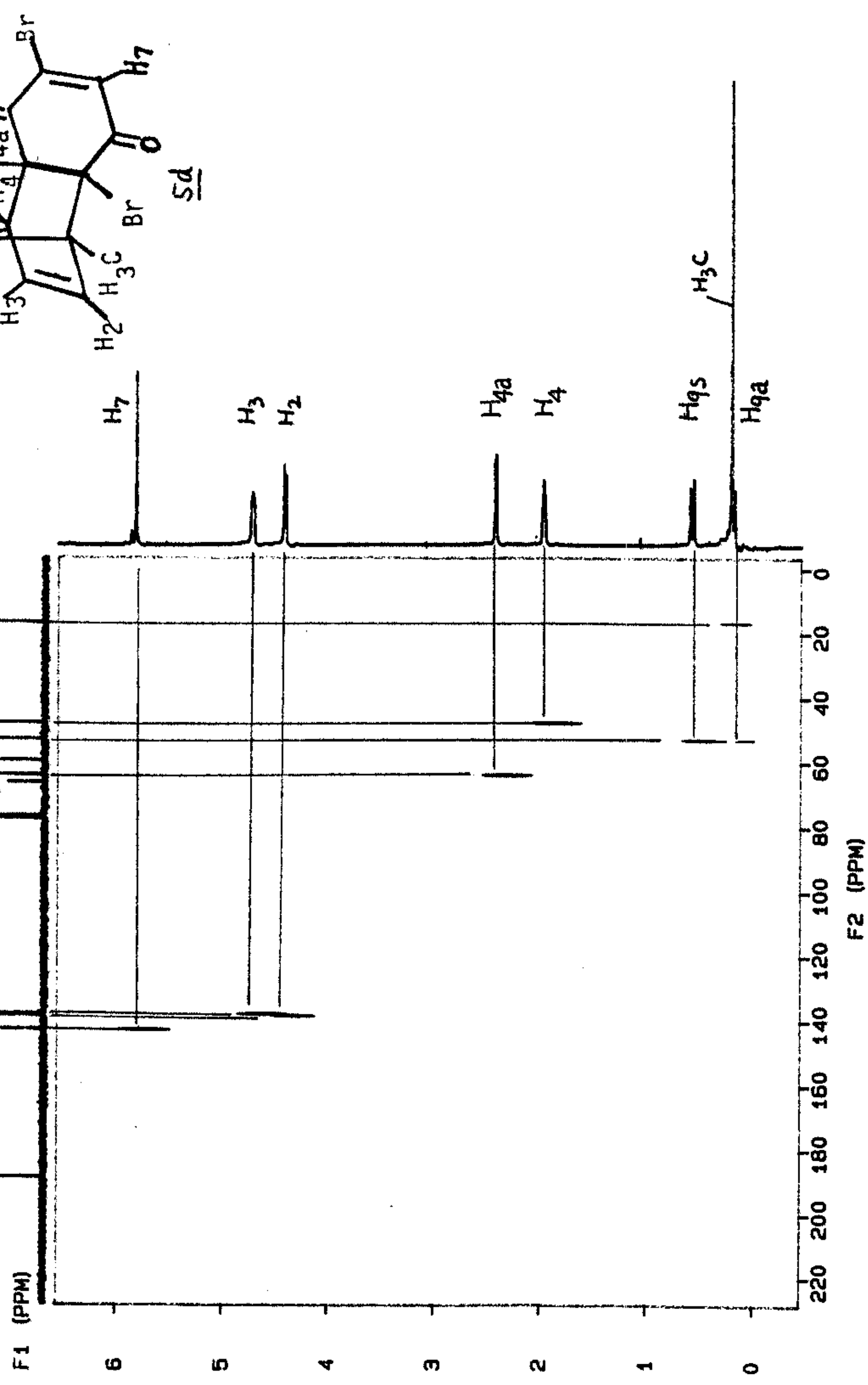


Figure 2 The HETCOR Spectrum of 5d.

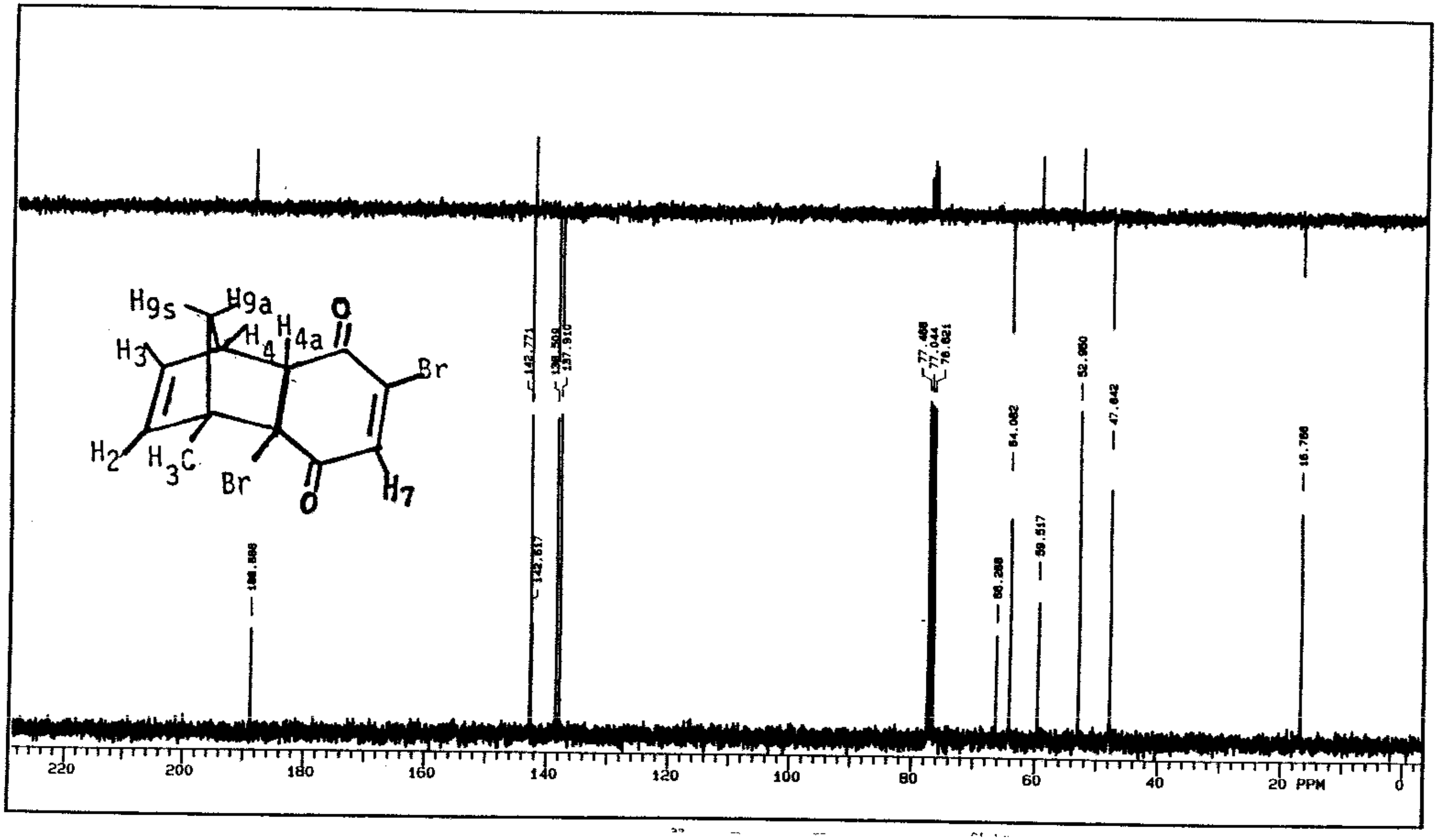


Figure 3 The ^{13}C NMR Spectrum (with APT) of 5d.

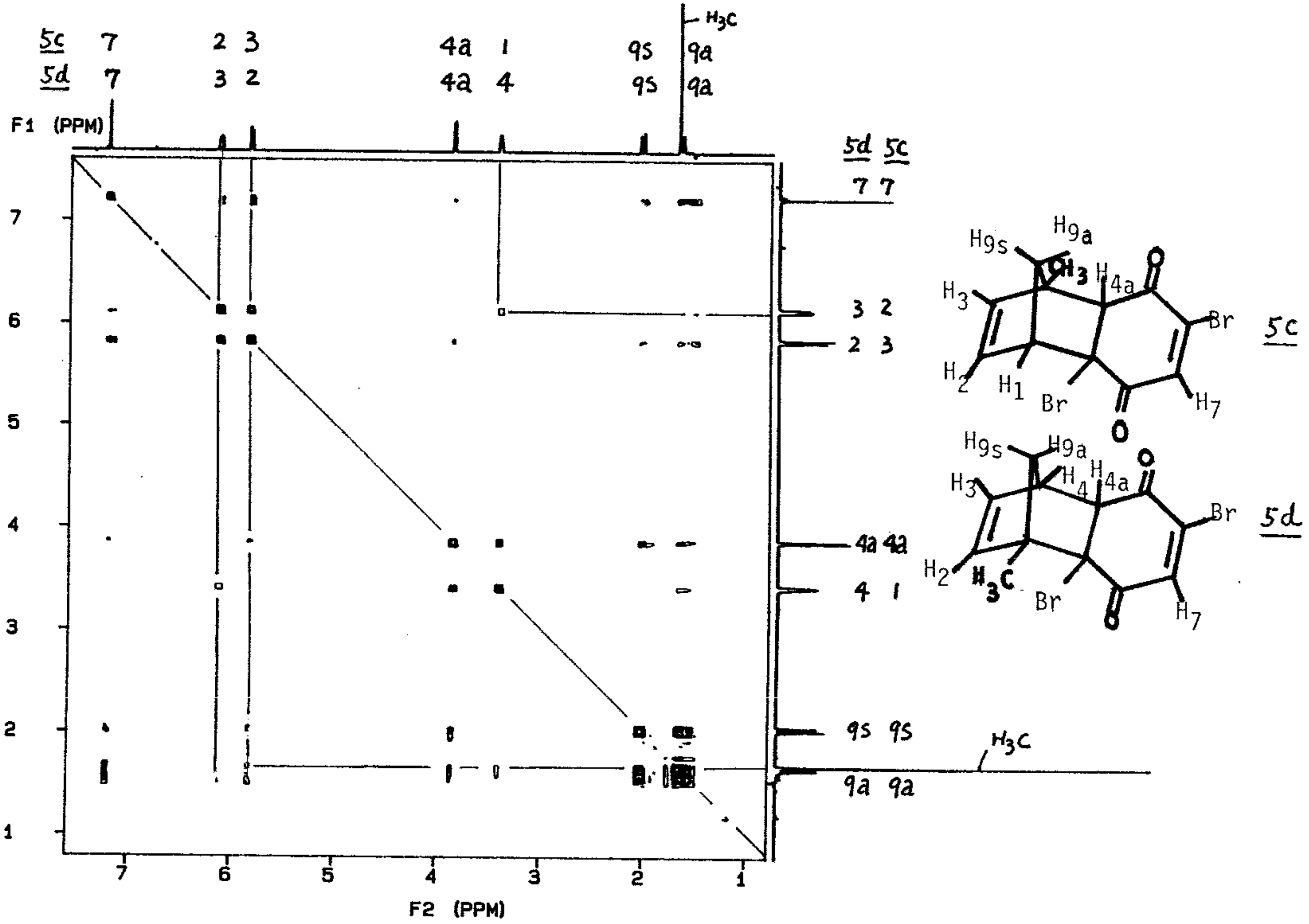


Figure 4 The COSY Spectrum of 5d.

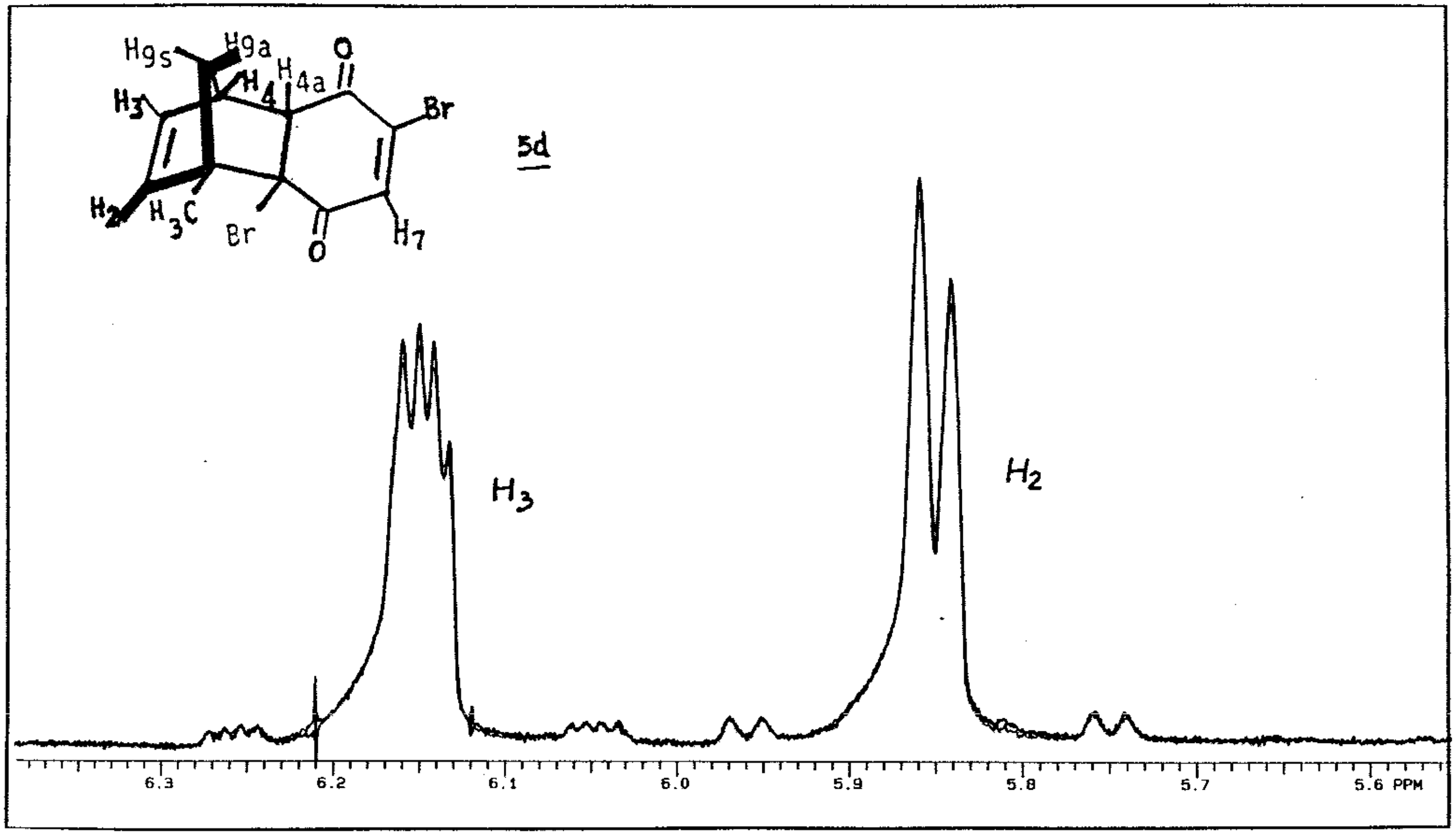


Figure 5 The Nuclesr Magnetic Double Resonance Spectrum of <u>5d</u>.

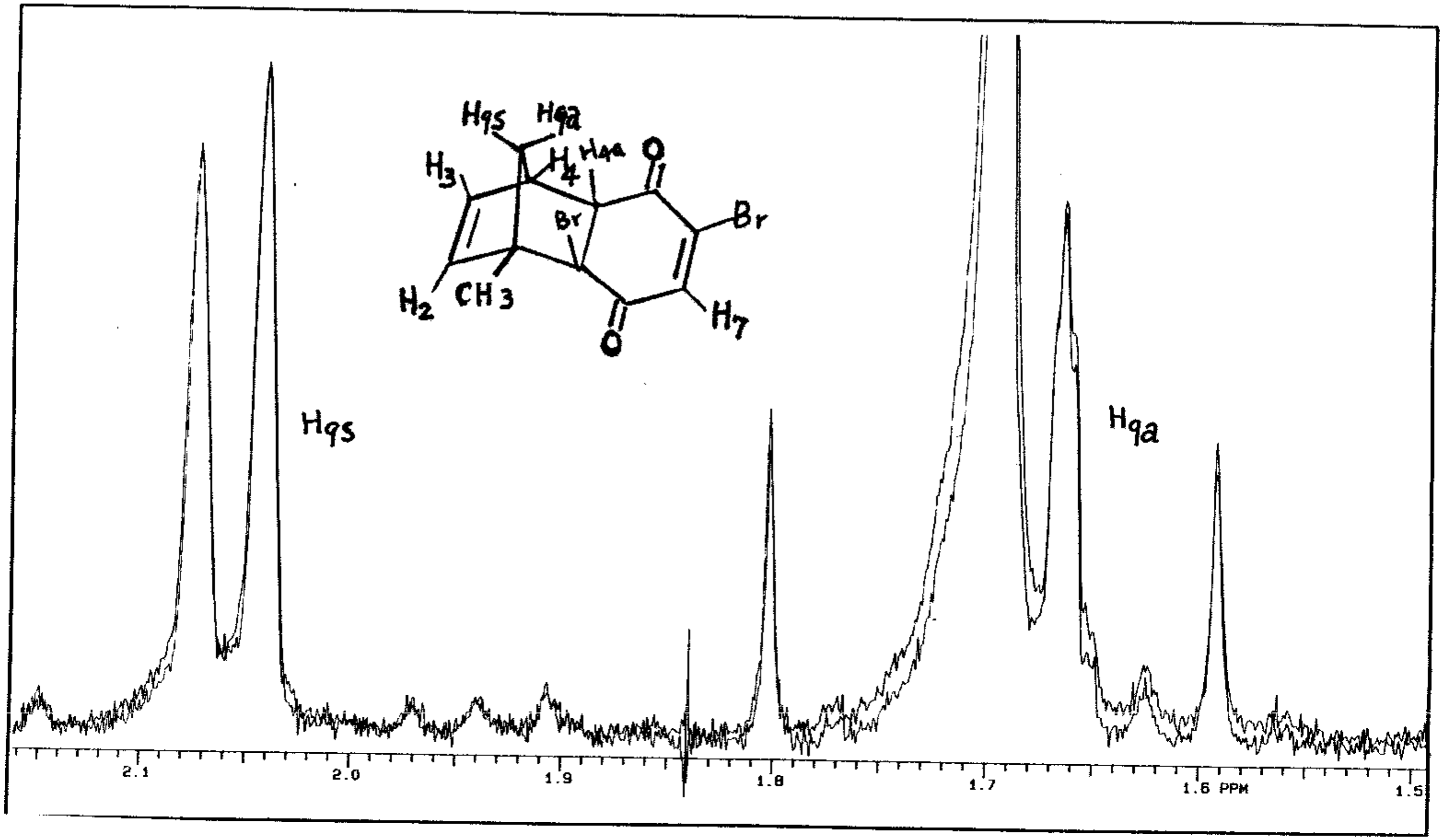


Figure 6 The NOE Spectrum of 5d.

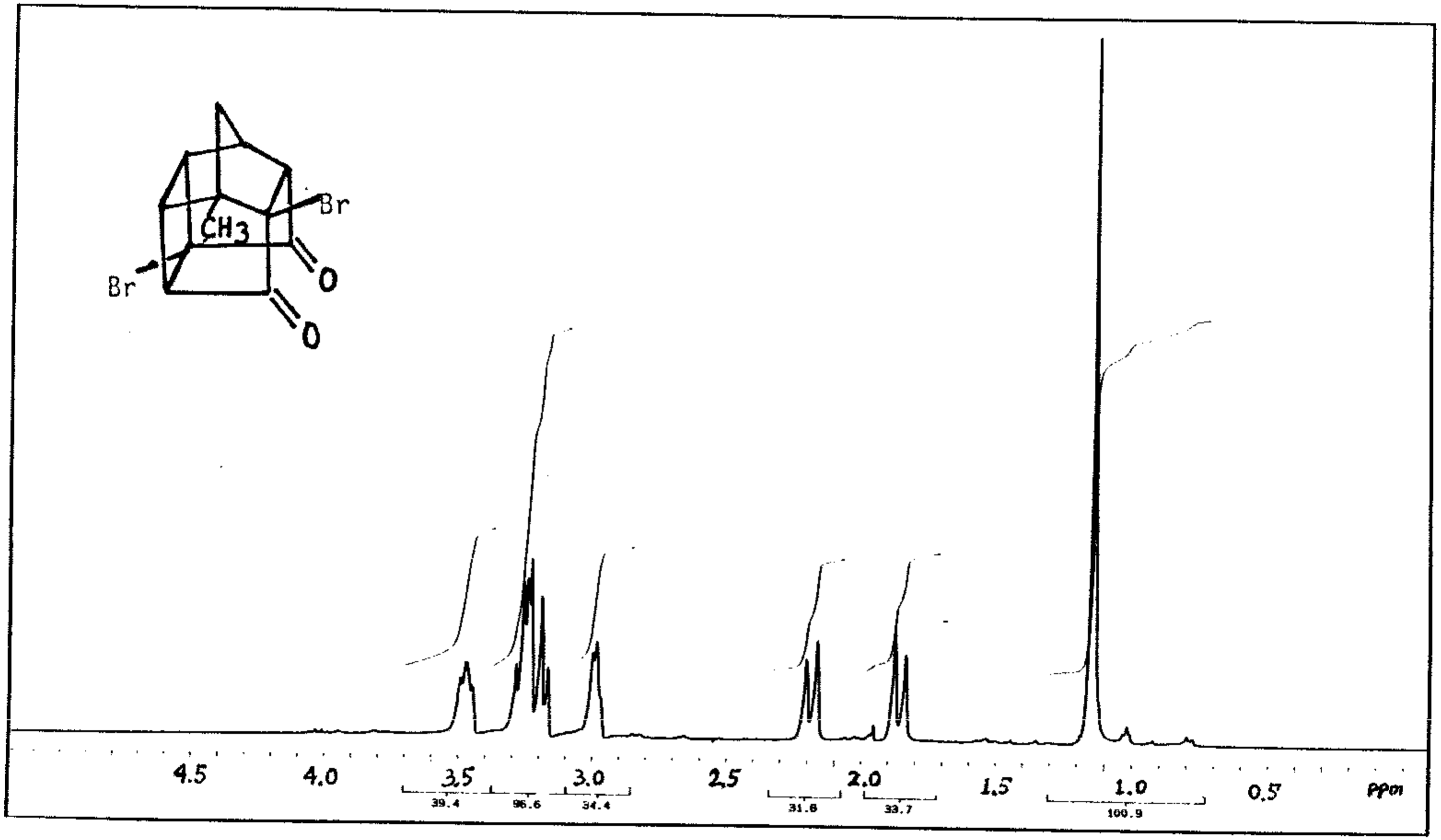


Figure 7 The ^1H NMR Spectrum of 6.

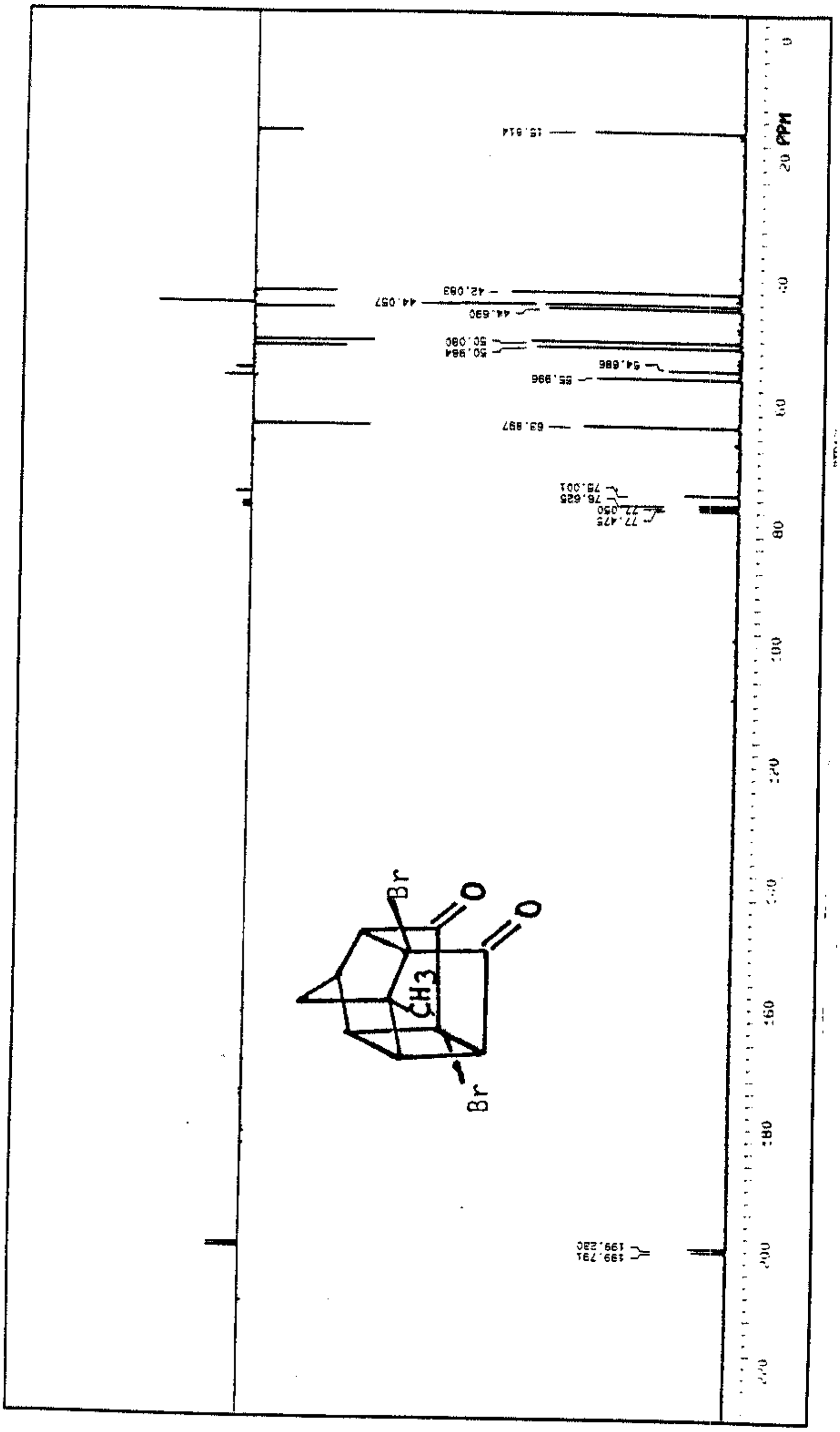


Figure 8 The ^{13}C NMR Spectrum of 6.

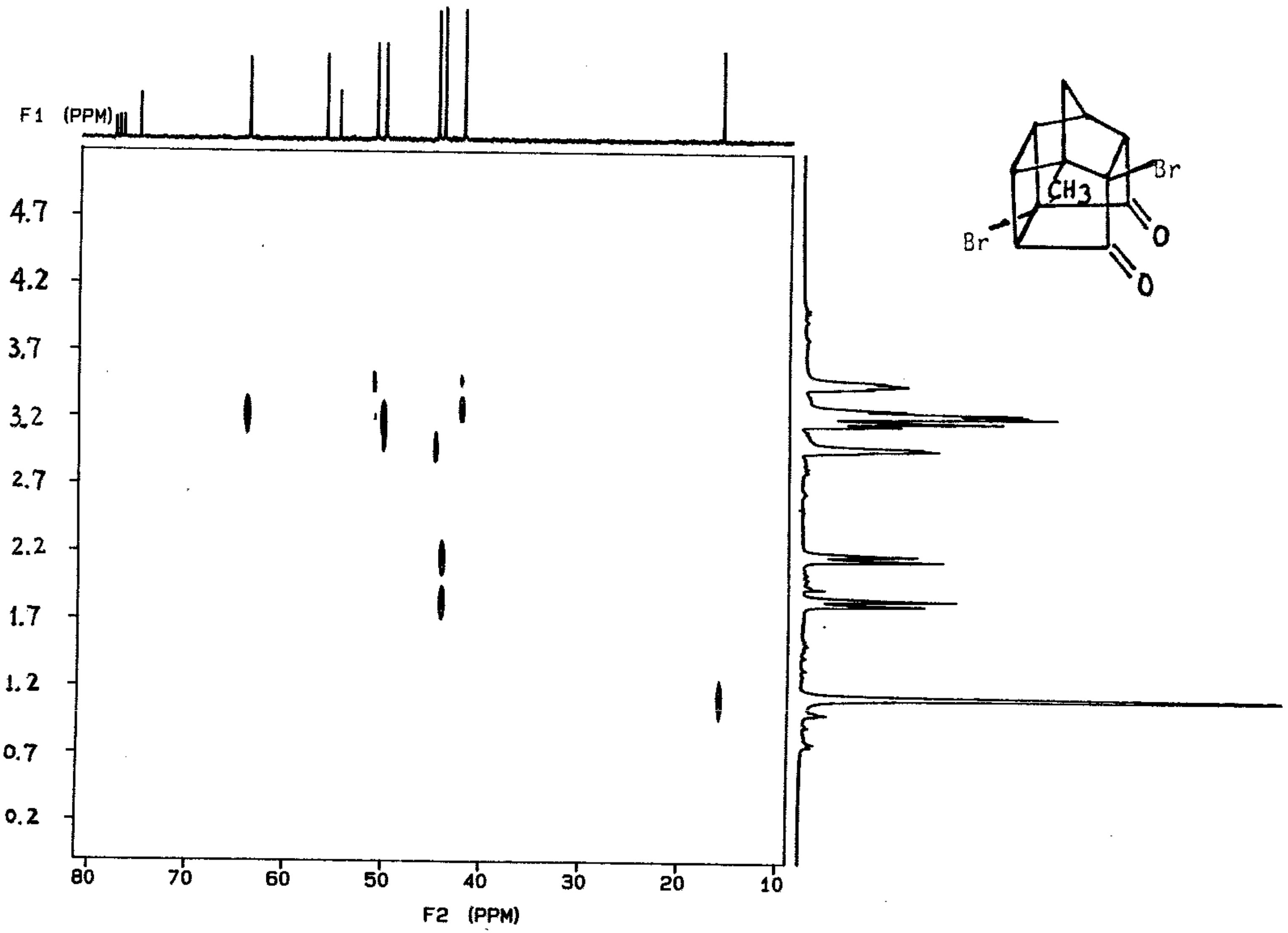


Figure 9 The HETCOR Spectrum of 6.

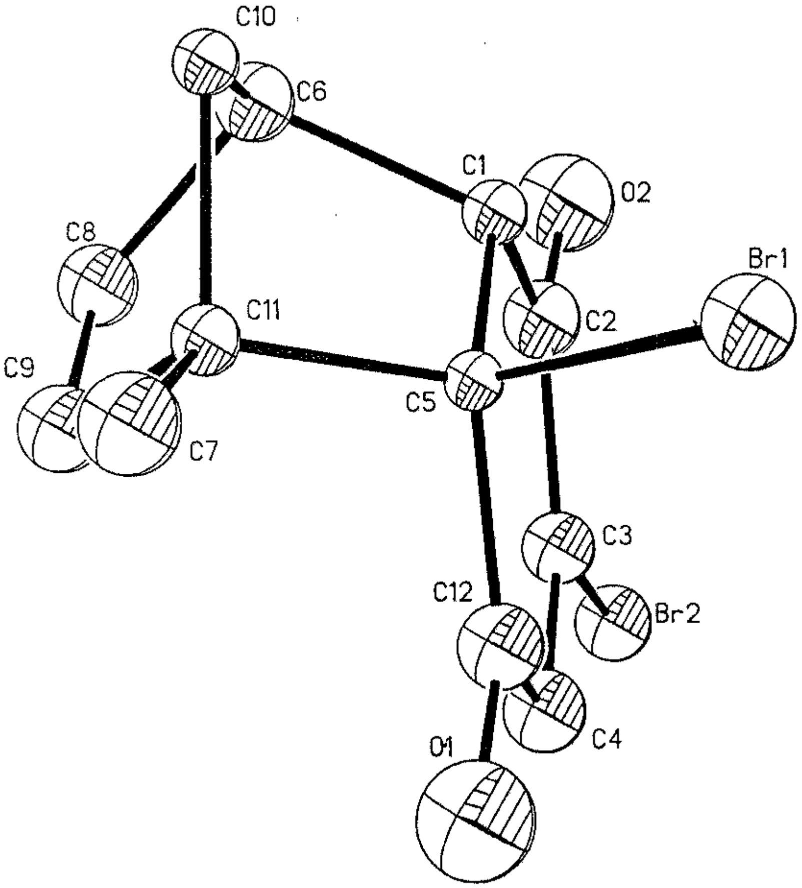


Figure 10 The Single crystal X-ray Structure of 5d.

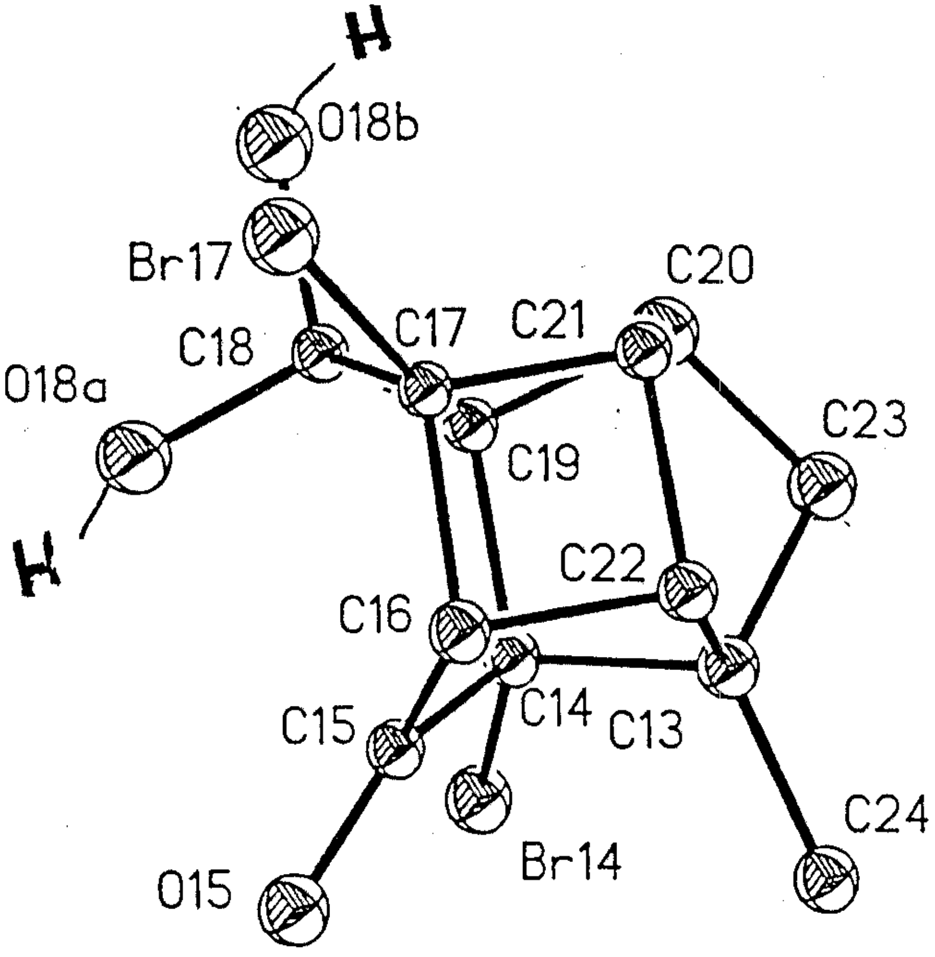


Figure 11 The Single crystal X-ray Structure of 7.

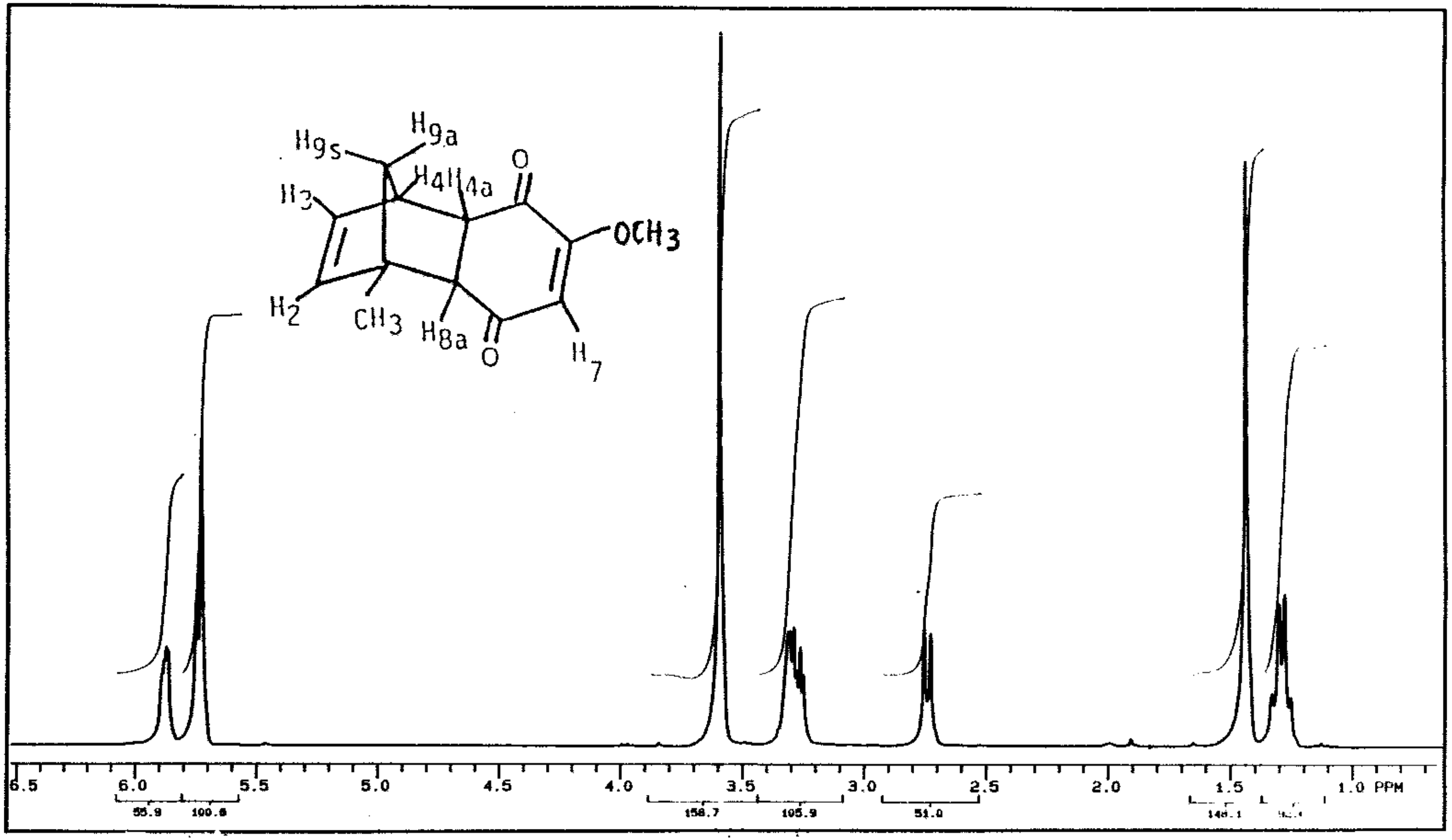


Figure 12 The ^1H NMR Spectrum of 9d.

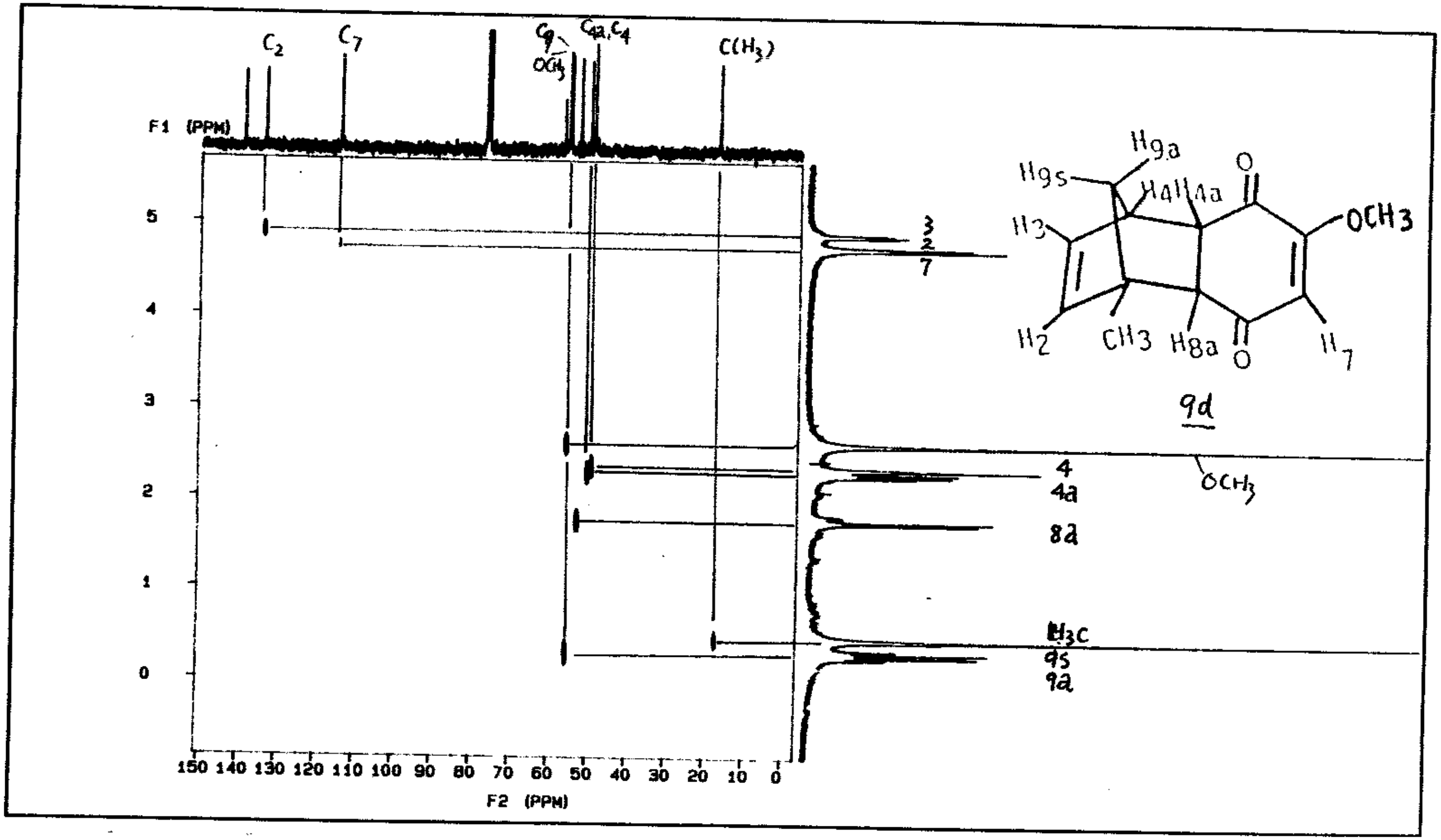


Figure 13 The HETCOR Spectrum of 9d.

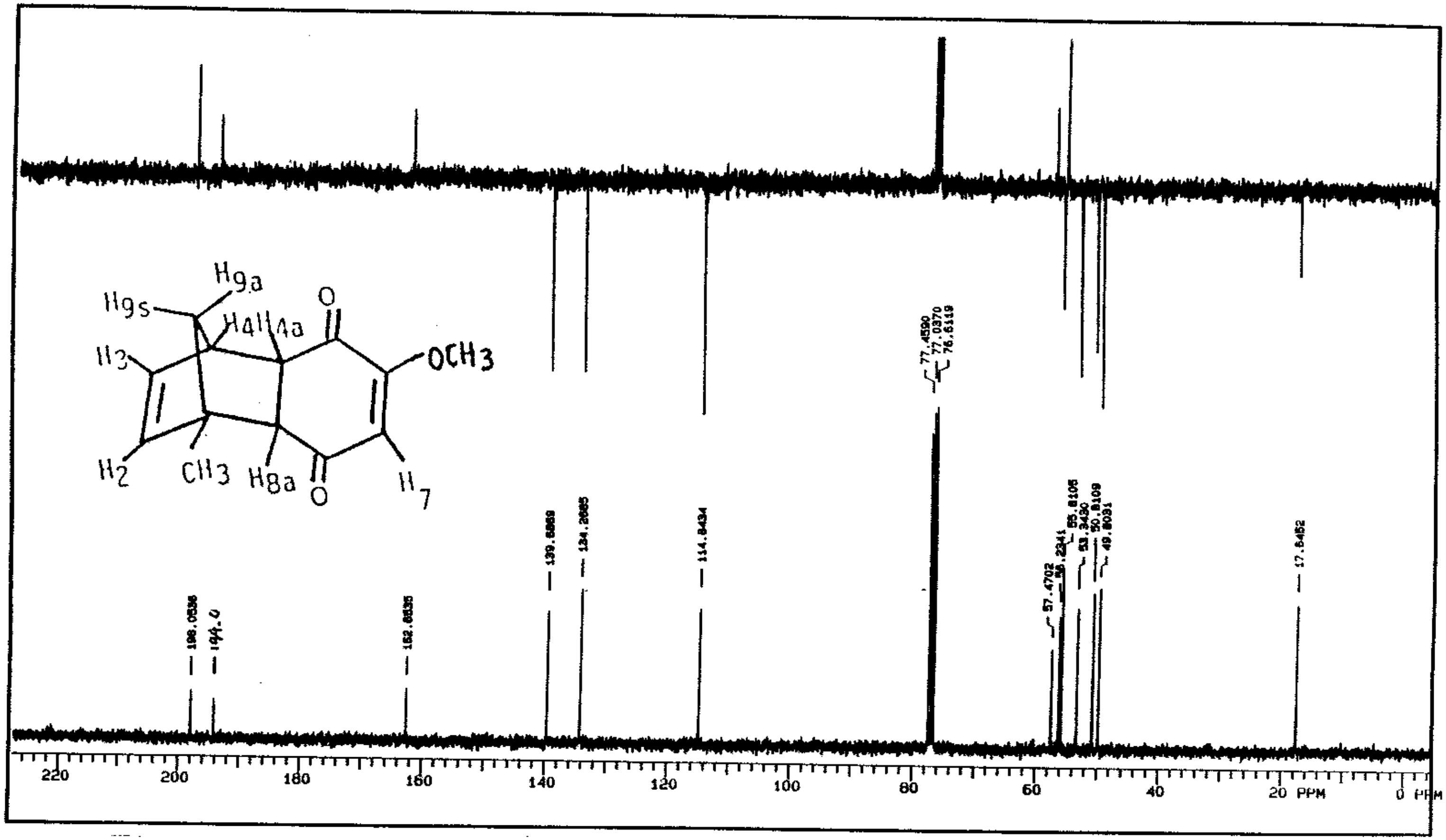


Figure 14 The ^{13}C NMR Spectrum (with APT) of 9d.

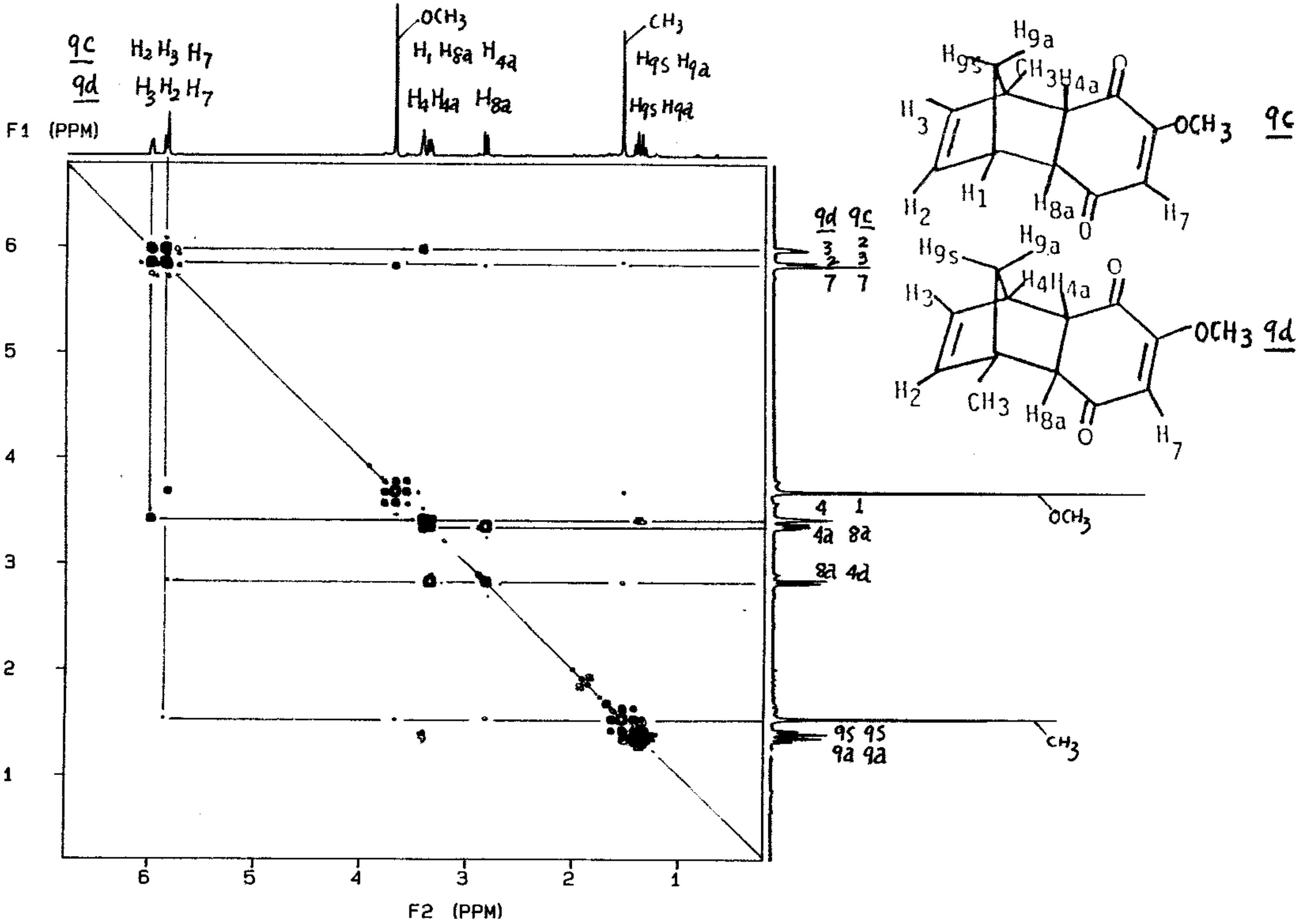


Figure 15 The COSY Spectrum of 9d.

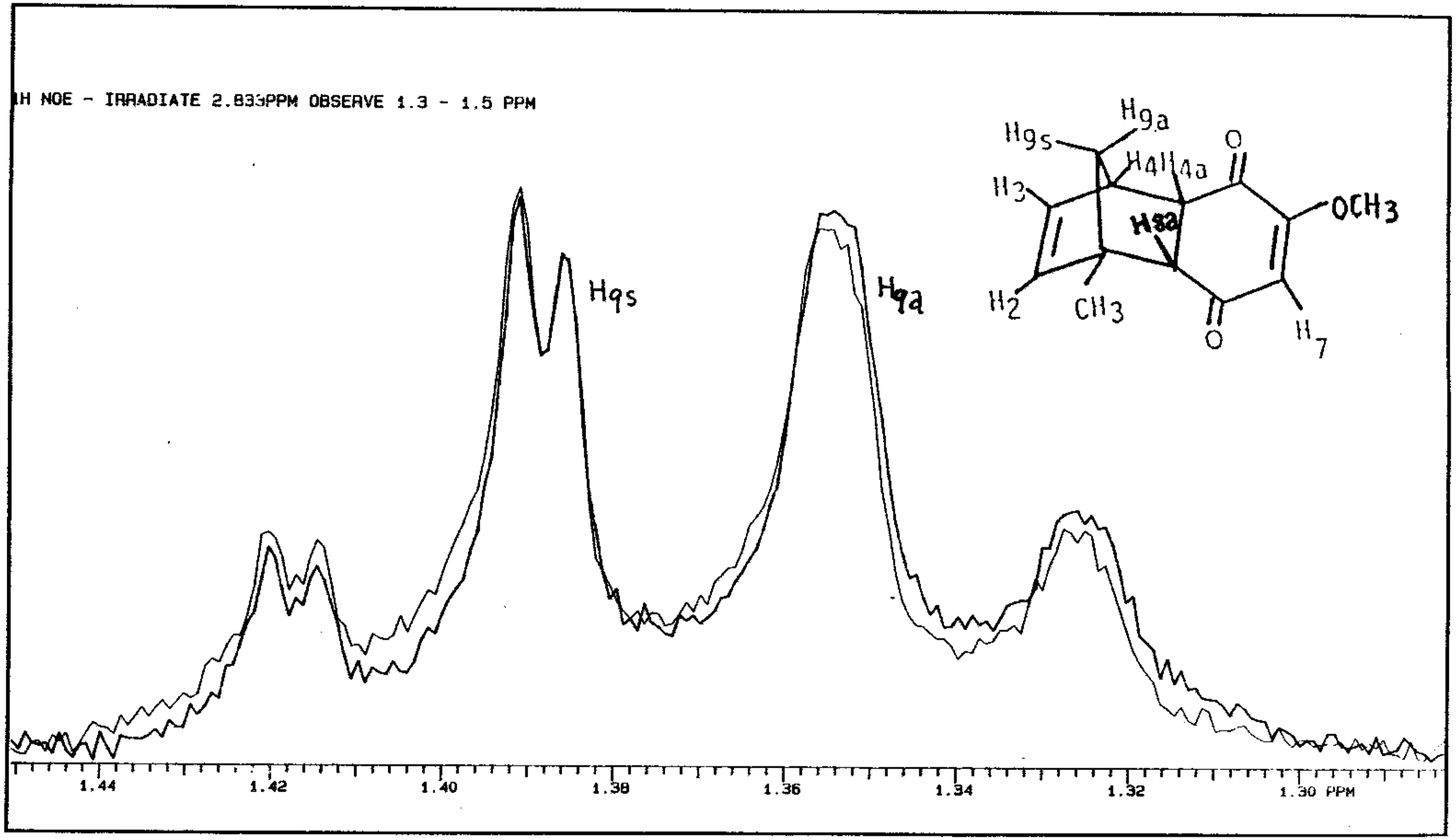
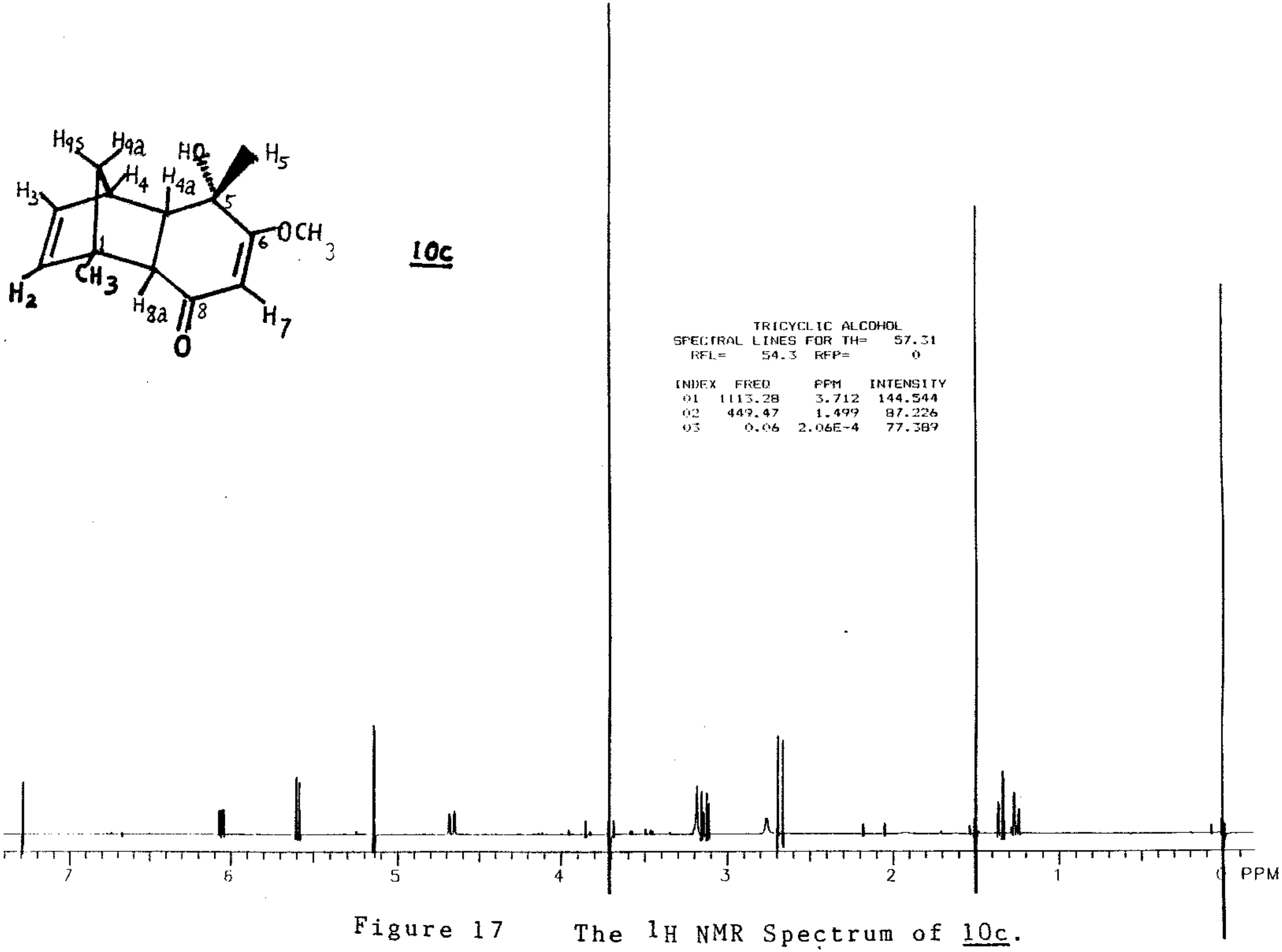


Figure 16 The NOE Spectrum of 9d.



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 01  1113.28     3.712  144.544
 02   449.47     1.499   87.226
 03     0.06  2.06E-4    77.389
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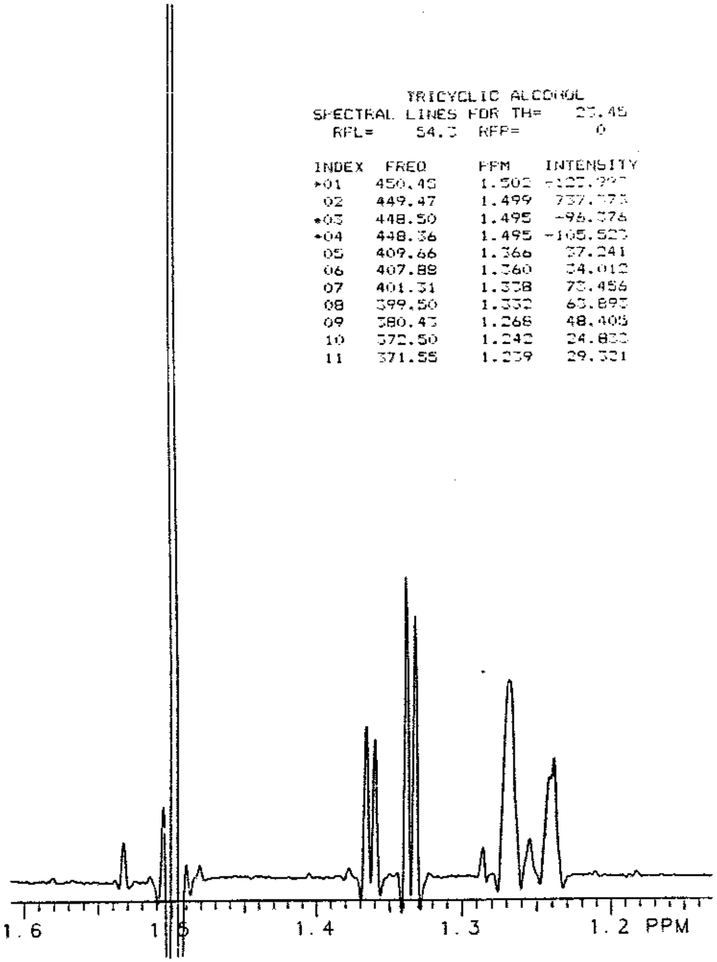
Figure 17   The ^1H NMR Spectrum of 10c.



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  RFL=    54.3  RFP=        0

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 02   449.47    1.499  737.373
*03   448.50    1.495  -96.376
*04   448.36    1.495 -105.523
 05   409.66    1.366   37.241
 06   407.88    1.360   34.012
 07   401.31    1.338   73.456
 08   399.50    1.332   63.893
 09   380.43    1.268   48.405
 10   372.50    1.242   24.833
 11   371.55    1.239   29.321
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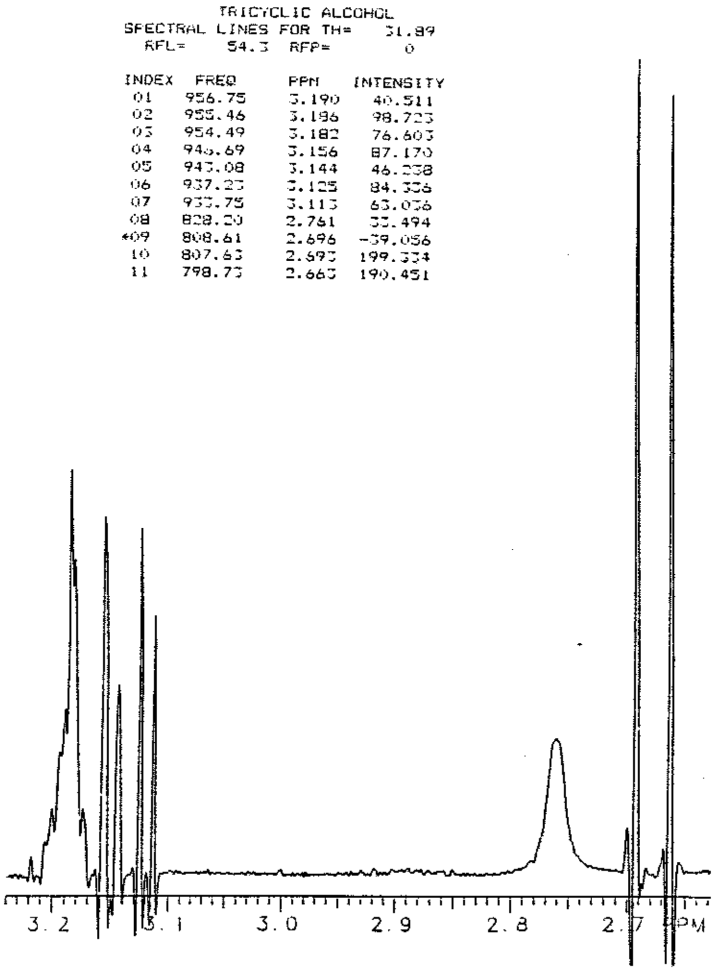
Figure 18 The ^{1}H NMR Spectrum of <u>10c</u>.



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   RFL=     54.3  RFP=        0

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  02   955.46    3.186    98.723
  03   954.49    3.182    76.603
  04   946.69    3.156    87.170
  05   943.08    3.144    46.238
  06   937.23    3.125    84.336
  07   933.75    3.113    63.036
  08   828.20    2.761    33.494
 *09   808.61    2.696   -39.056
  10   807.63    2.693   199.334
  11   798.73    2.663   190.451
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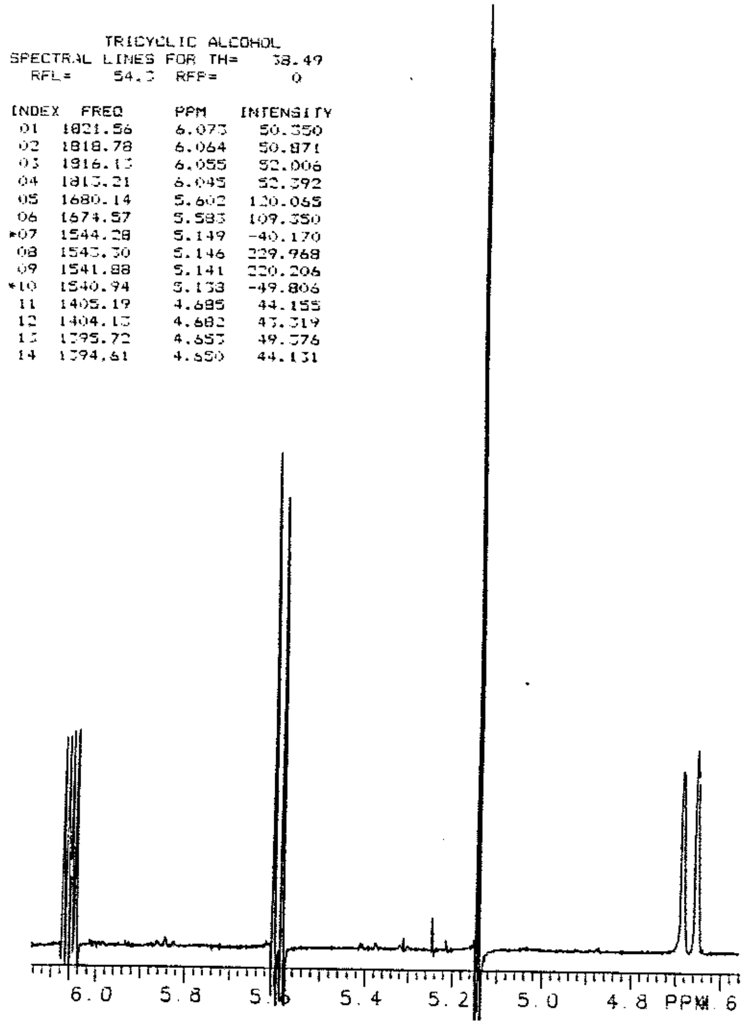
Figure 19 The ^1H NMR Spectrum of <u>10c</u>.



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  RFL=     54.3  RFP=        0

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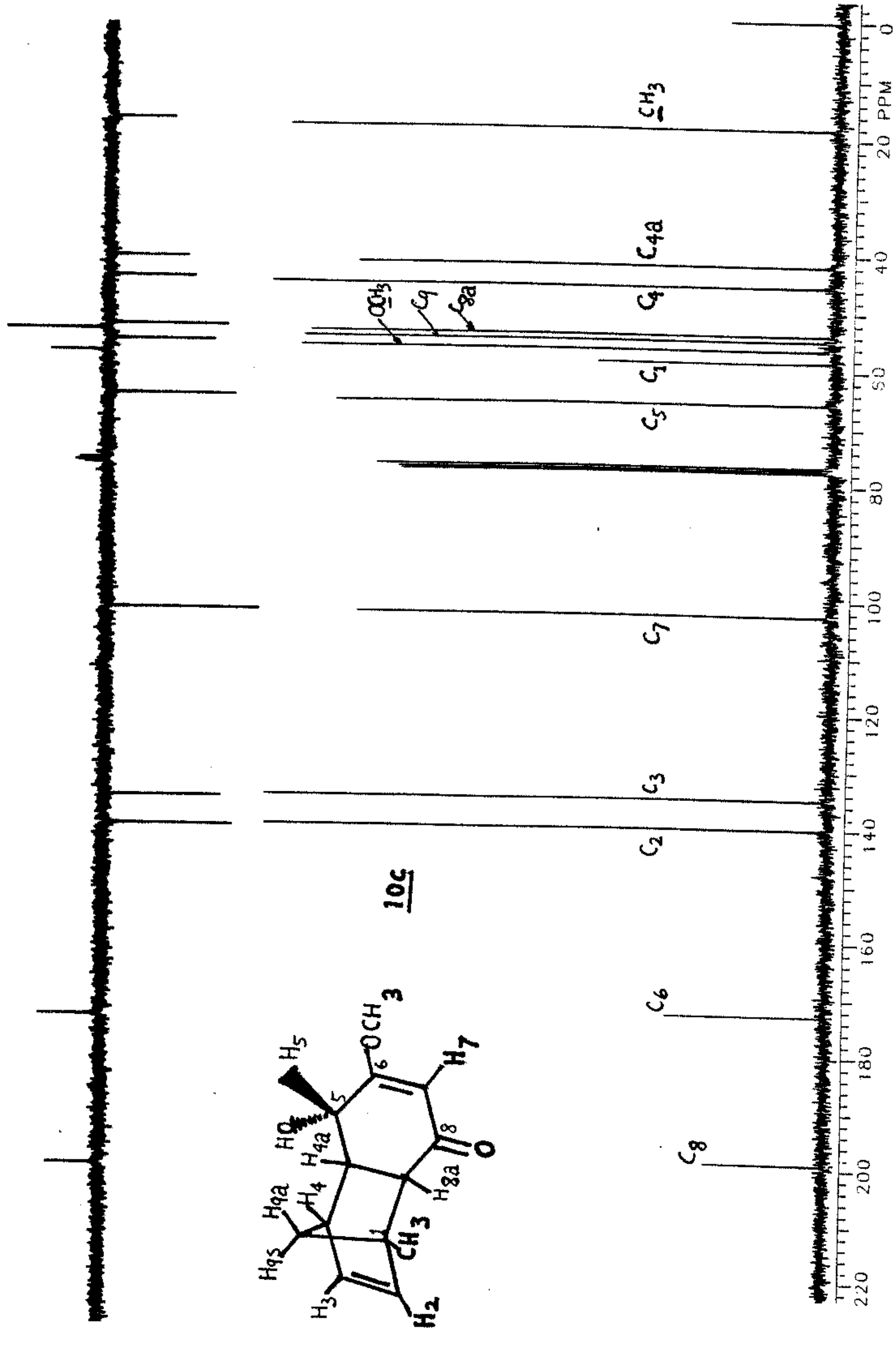
 02   1818.78    6.064    50.871
 03   1916.13    6.055    52.006
 04   1813.21    6.045    52.392
 05   1680.14    5.602   120.065
 06   1674.57    5.583   109.350
*07   1544.28    5.149   -40.170
 08   1543.30    5.146   229.968
 09   1541.88    5.141   220.206
*10   1540.94    5.133   -49.806
 11   1405.19    4.685    44.155
 12   1404.13    4.682    43.319
 13   1395.72    4.653    49.376
 14   1394.61    4.650    44.131
```

Figure 20 The ^1H NMR Spectrum of <u>10c</u>.



10c

Figure 21 The 13C NMR Spectrum of 10c.

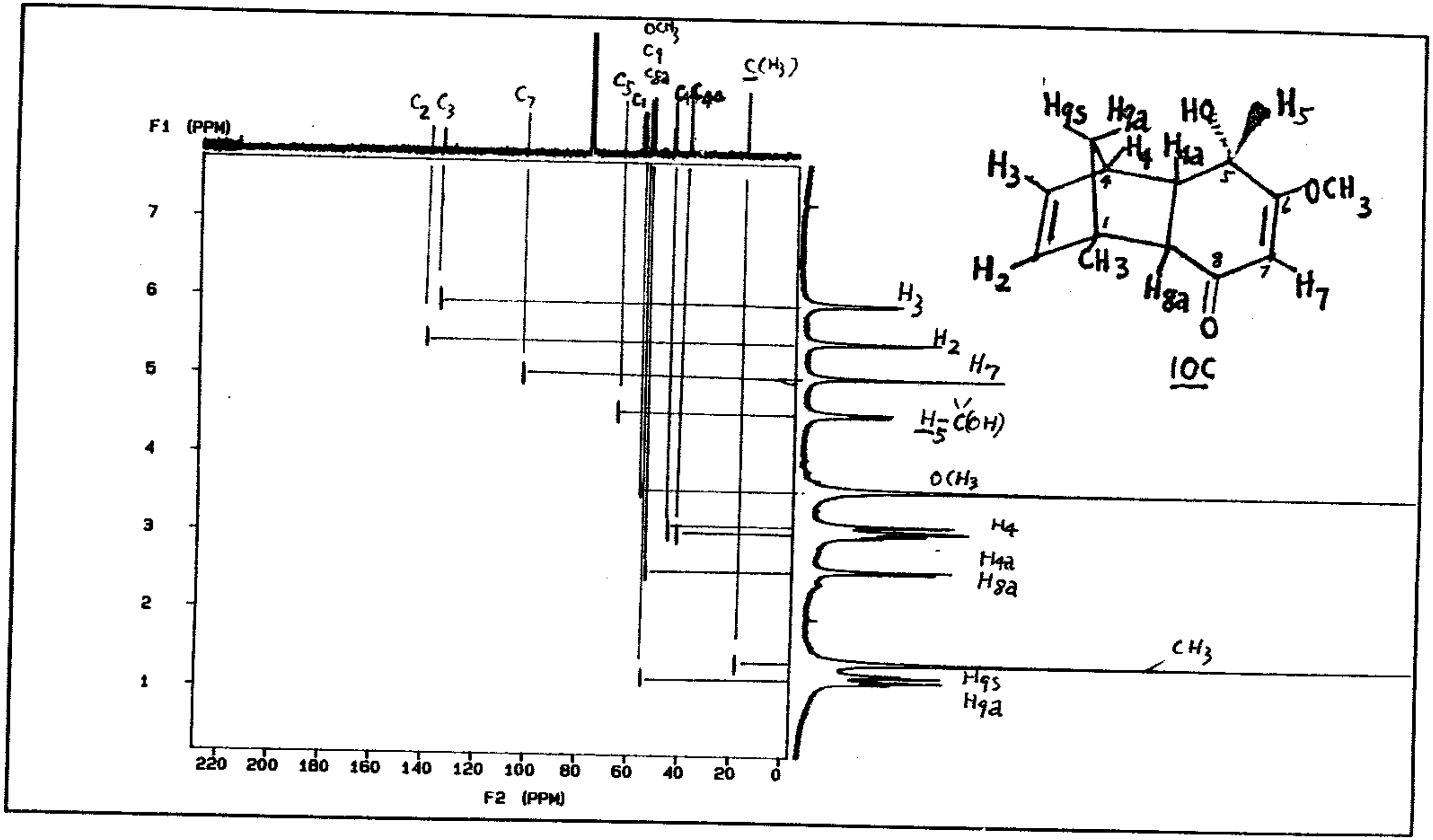


Figure 22 The HETCOR Spectrum of 10c.

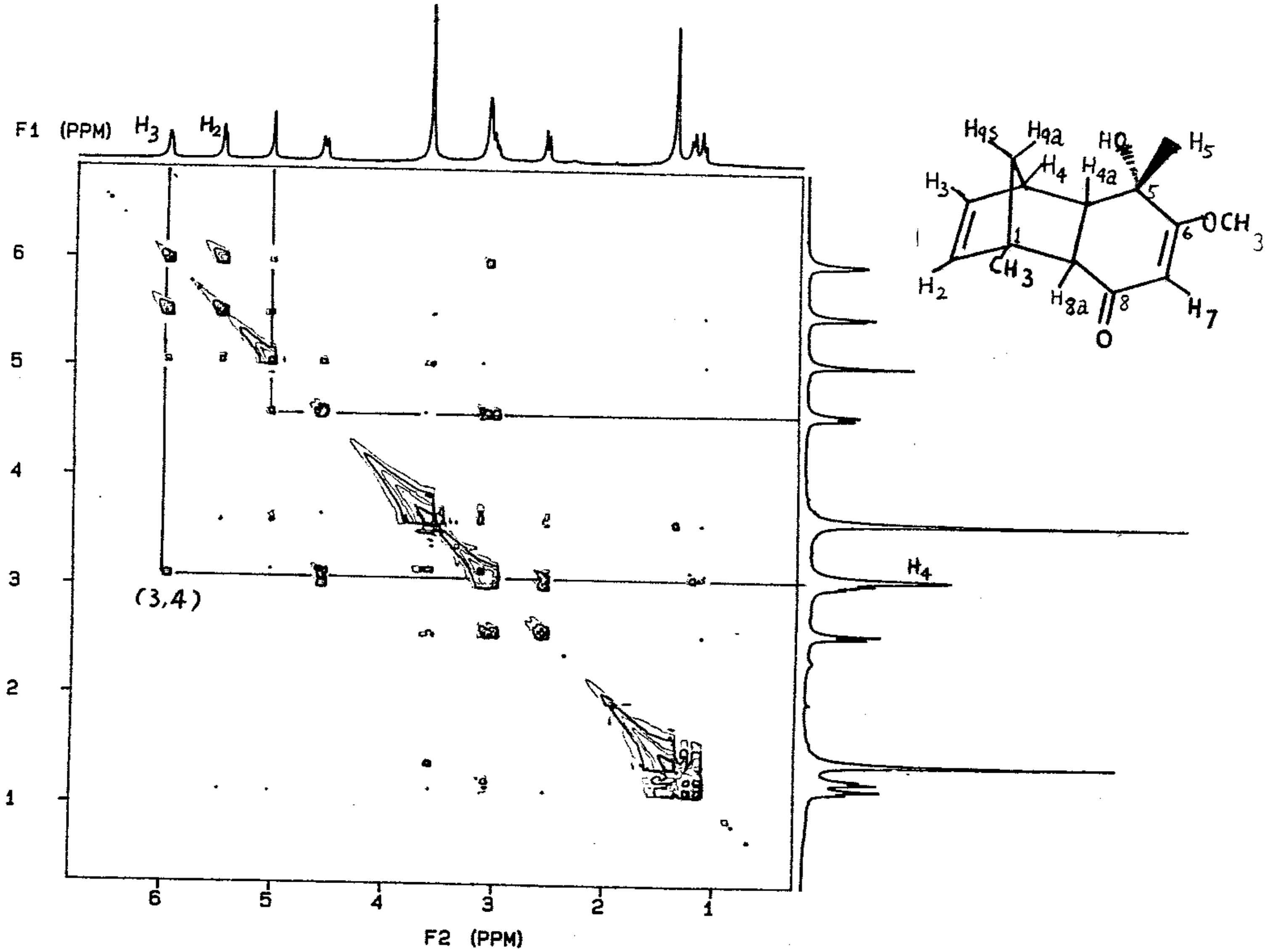


Figure 23 The COSY Spectrum of 10c.

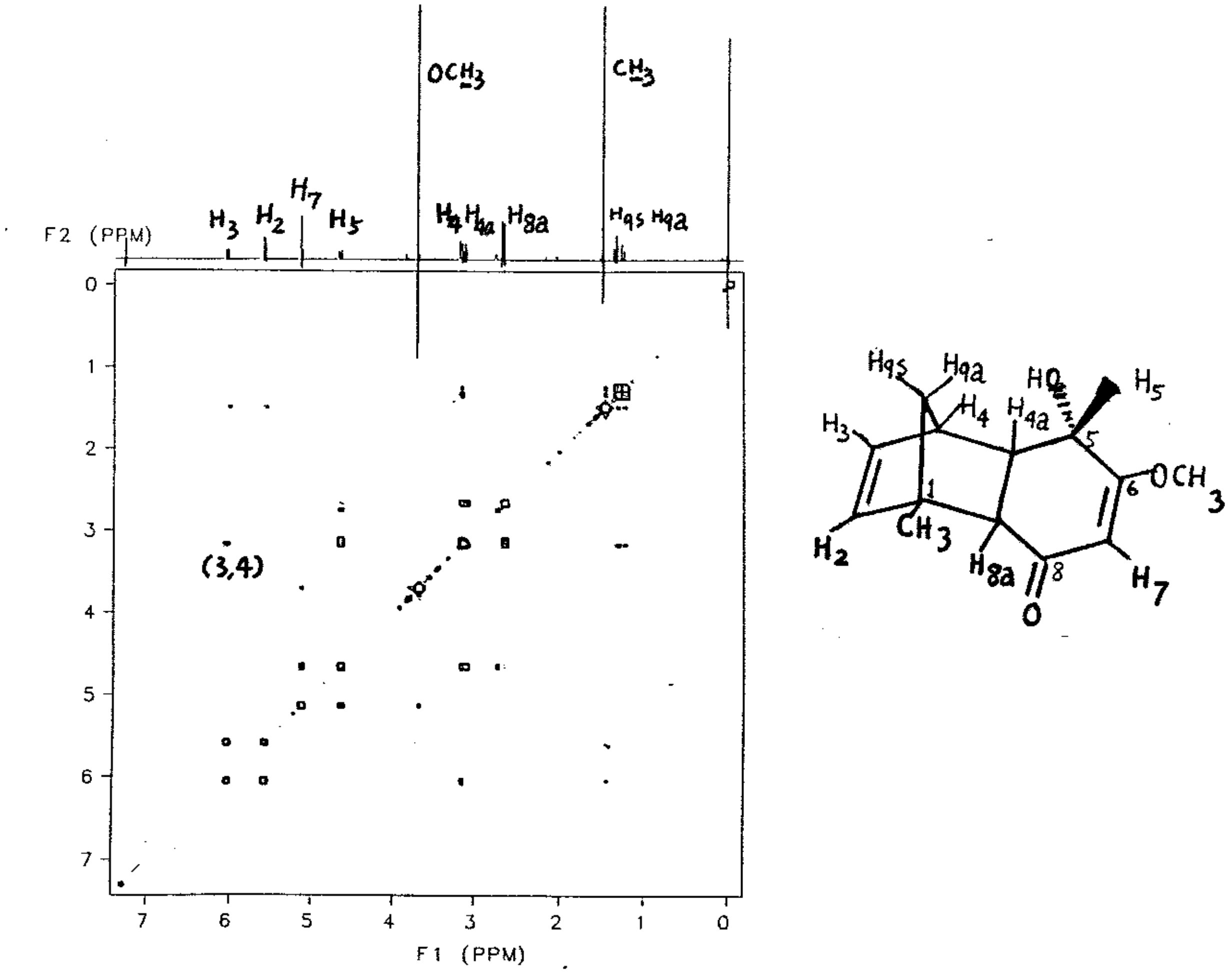


Figure 24 The Delayed COSY Spectrum of <u>10c</u>.

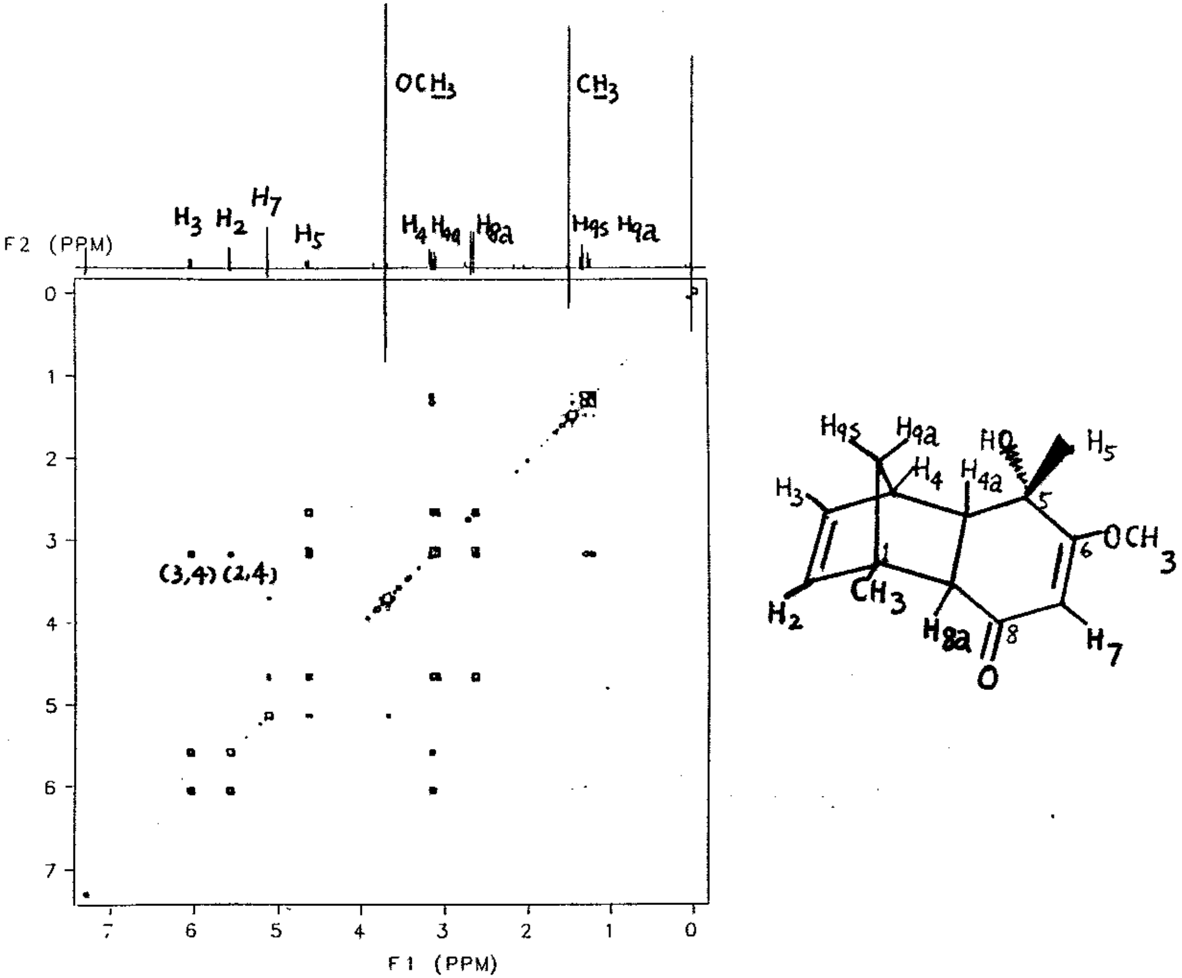


Figure 25 The RELAY COSY Spectrum of 10c.

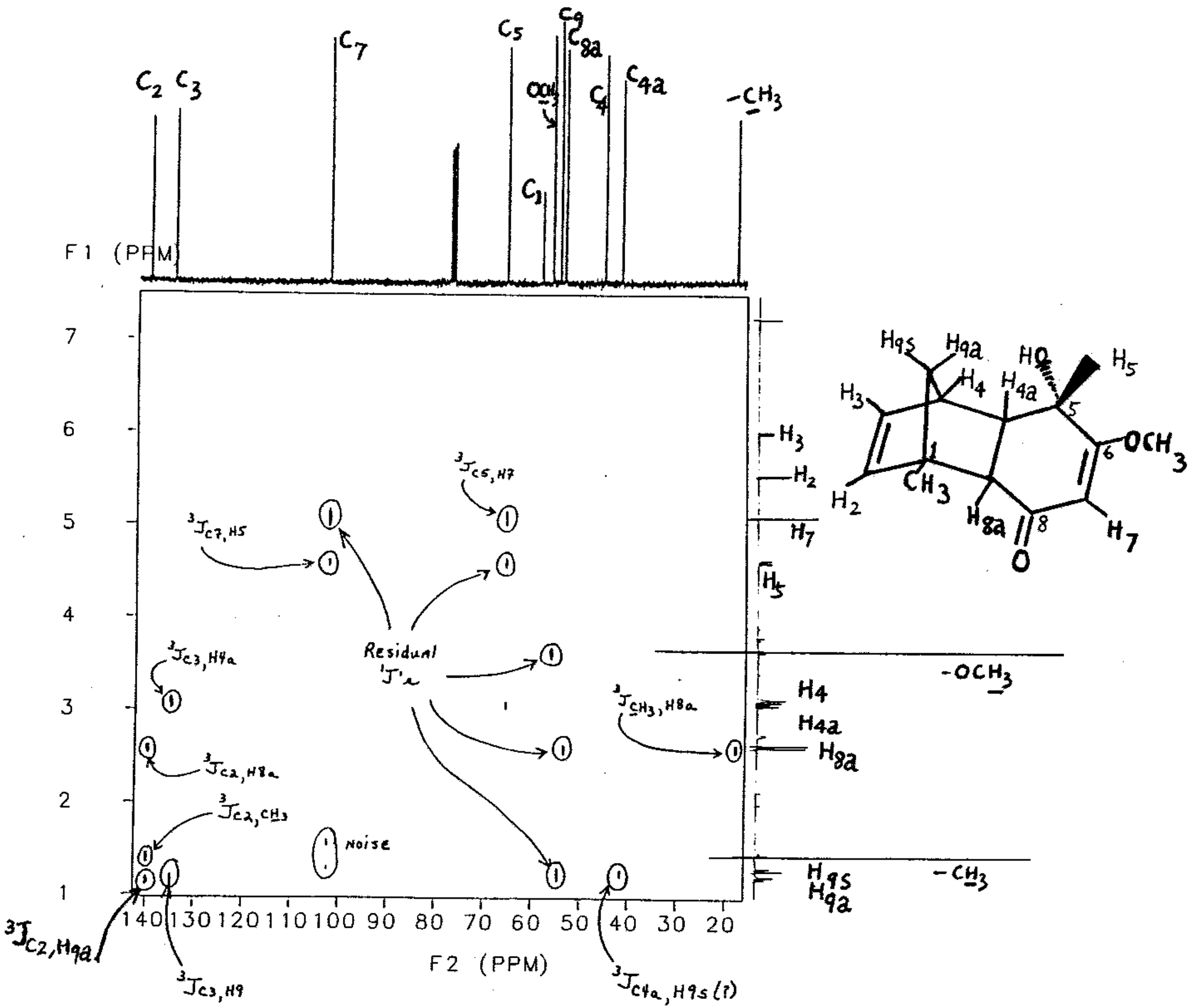


Figure 26 The Long-range HETCOR Spectrum of 10c.

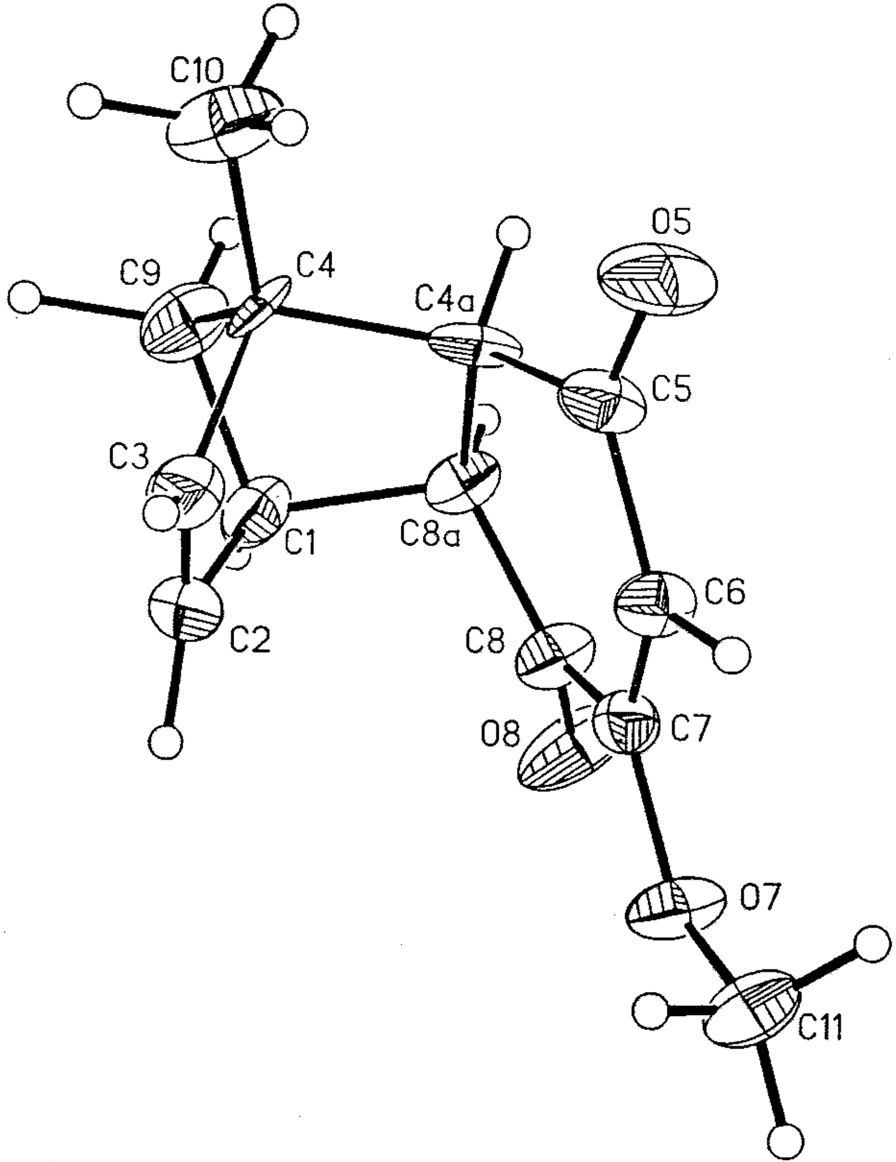


Figure 27 The Single-crystal X-ray Structure of <u>9d</u>.

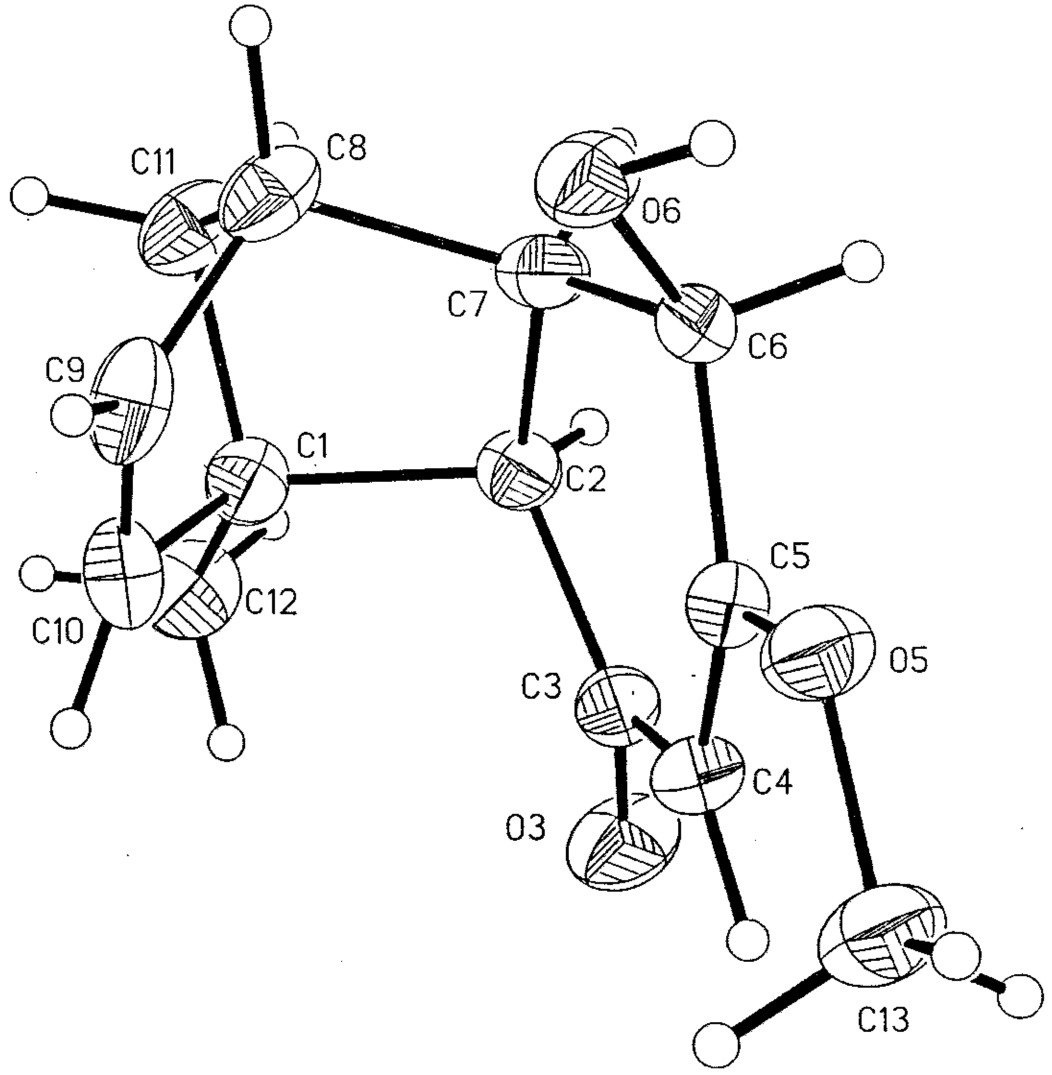


Figure 28 The Single-crystal X-ray Structure of 10c.

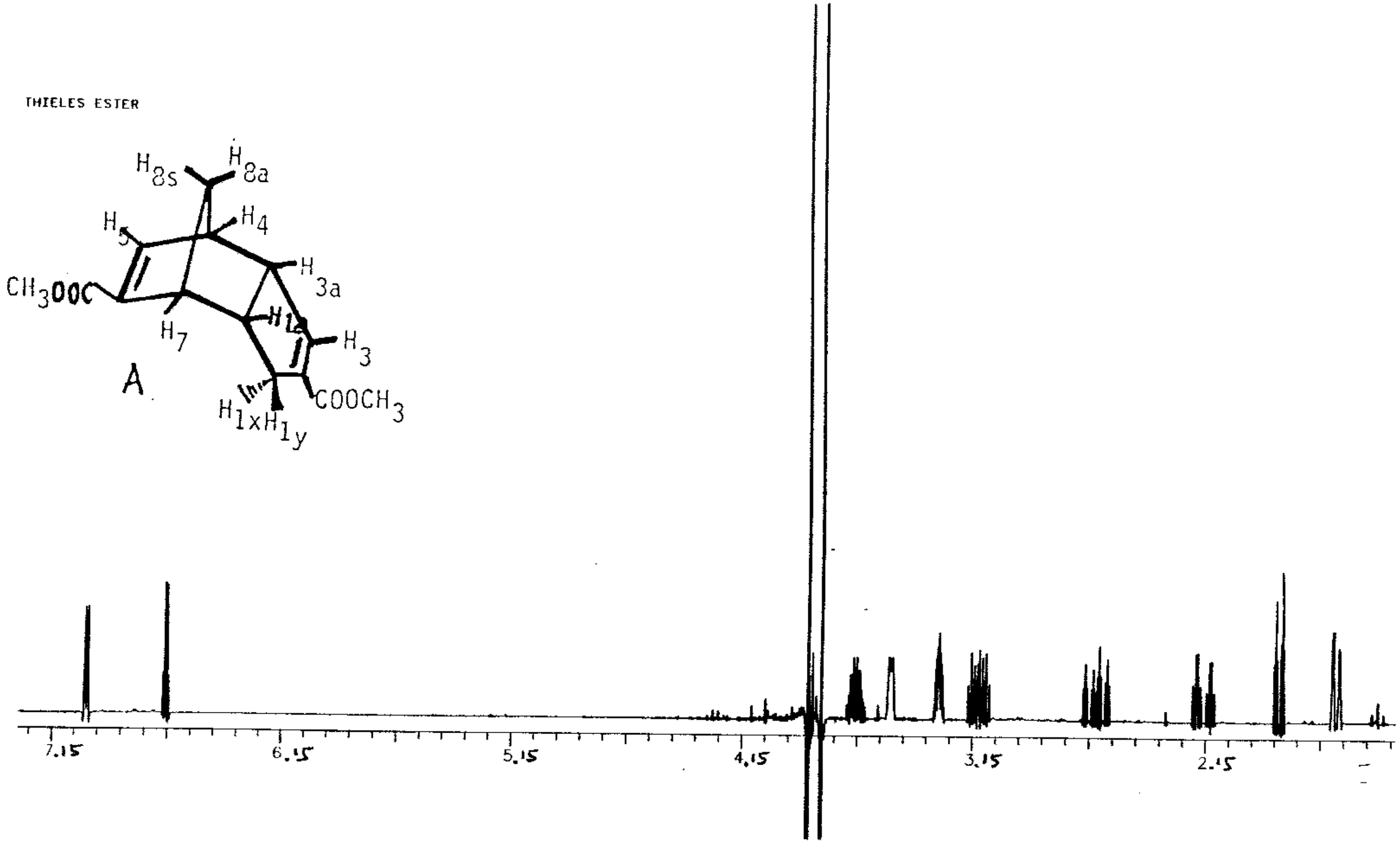


Figure 29 The ^{1}H NMR Spectrum of Thiele's Ester.

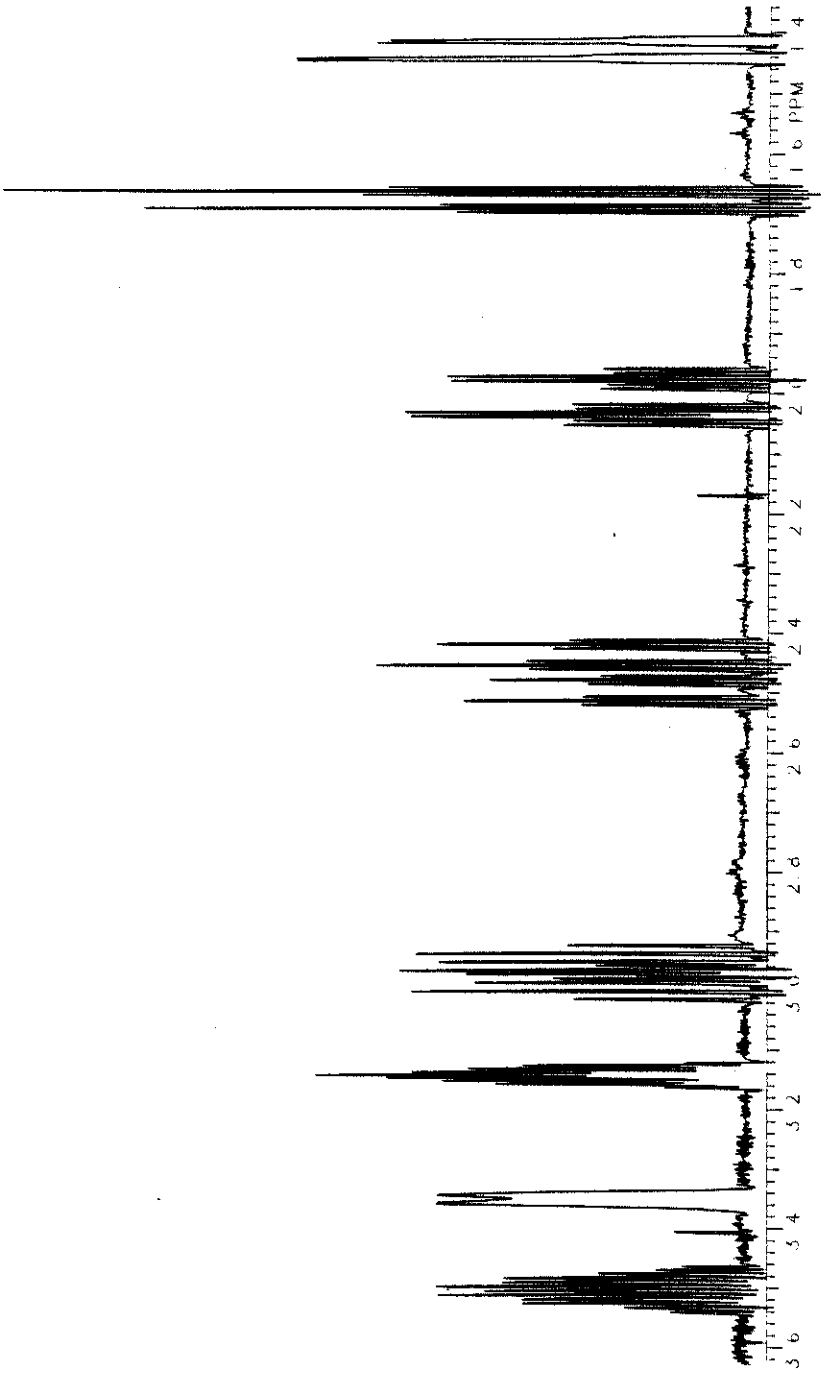


Figure 30 The ^1H NMR Spectrum of Thiele's Ester.

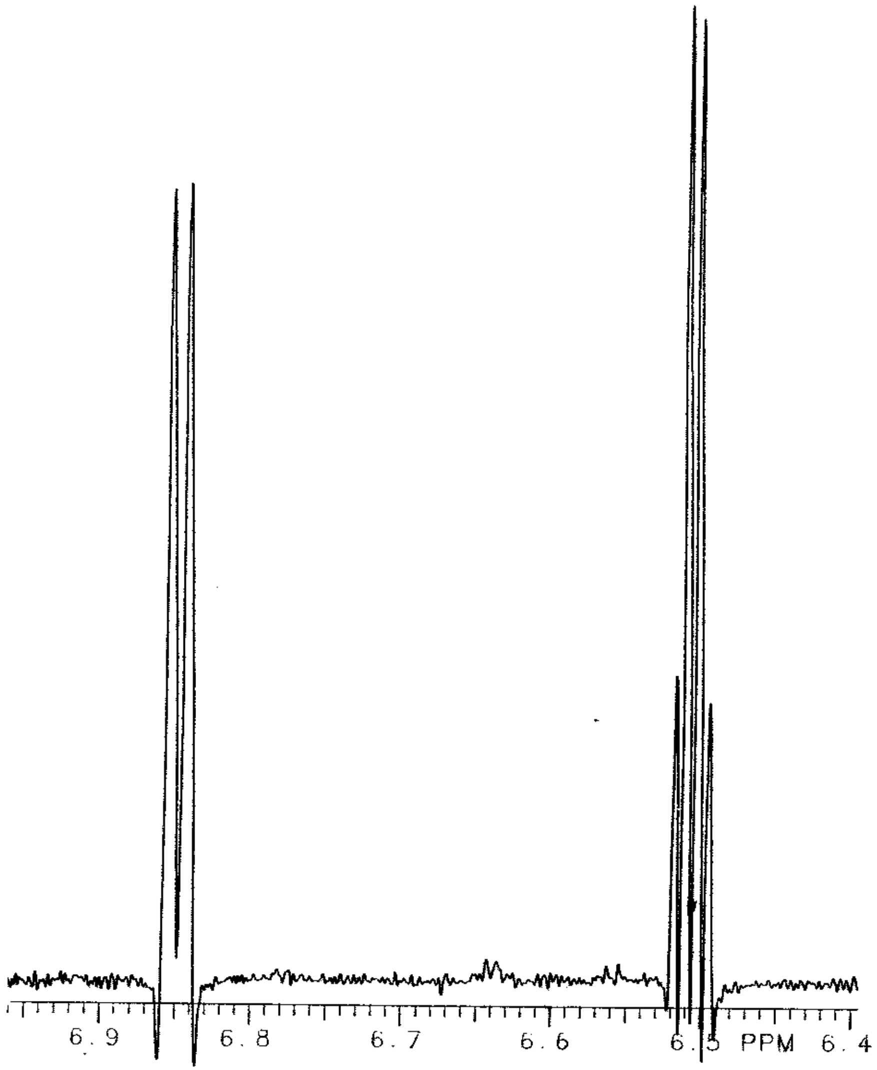


Figure 31 The ^{1}H NMR Spectrum of Thiele's Ester.

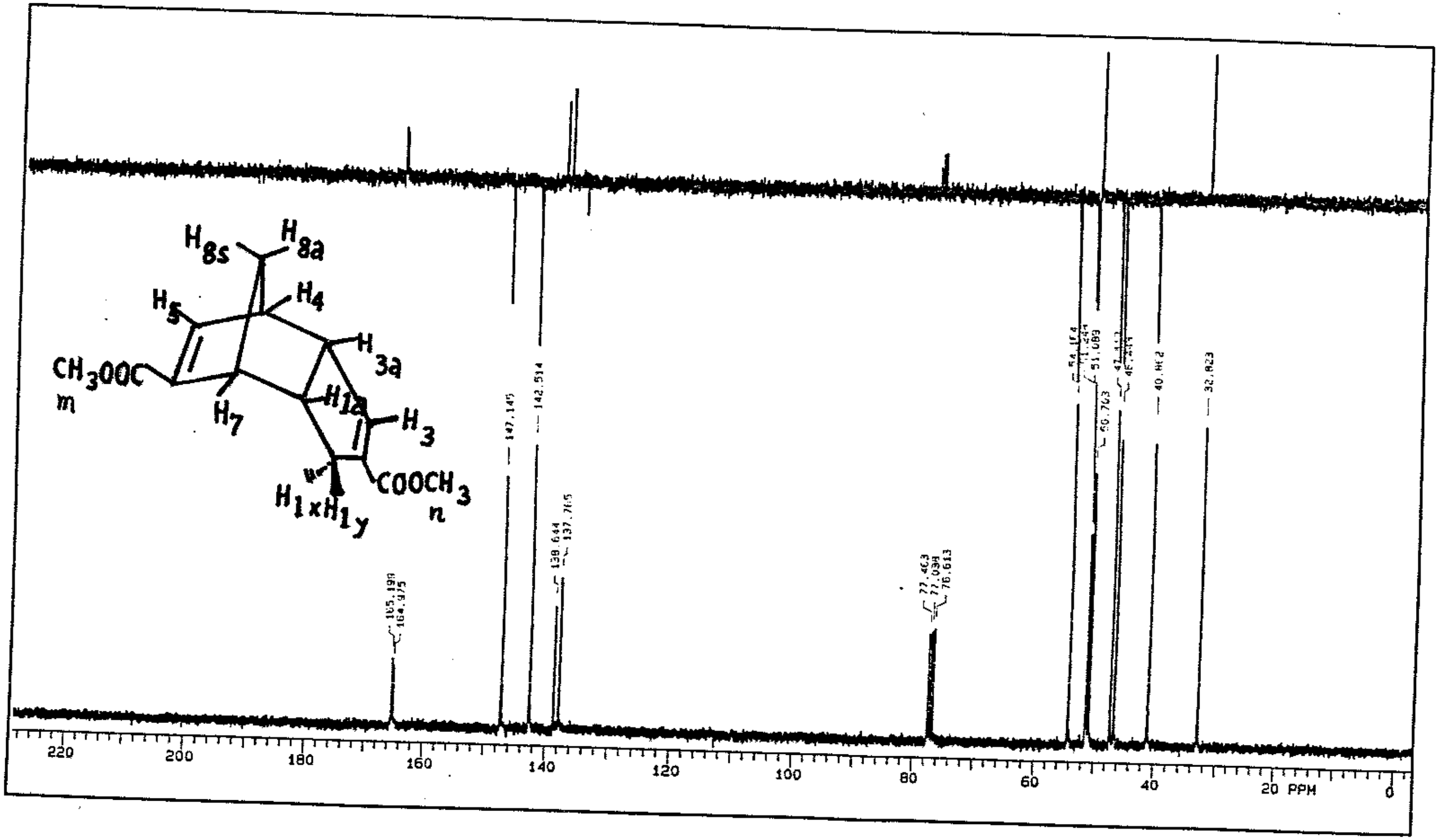


Figure 32 The ^{13}C NMR Spectrum of Thiele's Ester.

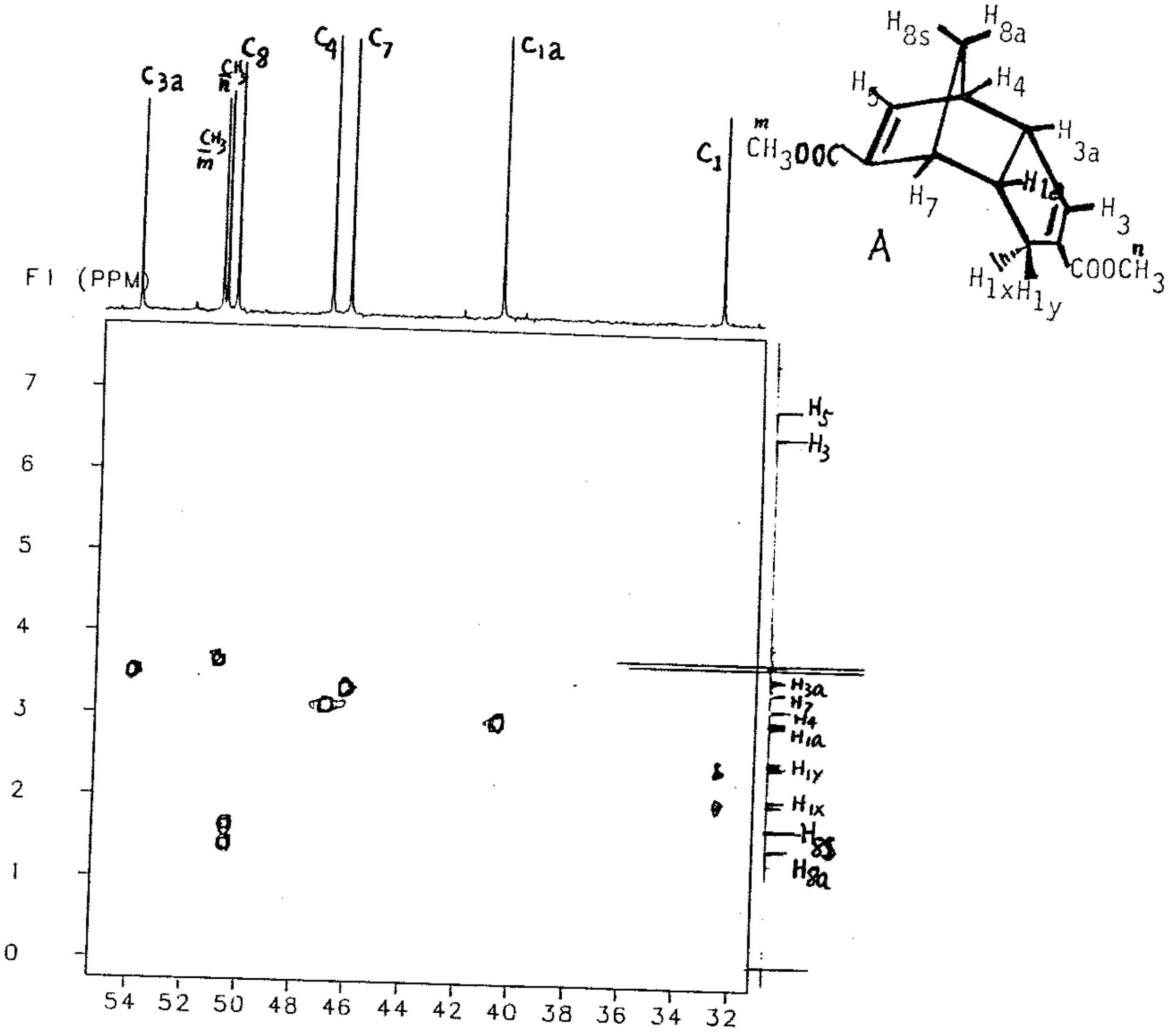


Figure 33 The HETCOR Spectrum of Thiele's Ester.

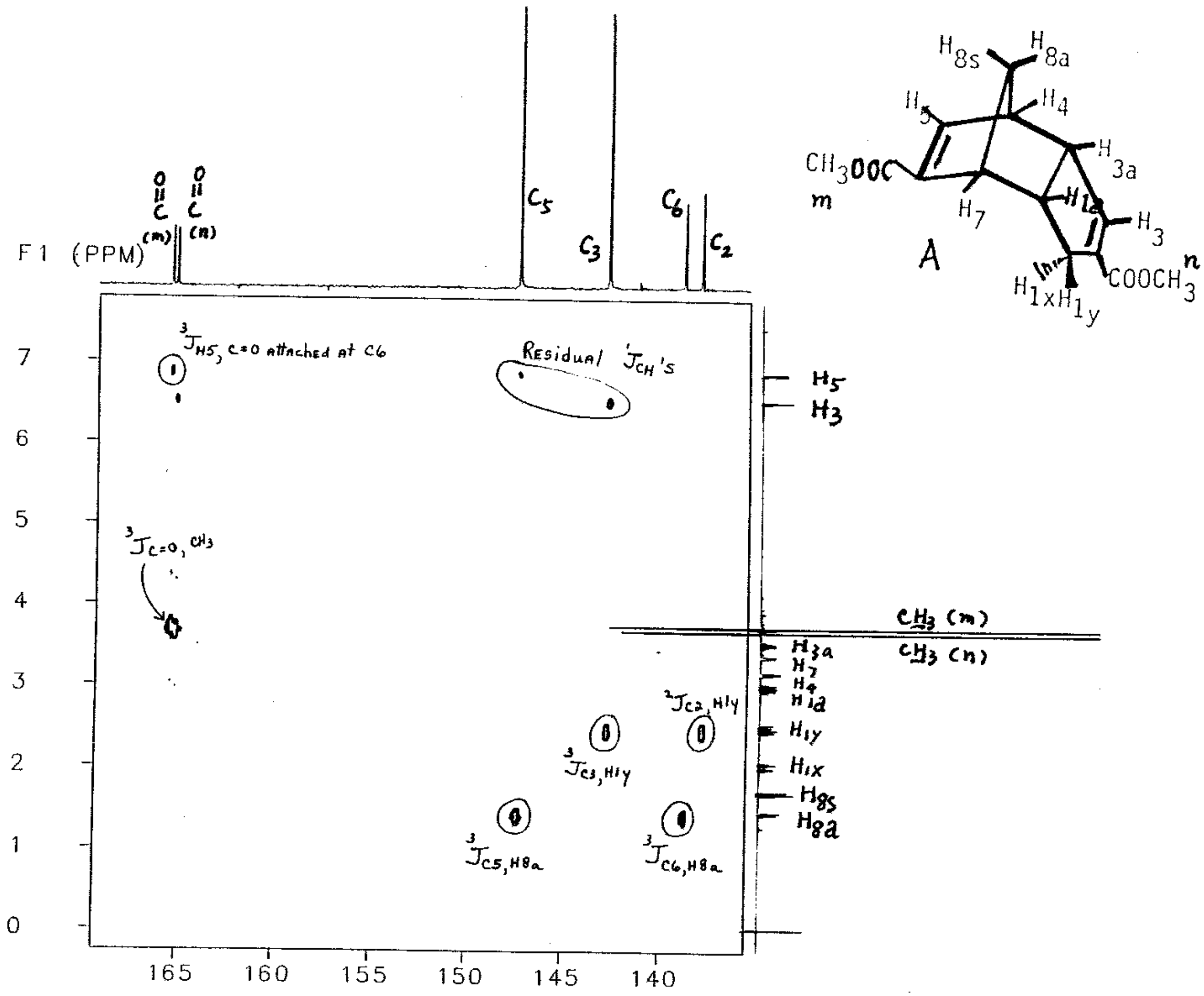


Figure 34 The Long-range HETCOR Spectrum I of Thiele's Ester.

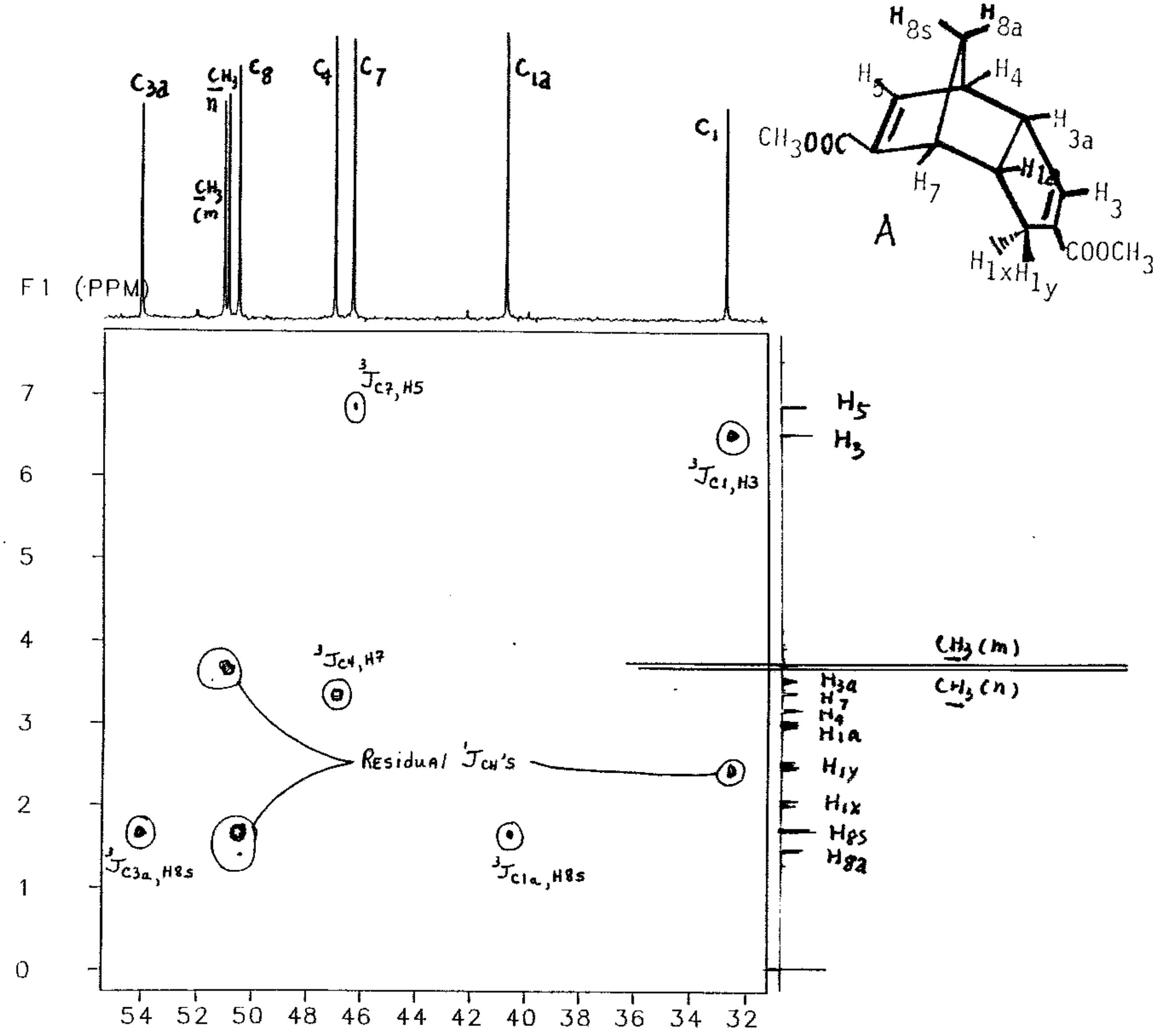


Figure 35 The Long-range HETCOR Spectrum II of Thiele's Ester.

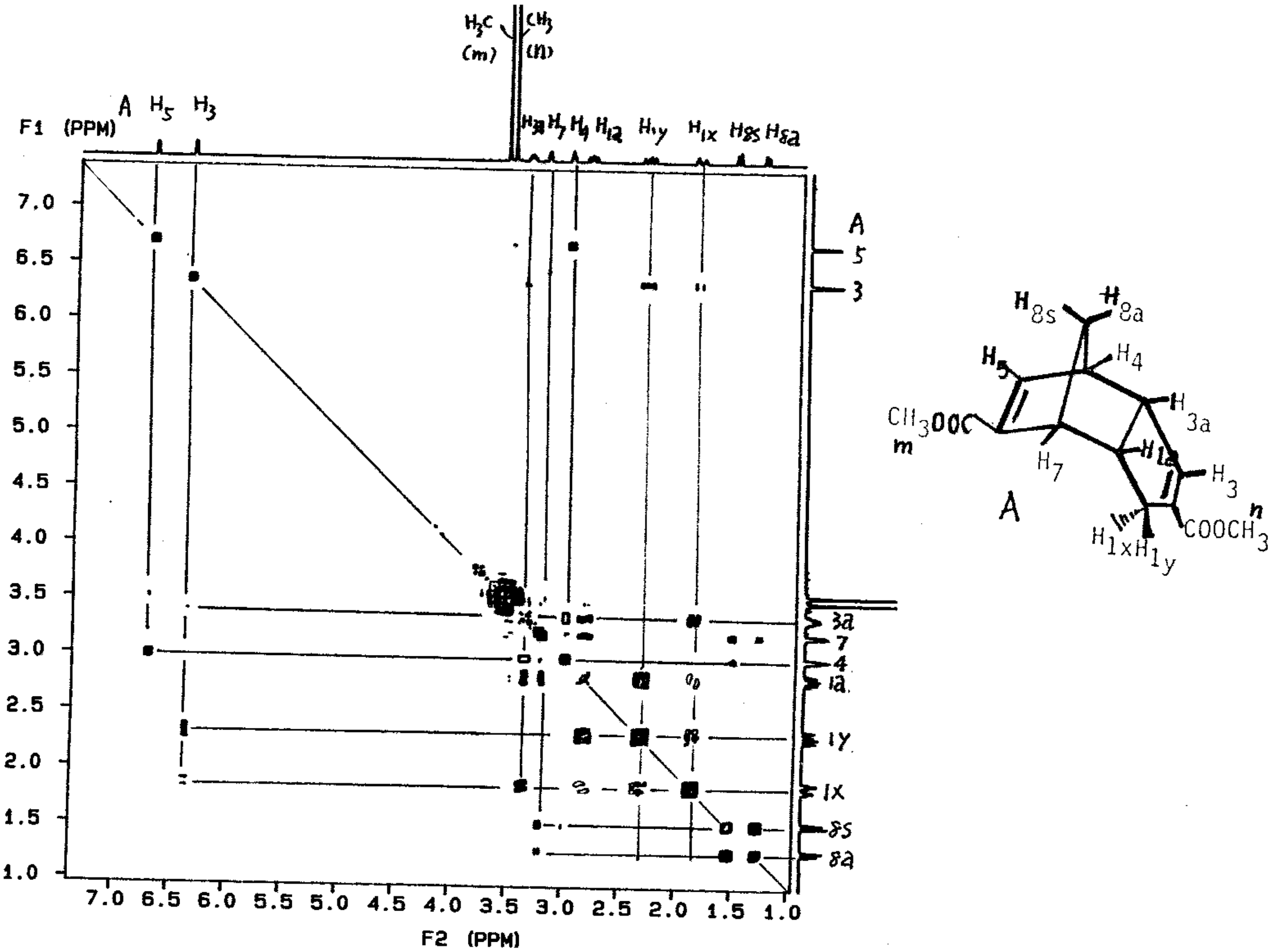
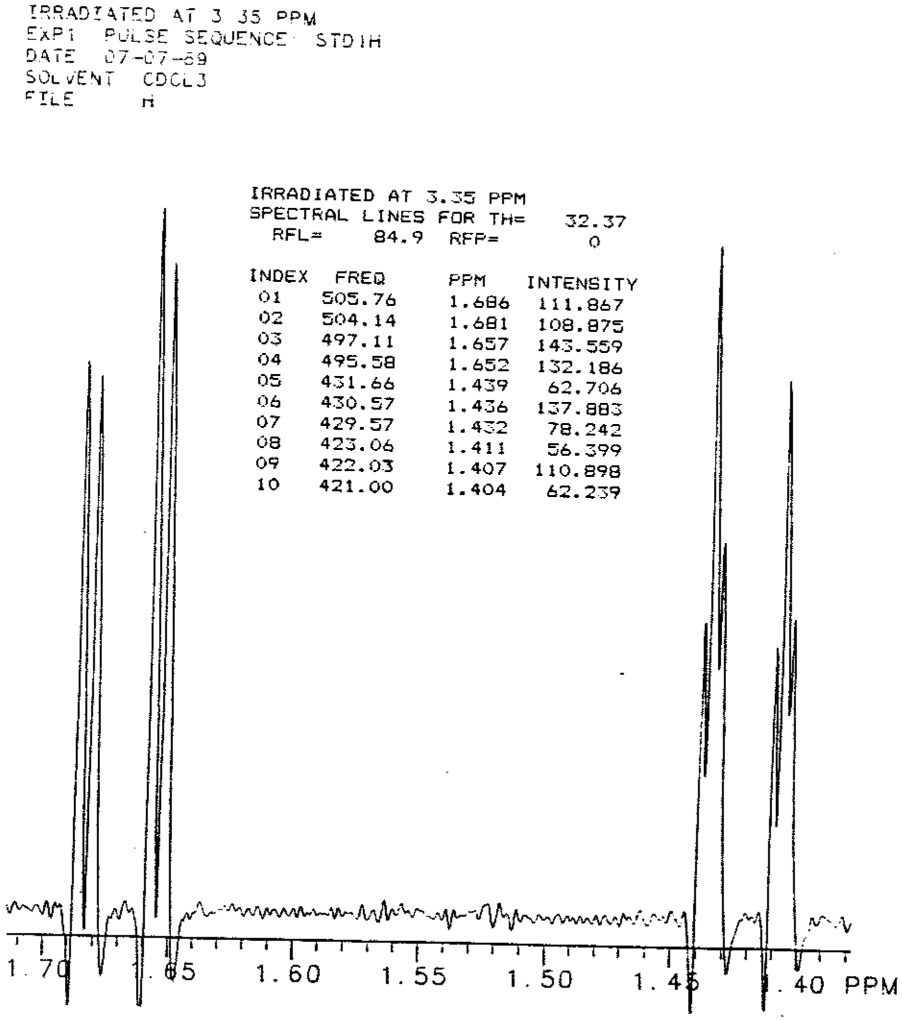


Figure 36 The COSY Spectrum of Thiele's Ester.



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DATE  07-07-89
SOLVENT  CDCL3
FILE     H
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  RFL=     84.9  RFP=        0

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 03    497.11    1.657  143.559
 04    495.58    1.652  132.186
 05    431.66    1.439   62.706
 06    430.57    1.436  137.883
 07    429.57    1.432   78.242
 08    423.06    1.411   56.399
 09    422.03    1.407  110.898
 10    421.00    1.404   62.239
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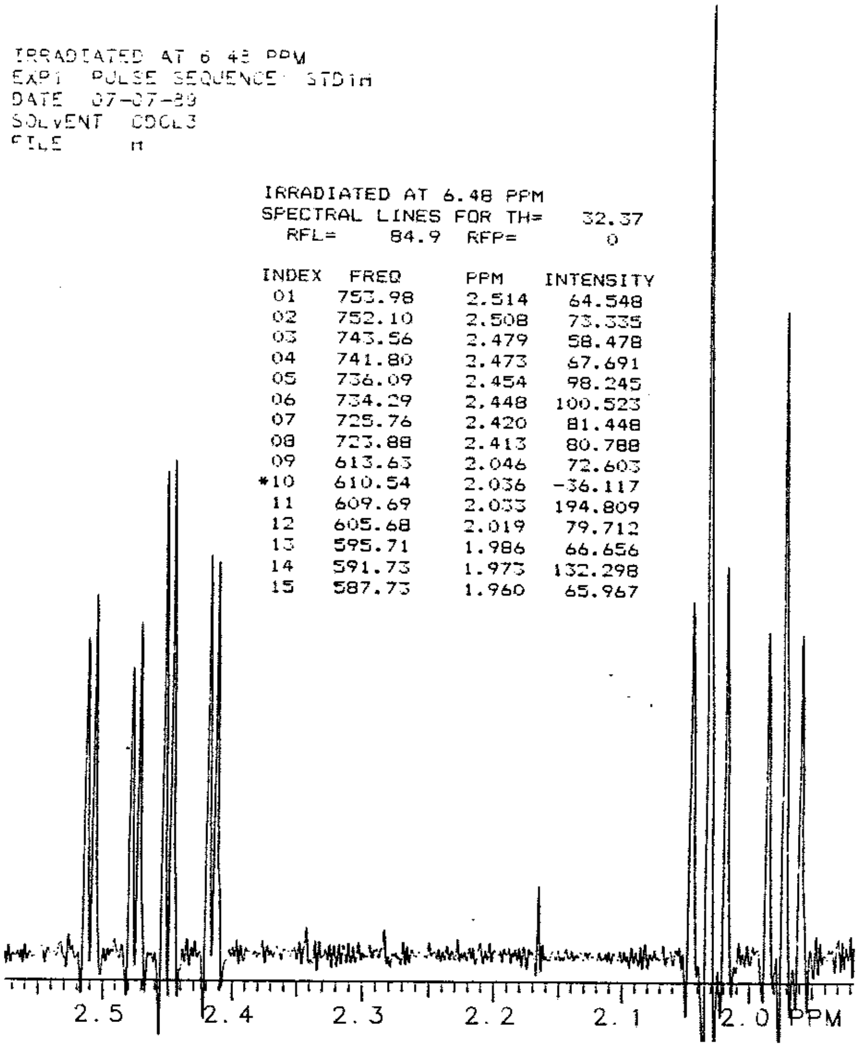
Figure 37 The Nuclear Magnetic Double Resonance Spectrum of Thiele's Ester.



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DATE  07-07-89
SOLVENT  CDCL3
FILE     H

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                      RFL=     84.9  RFP=      0

                    INDEX  FREQ      PPM   INTENSITY
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                     02   752.10    2.508    73.335
                     03   743.56    2.479    58.478
                     04   741.80    2.473    67.691
                     05   736.09    2.454    98.245
                     06   734.29    2.448   100.523
                     07   725.76    2.420    81.448
                     08   723.88    2.413    80.788
                     09   613.63    2.046    72.603
                    *10   610.54    2.036   -36.117
                     11   609.69    2.033   194.809
                     12   605.68    2.019    79.712
                     13   595.71    1.986    66.656
                     14   591.73    1.973   132.298
                     15   587.73    1.960    65.967
```

Figure 38 The Nuclear Magnetic Double Resonance Spectrum of Thiele's Ester.

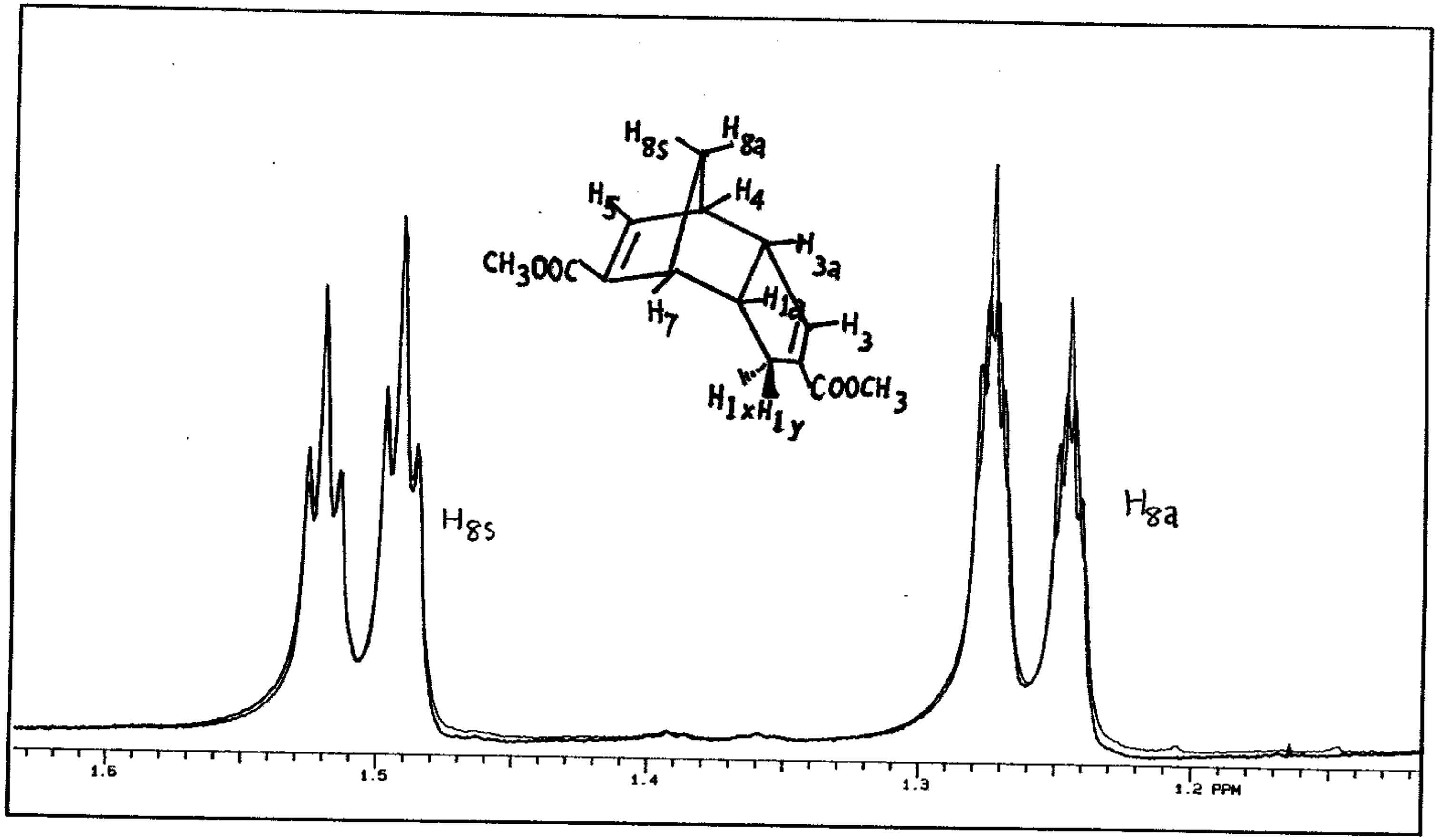

Figure 39 The Nuclesr Magnetic Double Resonance Spectrum of Thiele's Ester.

Table 1. Coupling Constants Between The Protons of Thiele's Ester

Shift	2.97	2.01	2.47	6.51	3.51	3.14	6.85	3.35	1.68	1.43
Proton	1a	1x	1y	3	3a	4	5	7	8s	8a
1a	---	4.0	10.4	---	8.6	---	---	4.1	---	---
1x	4.0	---	17.9	2.2	4.0	---	---	---	---	---
1y	10.4	17.9	---	2.2	1.9	---	---	---	---	---
3	---	2.2	2.2	---	2.3	---	---	---	---	---
3a	8.6	4.0	1.9	2.3	---	4.6	---	---	---	---
4	---	---	---	---	4.6	---	3.3	1.4	1.8	1.4
5	---	---	---	---	---	3.3	---	1.1	---	1.0
7	4.1	---	---	---	---	1.4	1.1	---	1.8	1.4
8s	---	---	---	---	---	1.8	---	1.8	---	8.6
8a	---	---	---	---	---	1.4	1.0	1.4	8.6	---

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