SYNTHESIS OF TIN CONTAINING CALIX[4]ARENES

AND THEIR ANION BINDING CAPABILITIES

THESIS

Presented to the Graduate Council of
Southwest Texas State University
in Partial Fulfillment of
the Requirements

For the Degree

Master of Science

By

Michael Allen Herren

San Marcos, Texas
May, 1999

DEDICATION

To my family.

TABLE OF CONTENTS

List of Tables

List of Figures

1.0 ABSTRACT

Extensive research has been done on the ability of calixarenes to complex cations and neutral species. The electron-rich molecular cavity and lower rim consisting of a cyclic array of oxygen donors makes the structure of the calixarene conducive to this type of complexation. Conversely, the calixarenes represent a synthetically malleable framework upon which charged, Lewis acidic or hydrogen bond donor or acceptor functionalities may be placed in order to design anion binding hosts of very specific dimensions and selectivities. The purpose of this research is to synthesize a ditopic species that has the ability to simultaneously complex anions and cations starting from the calix[4]arene skeleton.

Starting with the *p-tert*-butylcalix[4]arene, the lower rim was functionalized with four ethoxy ethyl groups to create a binding site for small cations. Subsequently, the upper rim was functionalized with four tin atoms positioned at the end of *n*-propyl chains. The Lewis acidic nature of the tin functionalized molecules provided a site for possible binding of anions.

Complexation of chloride ions by the new tetratin calix[4]arene was studied by ^{119}Sn NMR titration experiments. The stoichiometry of the host-guest complex was determined using Job's Method of Continuous Variations. Furthermore, the binding constant, K_a, was determined at various temperatures using the Benesi-Hildebrand method, also known as a double reciprocal plot.

2.0 INTRODUCTION

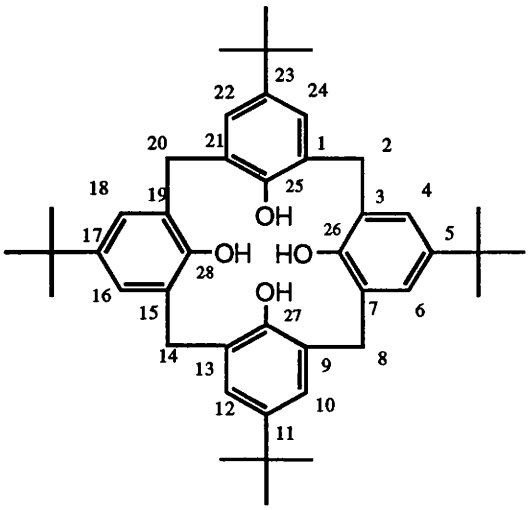
Calixarenes

2.1 Nomenclature

Before getting into the structure and functionalization of these cyclic macromolecules, naming of the molecules should be addressed. Many names have been used for these molecules. Zinke[1] first referred to them as **"cyclischenMehrkern-methylenephenolverbindungen."** The systematically derived name that has been adopted by Chemical Abstracts is **pentacyclo[19.3.1.1^{3,7}.1^{9,13}.1^{15,19}]octa-cosa-1(25),3,5,7-(28),9,11,13(27),15,17,19(26),21,23-dodecaene-25,26,27,28-tetrols.**[2] For the convenience of discussion, both written and verbal, Gutsche suggests the name *calixarene.*[2] The word calixarene is derived from the Greek work *calix* meaning chalice or vase, and *arene* which indicates the presence of aryl residues in the structure. The term calixarene will be used throughout the rest of this thesis. The numbering system put forth by Gutsche (see Figure 1) for the calix[4]arene will also be used.

Figure 1

Numbering Scheme for Calix[4]arene

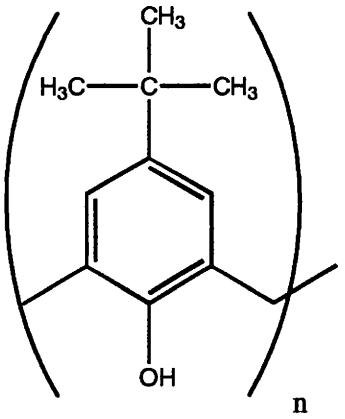


2.2 Definition of Calixarene

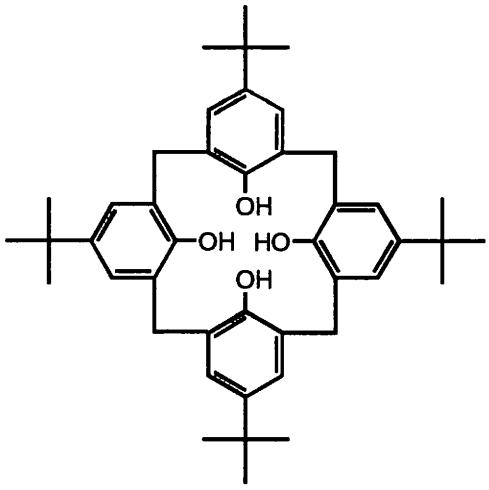
A calixarene is a cyclic oligomer synthesized from the condensation reaction of *p- tert*-butylphenol with formaldehyde[2] (see Figure 2). The phenolic residues are attached by methylene units at the positions *meta* to the *tert*-butyl groups. They have been recognized as having structural attributes that are conducive to host-guest complexation. The host-guest interactions of calixarenes are influenced by both the conformational shape of the calixarene as well as the functional groups attached to it. The calixarene has both an upper and lower rim. The upper rim is defined by the *para* positions of the aromatic nuclei and the lower rim is defined by the phenolic oxygen atoms. With the proper reaction conditions, the cyclic tetramer, pentamer, hexamer, heptamer, and octamer can be obtained, however, calixarenes with n = 4,6,8 aromatic units are the easiest to synthesize in large quantities. Calixarenes with an odd value for n, or with n > 8 are produced with low yields and are difficult to isolate (

Figure 2

Representations of Calix[4]arene



n = 4-16



Calix[4]arene

2.3 Synthesis of *p-tert*-butylcalix[4]arene

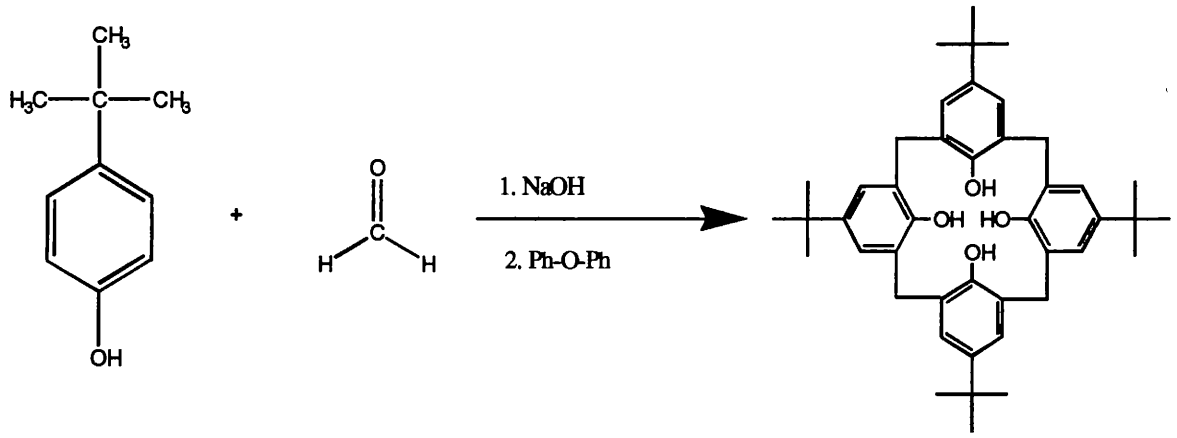
Calixarenes were first synthesized by Zinke and Ziegler[3] in 1941 by a base-induced condensation of *p-tert*-butylphenol and formaldehyde. For many years the preparation of *p-tert*-butylcalix[4]arene remained an uncertain event. Workable yields of desired products were obtained in some instances, but poor or even no yields occurred in other instances where reactions were presumably carried out under identical conditions.

The condensation of *p-tert*-butylphenol and formaldehyde has been studied in great detail, and is the best and most useful example of a calixarene forming reaction. Still, this reaction has had its difficulties with reproducing desired results. A set of procedures[4] has been established in hopes of being able to obtain reproducible yields of *p-tert*-butylcalix[4]arene without complications.

A mixture of *p-tert*-butylphenol, 37% formaldehyde, and 0.045 equivalents of NaOH is heated for 1.5-2 hours at 120-125° C to produce a viscous mass referred to as the "precursor". The precursor is then suspended in phenyl ether and refluxed for 2 hours under a constant pressure of an inert gas. The reaction mixture is then allowed to cool to room temperature. The calix[4]arene is then precipitated with the addition of chilled ethyl acetate. This process consistently gives yields of 60-70% (see Figure 3). Experiments have shown that when the amount of NaOH with respect to phenol deviates from 0.045, the reaction gives low yields of calix[4]arene as well as other calixarenes. Also, if KOH is used as the base, calix[6]arene and calix[8]arene are the major products.

Figure 3

Synthesis of Calix[4]arene

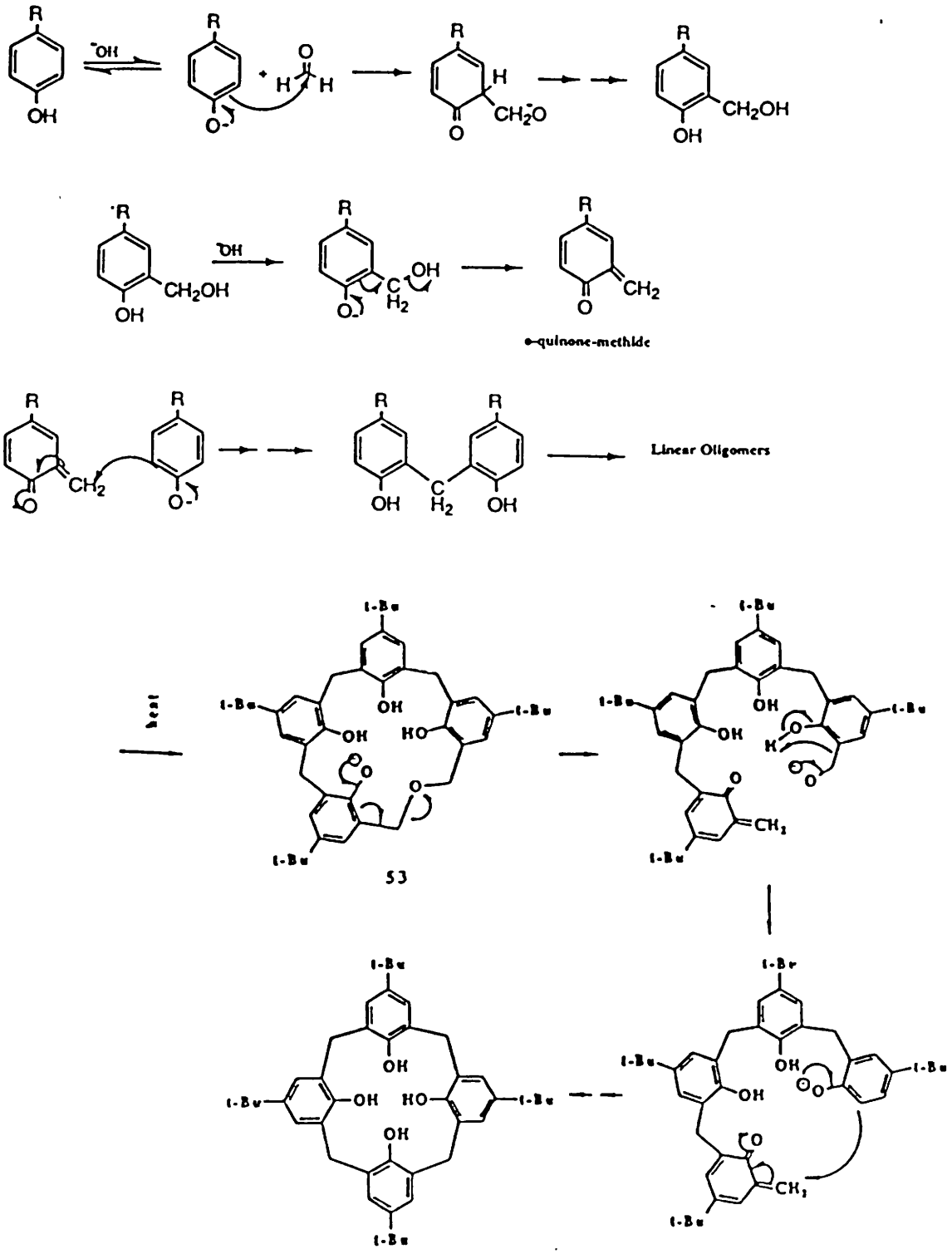


2.4 Mechanism of Calixarene-Forming Reaction

The mechanism by which the base-catalyzed oligomerization of phenols and formaldehyde occurs has been the subject of study for many decades. The first step is initiated by the formation of the phenoxide ion that acts as a nucleophile and attacks the carbonyl of the formaldeyde. This adduct rearranges after protonation to yield a hydroxymethylated phenol. This compound then undergoes base-catalyzed elimination to yield an *o*-quinone methide which is attacked by a second phenoxide ion. This sequence is repeated twice more to yield a linear oligomer which then cyclizes under the heat to form the calix[4]arene[5] (see Figure 4).

Figure 4.

Pathway for Base-Induced Formation of Calixarenes

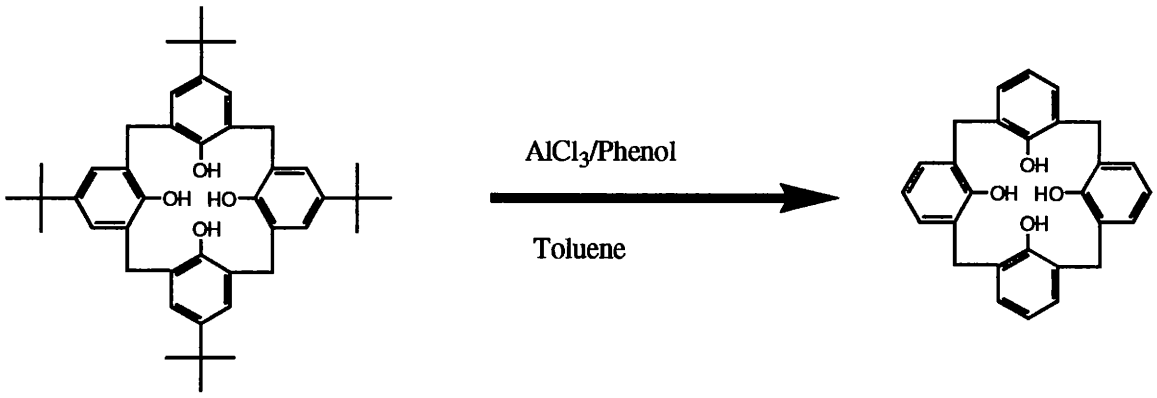


2.5 Dealkylation

In order to functionalize *p-tert*-butylcalix[4]arene at the upper rim, the *tert*-butyl groups must be removed. The total removal of the four *tert*-butyl groups by a reverse Friedel-Crafts reaction makes the *para* positions available for facile substitution. Treatment of *p-tert*-butylcalix[4]arene with excess $AlCl_3$ in toluene gives a compound useful for selective introduction of functional groups (see Figure 5). The *tert*-butyl groups can also be selectively removed to produce the di-*tert*-butylcalix[4]arene.[4]

Figure 5

Dealkylation of *p-tert*-butyl Calix[4]arene



2.6 Shaping the Basket

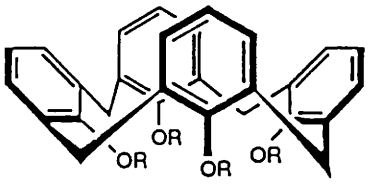
Calixarenes are sometimes referred to as molecular baskets due to their structure. Calixarenes are conformationally flexible compounds which means they are free to convert between different isomers at room temperature if substituents at the lower rim are smaller than ethyl groups. The rotation of the phenol residues through the macrocyclic

annulus occurs about the connecting methylene groups. An aryl group will rotate in the direction that brings the oxygen atom up through the annulus of the calixarene. X-ray crystallography has shown that the calix[4]arene has four different conformations in the solid state (see Figure 6).

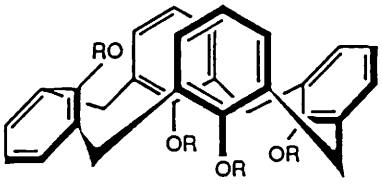
Figure 6

- **Cone conformation:** all of the OR groups are oriented in the same plane
- **Partial cone:** one of the aryl rings is in a different orientation than the other three
- **1,2 alternate:** two aryl rings next to each other are in opposite orientation relative to the other pair
- **1,3 alternate:** two opposite aryl rings have a different orientation than the other two

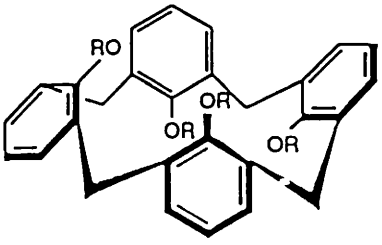
Conformational Isomers of Tetra-alkylated Calix[4]arenes



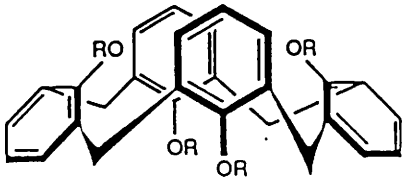
Cone



Partial Cone



1,2-Alternate



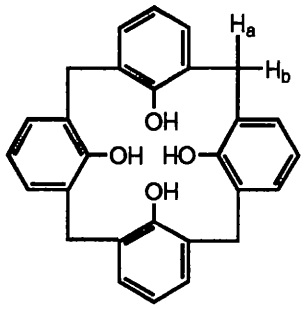
1,3-Alternate

Shaping the basket plays a vital role in the design of calixarenes as receptors because the host-guest interactions greatly depend on complementarity in shape as well as functionality. By introducing functional groups onto the oxygen atoms of the lower rim that are too large to allow free rotation through the annulus of the calixarene, the result is the "locking" of the calixarene into one or more of the conformations.

^{1}H-NMR spectroscopy has shown that each conformational isomer displays a distinctive pattern for the metylene protons that bridge the aromatic rings (see Figure 7).

Figure 7

^{1}H-NMR PATTERNS FOR CH_2 PROTONS OF CALIX[4]ARENES IN VARIOUS CONFORMATIONS



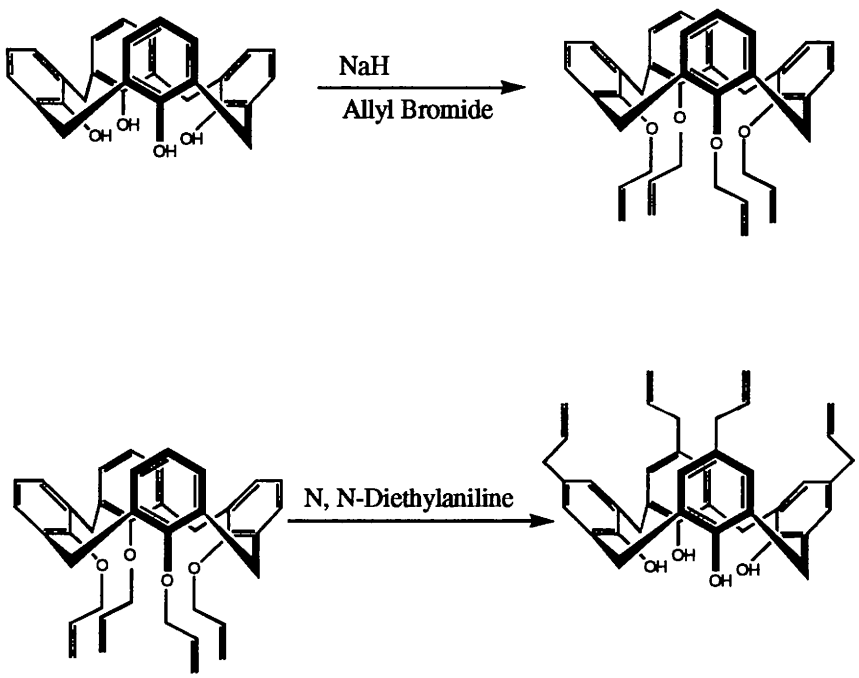
Conformation	**^{1}H-NMR Pattern**
Cone	One pair of doublets
Partial Cone	Two pairs of doublets (ratio 1:1) or one pair of doublets and one singlet (ratio 1:1)
1,2-Alternate	One singlet and two doublets (ratio 1:1)
1,3-Alternate	One singlet

2.7 Functionalization at the Upper and Lower Rim

Historically, the introduction of functional groups onto the calix[4]arene was not straight forward. In most cases electrophilic and nucleophilic substitution reactions are used. A very popular method is to convert the hydroxy groups on the calix[4]arene to an ether or ester. The tetra-allyl ether has been produced with high yields by reacting the dealkylated calix[4]arene with NaH and allyl bromide in DMF. When lower rim 25, 26, 27, 28-tetraallylcalix[4]arene is suspended in N, N-diethylaniline and refluxed, a heat induced Claisen rearrangement occurs (see Figure 8). The product is now the upper rim 5, 11, 17, 23-tetraallylcalix[4]arene.

Figure 8

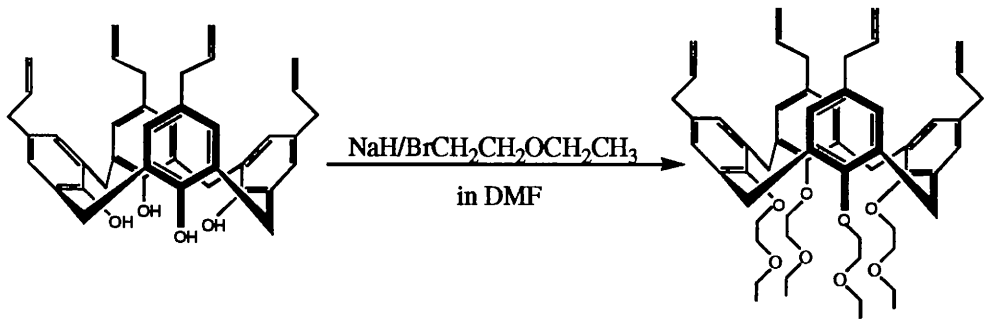
Functionalization of Lower Rim and Rearangement



This newly synthesized calixarene still has free rotation about the methylene groups, therefore and additional step in the synthesis is required to "lock" the stucture into cone conformation. The OH groups of the lower rim are now alkylated with 2-bromo ethyl ethyl ether using the same procedure as the tetraallyl alkylation (see Figure 9). The new alkyl groups on the lower rim are bulky enough to obtain the cone confromation by inhibiting rotaton about the methylene carbons. This reaction takes place at room temperature. Care must be taken to avoid excessive heat to prevent isomerization of the double bond on the allyl groups.

Figure 9

Functionalization of Lower Rim



2.8 Anion Complexation

Considerable research has been done on calixarenes complexing cations and neutral molecules[6], therefore this type of chemistry has progressed rapidly. The reason being that the structural characteristics of calixarenes cause the molecules to have a high affinity for cation complexation. In comparison, progress in complexation of anions has been slower, probably as a consequence of the large radii of anions, high free energies of solvation and the wide variety of topologies, resulting in greater difficulty in designing

multidentate receptors with appropriately situated Lewis-acidic or other acceptor sites. Recently, more attention has been turned toward supramolecular anion complexation, in part due to its environmental applications. Most importantly, anions such as phosphates and nitrates have been implicated in environmental contamination, resulting in eutrophication, while biological polyphosphates form a vital part of the metabolic processes of all living organisms.[7]

2.8.1 Historical Perspective

The earliest report of anion complexation dates back to 1967 when Shriver and Ballas reported the chelation of bidentate Lewis acids with methoxide ions.[8] It was not until 1976 that more results were reported. Graf and Lehn described a tetraprotonated, tricyclic, spheroidal cryptand that demonstrated a high affinity for Cl^- and Br^-.[9] Since then a steady level of research has been conducted but to a lesser extent than cation binding.

2.8.2 Types of Binders

Generally, the ligands that have been developed for anion complexation in organic solvents can be divided into two classes:

1. positively charged ligands like ammonium and guanidinium moieties – anion binding is achieved by electrostatic interactions.
2. neutral ligands of which most have Lewis acid centers, such as Si, B, Sn, or Hg—complexation is based on dative bonds between the Lewis acid center and the anion.

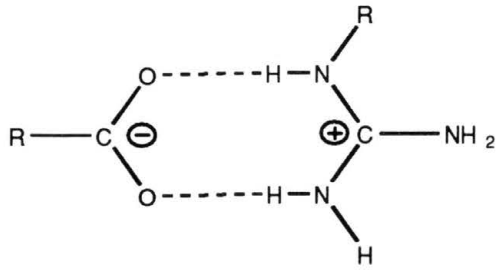
2.8.3 Non-Calixarene Anion Binders

The guanidinium group as present in the side chain of arginine is ubiquitous in enymes that bind anionic substrates.[10] This functional group also plays a part in the

stabilization of the *tert*iary structure of proteins via internal salt bridges with carboxylate functions. The strong interaction with oxoanions lies in the distinctive binding pattern featuring two parallel hydrogen bonds in addition to the electrostatic attraction (see Figure 10).

Figure 10

Binding Pattern of Guanidinium Groups with Oxoanions

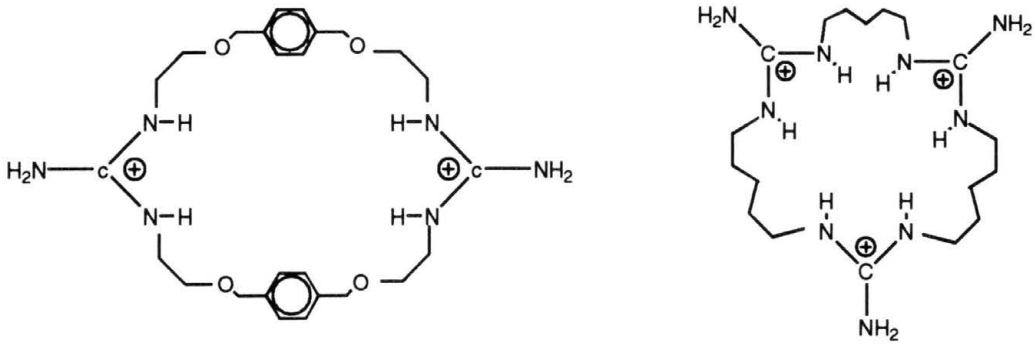


The extremely high basicity of guanidine (pKa =13.5), which guarantees protonation over a wide pH range, is another feature that makes the guanidinium moiety an attractive group for artificial anion binders.

The first examples of macrocyclic guanidinium-based receptors were reported by Lehn et al.[11] who synthesized the following compounds (see Figure 11).

Figure 11

Macrocyclic Guanidinium-Based Receptors

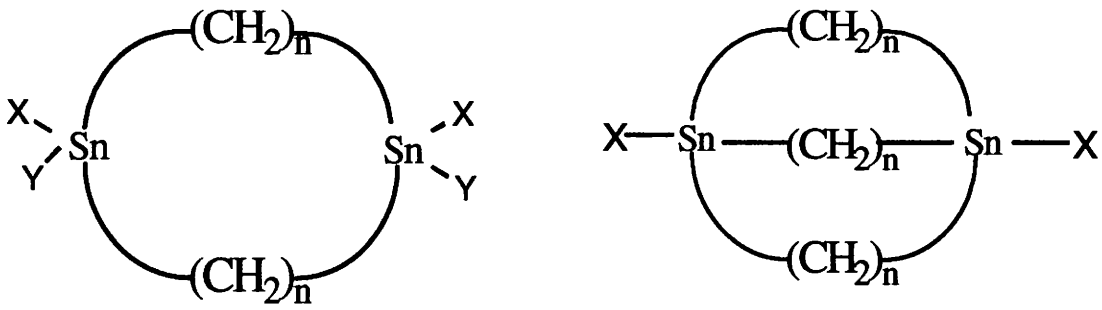


Either of these showed only weak complexation of PO_4^{3-} (log K_{assn} 1.7 and 2.4 respectively in methanol/water). Guest selectivity was primarily dependent on the charge density of the anions.

An example of an anion binding species that contains a Lewis acidic moeity was presented by Newcomb et al. Macro- cyclic, bicyclic, and tricyclic compounds containing two and four Sn atoms were synthesized as anion host molecules.[12] The simple macrocyclic molecules were found to bind chloride ion with little or no size selectivity. However, upon addition of a third linking chain to the molecule a host is created that binds chloride ion selectively based on size (see Figure 12). This size selectivity suggests that the chloride ion actually resides inside the cavity created by the linking chains.

Figure 12

Lewis Acid Containing Anion Receptors

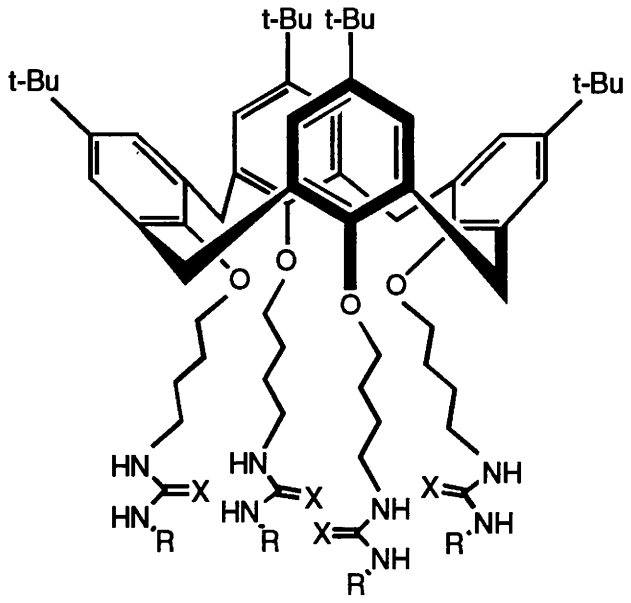


2.8.4 Calixarene Anion Binders

As a result of the synthetic versatility of the upper and lower rims of the calixarene, these molecules are attractive molecular building blocks to modify and create very unique cavities for the recognition of target guest species. Scheerder et al. modified the lower rim of *p-tert*-butylcalix[4]arene with spacers and four urea moieties.[13] This created eight hydrogen-bond donor sites directed to one face, which creates a cavity suitable for the complexation of anions (see Figure 13). It is known that the chloride and bromide ions are good hydrogen bond acceptors and the urea moiety acts as a hard Lewis acid.[14] A 1:1 stoichiometry was confirmed for both ions.

Figure 13

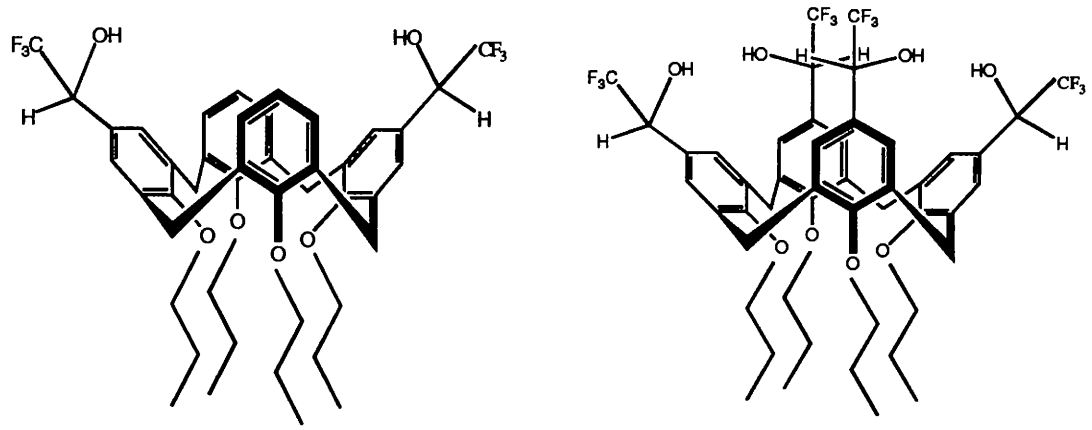
Calix[4]arene-Based Anion Receptor



Another model was presented by Ungaro et al. where two or four fluoro alcohol functional groups were introduced at the upper rim of calix[4]arenes that were blocked into the cone conformation.[15] This creates a neutral binding site for anions (see Figure 14). Using NMR titration experiments, the preliminary binding studies show that both receptors are able to bind anions in $CDCl_3$. The difunctionalized receptors showed selectivity in recognition of carboxylate over spherical anions. The tetrafunctionalized receptor bound spherical anions such as bromide more effectively than acetate anion.

Figure 14

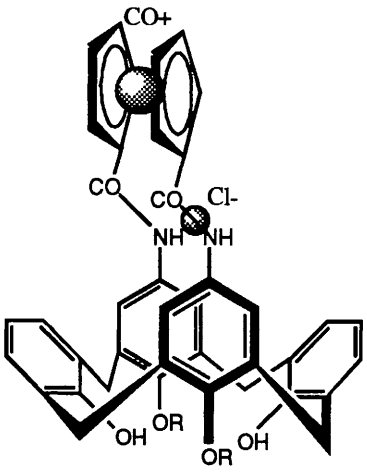
Neutral Anion Receptors



One final example of an anion binder is presented by Beer et al. His group reported the synthesis of a new upper-rim cobaltocenium-bridged calix[4]arene receptor.[16] The anion complexation properties of the receptor (see Figure 15) were tested by ^{1}H-NMR titration experiments. This new receptor exhibited good thermodynamic stability and high selectivity for carboxylate anions.

Figure 15

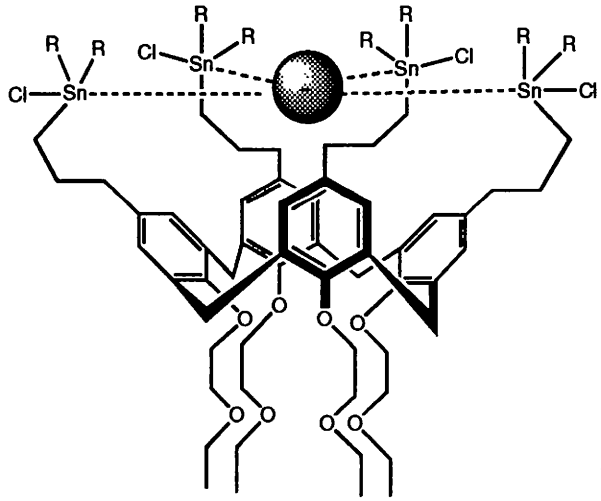
Cobaltocenium-Bridged Calix[4]arene Receptor



R=$O_2SC_6H_4Me$-*p*

2.9 Thesis Proposal

Calixarenes are well known for their capacity to transport cations and neutral molecules through their phenolic oxygen atoms and cavity, respectively. The anion binding capabilities have not been considered with such depth. The purpose of this research is to synthesize a tetra substituted calix[4]arene appropriately functionalized at the upper and lower rims, and then test the anion binding capacity of the synthesized molecule. The calix[4]arene is used for this research due to its accessibility and suitability for selective functionalization. The 5, 11, 17, 23-tetra[1-(diphenyl-stannylchloro)propyl]- calix[4]arene will be derived from the principle starting material, *p-tert*-butyl calix[4]arene, which was prepared from the procedures outlined by Gutsche et al.[4]



3.0 EXPERIMENTAL

3.1 MATERIALS

Chloroform ($CHCl_3$) was dried over molecular sieves (4 A°). Dimethylformamide (DMF) was purchased from Aldrich and used as is. Tetrahydrofuran (THF) was freshly distilled from sodium ketal or purchased from Aldrich in a sure seal bottle. All the other reagents were purchased through Aldrich, and used without purification. ^{1}H-NMR and ^{13}C-NMR spectra were recorded in $CDCl_3$ at 400 MHz. Chemical shifts (δ) are expressed in ppm relative to the internal standard tetramethylsilane (TMS). Elemental analyses were performed at Desert Analytics Laboratory in Tucson, Arizona. All reactions were carried out in a dry argon atmosphere. Analytical TLC was performed on precoated silica gel plates (Silica Gel IB2-F) and column chromatography was performed with Silica Gel IB2-F 150, 60-200 Mesh (75-250 micron).

3.2.0 SYNTHESIS

3.2.1 Preparation of 4-*tert*-butylcalix[4]arene[4] 1

To a three liter, three necked, round bottom flask equipped with a mechanical stirrer were added 150 g, (0.9975 mol) of 4-*tert*-butyl phenol and 93.35mL (3.367 mol) of 37% formaldehyde. The flask was placed in a 130° C oil bath and allowed to heat for 15 minutes. Then, 1.795g (0.045 mol) of sodium hydroxide dissolved in 10 mL of water was added to the stirring solution via disposable pipette. The beaker in which the NaOH was dissolved was rinsed with 5 additional mL of water and this was added to the flask.

The reaction mixture was stirred at 130° C for 1-2 hours. During this time the reaction mixture became turbid, changed to clear orange and then began to foam. After foaming, the reaction flask was removed from the oil bath and placed into a heating mantel. Diphenyl ether (1000 mL) was added and the mixture was heated, while stirring, to 252° C under a continuous flow of argon to facilitate the removal of water.

This heating process took approximately three hours. During this heating period, the color of the solution changed from a bright orange to a dark brown. Once the temperature reached 252° C, the flask was equipped with a reflux condenser and sealed under a constant pressure of argon. The solution was maintained at reflux with stirring for two hours. The heating mantle was then removed to allow the reaction mixture to cool. Once the solution was at room temperature, the solid 4-*tert*-butylcalix[4]arene was precipitated by adding two liters of cool ethylacetate. The mixture was stirred for at least two hours. The product was then collected via vacuum filtration. The white solid was washed twice with ethylacetate and once with glacial acetic acid. This was followed by a final ethylacetate wash. The white solid was dried to give 4-*tert*-butylcalix[4]arene 102 g (63% yield).

3.2.2 Dealkylation of 4-*tert*-butylcalix[4]arene[4] 2

4-*tert*-butylcalix[4]arene (40 g, 61.7 mmol) was placed in a 2000 mL round bottomed flask equipped with a mechanical stirrer. To this were added toluene (1000 mL), $AlCl_3$ (66 g, 494.4 mmol) and phenol (35 g, 372.3 mmol). The reaction was stirred at room temperature under argon overnight. Then, 500 mL of 0.2 M HCl was added to

quench the reaction. The reaction mixture was transferred to a 2000 mL separatory funnel. The organic layer was washed twice with water followed by one wash with brine solution. The organic layer was then dried over $MgSO_4$ and filtered. The solvent was evaporated under pressure to a volume of 10 mL. The crude product was poured into approximately 700 mL of methanol while stirring to produce a light yellow solid. The solid was then redissolved in 300 mL of hot chloroform and poured into methanol while stirring. The product was collected and allowed to dry giving a white solid 20.71 g (79% yield). ^{1}H-NMR ($CDCl_3$) δ 10.187 (s, 4H), 7.09-7.007 (t, 6H), 6.72-6.62 (t, 6H), 3.90 (br, 8H) (spectrum 1). ^{13}C-NMR ($CDCl_3$) δ 31.68, 122.22, 128.22, 128.95, 148.74 (spectrum 2).

3.2.3 Synthesis of 25, 26, 27, 28-tetraallylcalix[4]arene[17] 3

To a 2000 mL round bottom flask, a solution of dealkylated calix[4]arene (22.3 g, 52.53 mmol) and 1000 mL of DMF was added. While stirring, sodium hydroxide (60% dispersion in mineral oil, 21.01 g, 525.3 mmol) was slowly added to the mixture. The reaction was allowed to stir while under argon for 30 minutes. Then, allyl bromide (36.37 mL, 420.2 mmol) was added to the mixture via syringe. The reaction was allowed to stir while under argon at room temperature for 48 hours. The solvent was evaporated under reduced pressure, and the residue was taken up in 800 mL of ethylacetate and 800 mL of water. The solution was transferred to a 2000 mL separatory funnel. The organic layer was separated and washed twice with .1 M HCl solution and once with brine solution. The organcic layer was then dried over $MgSO_4$ and filtered. The solvent was

evaporated under reduced pressure until approximately 20 mL remained. This was then slowly poured into 1000 mL of methanol while stirring. The product was collected via vacuum filtration to give an off-white solid 26.2 g (85% yield). ^{1}H-NMR ($CDCl_3$) δ 3.14-3.17 (d, 4H), 4.37-4.70 (q, 12H), 5.13-5.25 (q, 8H), 6.26-6.37, (m, 4H), 6.54-6.62, (m, 12H) (spectrum 3). ^{13}C-NMR ($CDCl_3$) δ 31.33, 75.85, 116.93, 122.28, 128.10, 135.29, 135.57, 155.84 (spectrum 4).

3.2.4 Synthesis of 5, 11, 17, 23-tetraallylcalix[4]arene[17] 4

To a 250 mL round bottom flask, a solution of 15.39 g (26.32 mmol) of compound **3** in 75 mL *N,N*-diethylaniline was added. The flask was put into a heating mantle. The reaction mixture was then heated overnight at reflux while under argon. The solution was cooled to room temperature, then poured into 250 mL of ice water, stirred with 250 mL of concentrated HCl. To this mixture, 200 mL of chloroform was added while stirring. This was allowed to stir for 15 minutes. The reaction mixture was then transferred to a 1000 mL separatory funnel. The organic layer was separated and then washed twice with 6 M HCl soulution and once with brine solution. The organic layer was then dried over $MgSO_4$ and filtered. The solvent was evaporated under reduced pressure until approximately 10 mL remained. The remaining organic layer was then slowly poured into 700 mL of methanol while stirring. The product was collected via vacuum filtration to yield an off-white solid 10.87 g (71% yield). ^{1}H-NMR ($CDCl_3$) δ 3.21-3.23 (d, 8H), 3.46-3.49 (broad, s, 4H), 4.23-4.25 (broad, s, 4H), 5.05-5.10 (m, 8H),

5.85-5.95 (m, 4H), 6.88 (s, 8H), 10.2 (s, 4H) (spectrum 5). ^{13}C-NMR ($CDCl_3$) δ 32.91, 40.45, 116.68, 129.30, 130.07, 134.55, 138.70, 148.17 (spectrum 6).

3.2.5 Synthesis of 5, 11, 17, 23-tetraallyl-25, 26, 27, 28-tetraethoxy-ethylcalix[4]arene[18] 5

To a 1000 mL round bottom flask, a solution of 7.66 g (13.10 mmol) of compound **4** in 300 mL of DMF was added. While stirring, sodium hydroxide (60% dispersion in mineral oil, 2.62 g, 65.5 mmol) was slowly added to the mixture. The reaction was allowed to stir while under argon for 30 minutes. Then, 2-bromoethyl ethyl ether (7.39 mL, 65.5 mmol) was added to the reaction mixture via syringe. The reaction was allowed to stir while under argon at room temperature for 48 hours. The solvent was evaporated under reduced pressure, and the residue was taken up in 300 mL of chloroform and 300 mL of water. The solution was transferred to a separatory funnel. The organic layer was separated and washed twice with 0.1 M HCl solution and once with brine solution. The organic layer was then dried over $MgSO_4$ and filtered. The solvent was evaporated under reduced pressure to give a viscous oil. Purification by column chromatography (chloroform/ethylacetate 90:10) gave 6.64 g (58% yield) of compound **5** as a viscous oil which solidified after two days at room temperature. ^{1}H-NMR ($CDCl_3$) δ 1.18-1.21 (m, 12H), 3.03-3.07 (t, 12H), 3.51-3.56 (q, 8H), 3.83-3.86 (t, 8H), 4.06-4.09 (t, 8H), 4.40-4.43 (d, 4H), 4.83-4.95 (q, 8H), 5.74-5.81 (m, 4H), 6.46 (s, 8H) (spectrum 7). ^{13}C-NMR ($CDCl_3$) δ 15.29, 30.72, 39.36, 66.32, 69.63, 73.10, 114.82, 128.30, 133.11, 134.63, 138.22, 154.47 (spectrum 8).

3.2.6 Synthesis of 5, 11, 17, 23-tetra(1-hydroxylpropyl)-25, 26, 27, 28-tetra-ethoxyethyl-calix[4]arene[19] 6

A three neck, 1000 mL round bottom reaction flask was equipped with an addition funnel and a condenser. The third neck was capped with a glass stopper. A solution of 8.65 g (9.9 mmol) of compound 5 and 100 mL of THF was added to the reaction vessel. To the reaction, 158.4 mL of 9-BBN (79.2 mmol, 0.5 M solution in THF) was added while stirring via the addition funnel. A heating mantle was added to the flask and the reaction was heated at reflux while under argon overnight. The reaction was allowed to cool to room temperature. To the reaction were added, in order, via addition 47.5 mL absolute alcohol, 15.84 mL 6 N NaOH and 31.7 mL hydrogen peroxide. The H_2O_2 was added slowly to prevent violent reflux. The reaction mixture was once again heated at reflux while under argon overnight. The reaction was allowed to cool. While stirring, approximately 2 g of K_2CO_3 were added to saturate the aqueous phase. Approximately 100 mL of diethyl ether were added to facilitate the separation of the organic and aqueous layers. The organic layer was then separated and washed three times with 1 M ammonium hydroxide solution and once with brine solution. The solvent was evaporated under reduced pressure to give a viscous oil. Purification by column chromatography (methylene chloride/methanol 95:5) gave 2.63 g (28% yield) of compound **6** as a viscous oil. ^{1}H-NMR ($CDCl_3$) δ 1.15-1.19 (t, 12H), 1.58-1.62 (t, 8H), 2.29-2.33 (t, 8H), 2.99-3.01 (d, 4H), 3.41-3.44 (t, 8H), 3.50-3.52 (q, 8H), 3.82-3.85 (t, 12H), 4.02-4.05 (t, 8H), 4.37-4.40 (d, 4H), 6.48 (s, 8H) (spectrum 9). ^{13}C-NMR ($CDCl_3$) δ 15.25, 30.51, 31.22, 33.89, 61.86, 66.28, 69.61, 73.14, 127.87, 134.52, 135.11, 153.99 (spectrum 10).

3.2.7 Synthesis of 5, 11, 17, 23-tetra(1-chloropropyl)-25, 26, 27, 28-tetra-ethoxyethylcalix[4]arene 7

A 100 mL round bottom reaction flask was equipped with a stir bar. A solution of 2.63 g (2.78 mmol) of compound **6** and 30 mL of carbon tetrachloride were added to the reaction vessel. To the reaction, 13.78 mL (27.8 mmol) of trioctylphosphine were added via syringe. The reaction was allowed to stir at room temperature while under argon overnight. The exothermic reaction turned pale yellow. The solvent was evaporated under reduced pressure to give a viscous oil. Purification by column chromatography (methylene chloride/ethylacetate 95:5) gave 2.3 g (82% yield) of compound **7** as a viscous oil that solidified overnight at room temperature. ^{1}H-NMR ($CDCl_3$) δ 1.13-1.17 (t, 12H), 1.77-1.80 (t, 8H), 2.36-2.40 (t, 8H), 2.99-3.02 (d, 4H), 3.28-3.31 (t, 8H), 3.46-3.52 (q, 8H), 3.79-3.82 (t, 8H), 4.02-4.05 (t, 8H), 4.36-4.40 (d, 4H), 6.44 (s, 8H) (spectrum 11) ^{13}C-NMR ($CDCl_3$) δ 15.28, 30.70, 31.91, 34.07, 44.17, 66.31, 69.65, 73.14, 128.12, 133.95, 134.68, 154.41 (spectrum 12).

3.2.8 Synthesis of 5, 11, 17, 23-tetra[1-(triphenylstannyl)-*n*-propyl]-25, 26, 27, 28-tetraethoxy-ethylcalix[4]arene[20] 8

A 250 mL, three necked, round bottom flask was equipped with a stir bar and condenser. Broken glass was added to the flask. One neck was capped with a glass stopper and the other was capped with a rubber septum. The flask was then flame dried while under argon. In a small Erlenmeyer flask, a solution was made by dissolving 5 g (XX mmol) of hexaphenylditin in 50 mL of freshly distilled THF. The solution was transferred to the reaction vessel via syringe. An additional 50 mL of THF was added to

the reaction flask. The reaction was begun stirring. Next, 1.5 g (216 mmol) of Lithium metal was washed in hexane and then cut into small pieces. The lithium was then added to the reaction flask. A heating mantel was added and the reaction was heated to reflux while under argon overnight. A second 250 mL round bottom was equipped with stir bar and flame dried while under argon. To the flask, were added 2 g (1.96 mmol) of compound **7** and 5 mL of freshly distilled THF. The tin anion was then transferred to the second round bottom via cannula. The reaction was allowed to stir overnight. The reaction was quenched with water. Approximately 20 mL of diethyl ether were added to facilitate the separation of the organic and aqueous layers. The ether layer was then dried over $MgSO_4$ and filtered. The solvent was evaporated under reduced pressure to give a viscous oil. The product was then recrystallized in hot hexane giving 1.8 g (40% yield) of compound **8** as a white powder. ^{1}H-NMR ($CDCl_3$) δ 1.15-1.17 (t, 12H), 1.32-1.36 (t, 8H), 1.71-1.75 (t, 8H), 2.12-2.16 (t, 8H), 2.92-2.95 (d, 4H), 3.48-3.53 (q, 8H), 3.80-3.83 (t, 8H), 4.03-4.06 (t, 8H), 4.32-4.35 (d, 4H), 6.21 (s, 8H), 7.24-7.48 (m, 60H) (spectrum 13) ^{13}C-NMR ($CDCl_3$) δ 10.53, 15.31, 28.62, 30.83, 39.47, 66.29, 69.64, 72.93, 128.09, 128.43, 128.77, 134.34, 135.12, 137.04, 139.08, 154.32 (spectrum 14).

3.2.9 Synthesis of 5, 11, 17, 23-tetra[1-(diphenylchlorostannyl)-*n*-propyl]-25, 26, 27, 28-tetraethoxyethyl-calix[4]arene 9

An anhydrous HCl solution was prepared by bubbling HCl gas into 1000 mL of methylene chloride at -78° C for approximately one hour. The flask containing the solution was fitted with a drying tube containing $CaSO_4$, and allowed to warm to room temperature, and then sealed with a rubber septum. Prior to its use, the HCl

concentration was determined by removal of an aliquot, and extraction into deionized water. The aqueous solution was titrated with a standardized NaOH solution to the phenolphthalein end point.

General Procedure

Into a 100 mL, round-bottomed flask was placed 1.123 g (0.493 mmol) of compound **8** dissolved in 10 mL of methylene chloride. The flask was fitted with a septum and began stirring while under argon. To the reaction, was added 4.9 mL of 0.202 M (2 molar equiv) HCl solution via syringe. The reaction was allowed to stir for six hours. The resulting mixture was concentrated under reduced pressure. Completion of the reaction was monitored by ^{13}C NMR. The reaction was dissolved in 10 mL of methylene chloride and was began stirring. To the reaction, was added 3.5 mL (4 molar equiv of unreacted starting material) HCl solution via syringe. The reaction was allowed to stir for six hours. The resulting mixture was concentrated under reduced pressure. Completion of the reaction was monitored by ^{13}C NMR. The reaction was dissolved in 10 mL of methylene chloride and was began stirring. To the reaction, was added 0.68 mL (4 molar equiv of unreacted starting material) HCl solution via syringe. The reaction was allowed to stir for six hours. The resulting mixture was concentrated under reduced pressure, leaving a viscous oil of compound **9.** Completion of the reaction was confirmed by ^{13}C NMR.

3.3.0 Anion Binding Studies

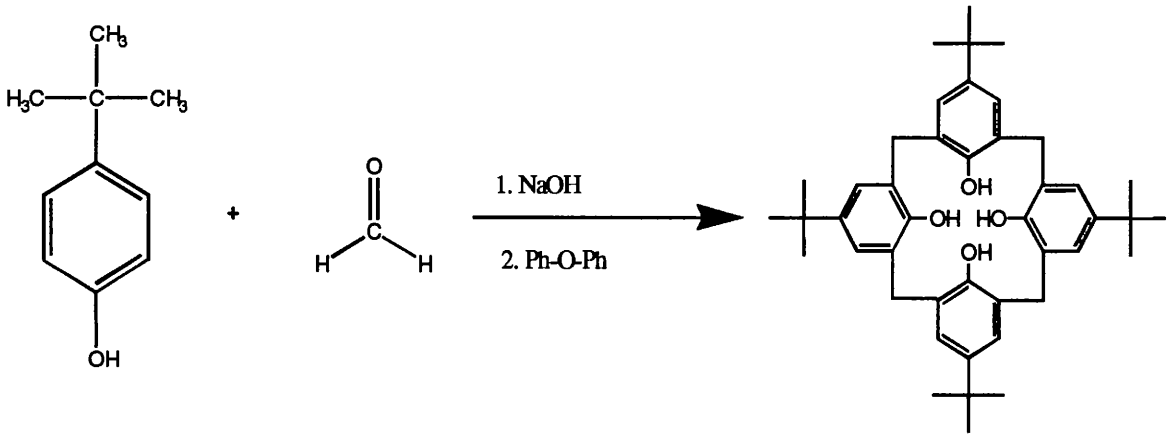
The stoichiometries of the anion complexes in solution were determined by the method of continuous variations.[21] In this method, equimolar solutions of the host and guest were added so that the mole fractions change but the total concentration of all species in solution was constant. The solutions (0.1 M) of the host and guest were prepared in 1 mL volumetric flasks. The solutions were mixed thoroughly and transferred to an NMR tube. The ^{119}Sn NMR spectra were recorded on a Varion 400 MHz spectrometer.

Equilibrium constants were determined by the Benesi-Hildebrand method, wherein a large excess of guest species was present relative to the amount of host. In these experiments, aliquots of a 1.72 M solution of guest were added 0.780 mL (0.071 mmol) of a 0.091 M solution of the guest in 1 mL volumetric flasks. The solutions were mixed thoroughly and transferred to an NMR tube. The ^{119}Sn NMR spectra were recorded on a Varion 400 MHz spectrometer.

4.0 RESULTS AND DISCUSSION

4.1.0 Model Compound Synthesis

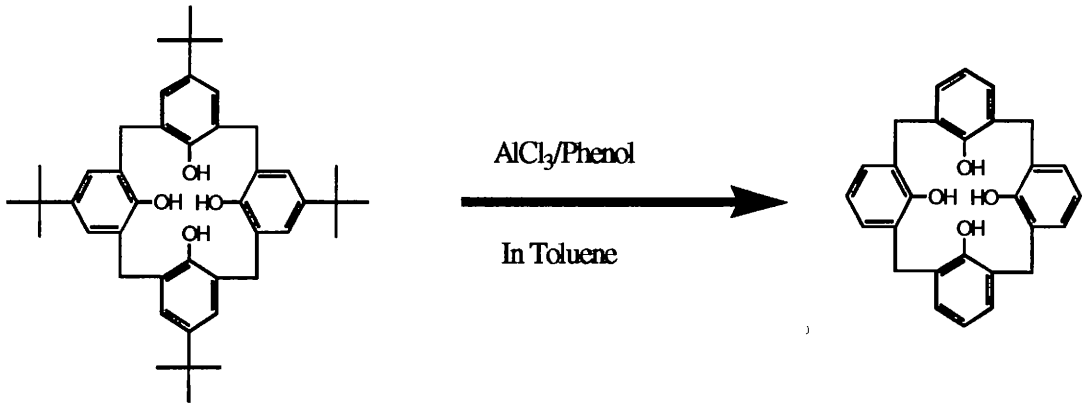
4.1.1 Preparation of 5, 11, 17, 23-p-*tert*-butyl-25, 26, 27, 28-tetrahydroxy-calix[4]arene 1



1

Tert-butyl calix[4]arene was prepared in 63% yield from the base-induced condensation of formaldehyde and *p-tert*-butyl phenol as described in the literature.[4] The base concentration has an effect on the formation of *p-tert*-butyl calix[4]arene. Experiments have shown that when the molar equivalents of NaOH with respect to the phenol are higher or lower than 0.045, the reaction gives a low yield of calix[4]arene as well as other calixarenes.

4.1.2 Preparation of 25, 26, 27, 28-tetrahydroxycalix[4]arene 2

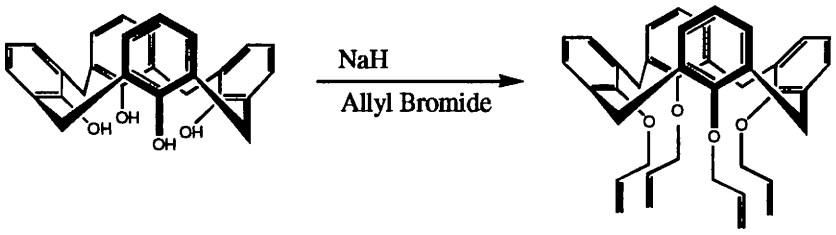


2

Calix[4]arene **2** was obtained in 79% yield by $AlCl_3$ –catalyzed removal of the *tert*-butyl groups from the parent tetra-*tert*-butylcalix[4]arene **1**. The most pronounced features of calix[4]arenes are the relatively simple synthetic modifications that can be achieved at both the lower rim (by reaction at the OH groups), and at the upper rim, after the removal of the *tert*-butyl groups.

The ^{1}H-NMR spectrum 1 shows the resonance peaks for the OH protons at 10.18 ppm, two multiplets between 6.0 and 7.09 ppm for the aromatic protons, and a broad singlet at 3.90 ppm for the bridged methylene protons due to a free rotation of the aromatic rings around the bridging methylene groups.

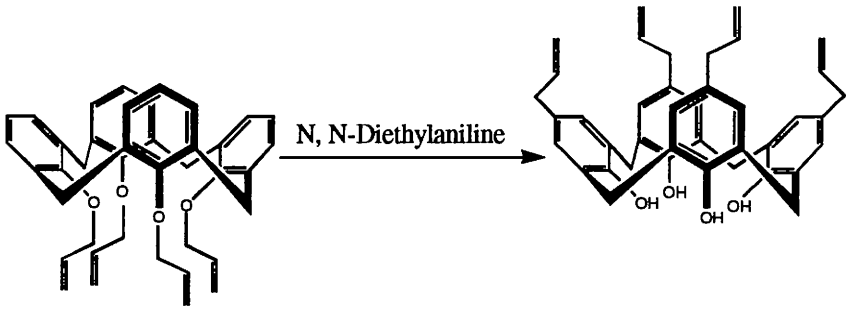
4.1.3 Synthesis of 25, 26, 27, 28-tetraallylcalix[4]arene 3



3

With the removal of the *tert*-butyl groups, calix[4]arene became an attractive starting material for the preparation of various substituted calix[4]arene. Early on, a problem arose concerning the introduction of functional groups directly onto the calix[4]arene. In most cases electrophilic and nucleophilic substitution reactions are used to convert the calix[4]arene to an ether or ester. The tetraallyl ether was produced in 85% yield by reacting the dealkylated calix[4]arene with an excess of NaH and allyl bromide in DMF.

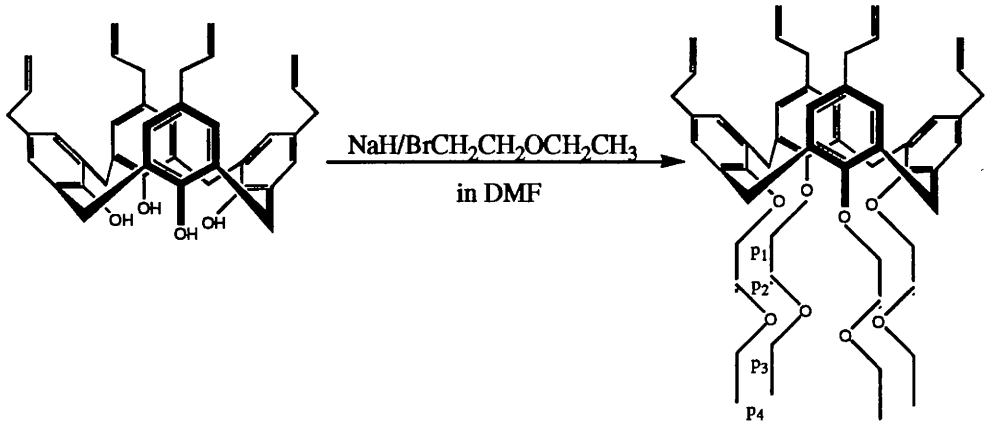
4.1.4 Synthesis of 5, 11, 17, 23-tetraallylcalix[4]arene 4



4

Both as a means of introducing functional groups at the upper rim and freeing up the lower rim for an additional protection, it was necessary to move the allyl groups from the lower rim to the upper rim. When a solution of the lower rim tetraallyl calix[4]arene in N, N-diethylaniline is refluxed, a heat induced Claisen rearrangement occurs in 71% yield.

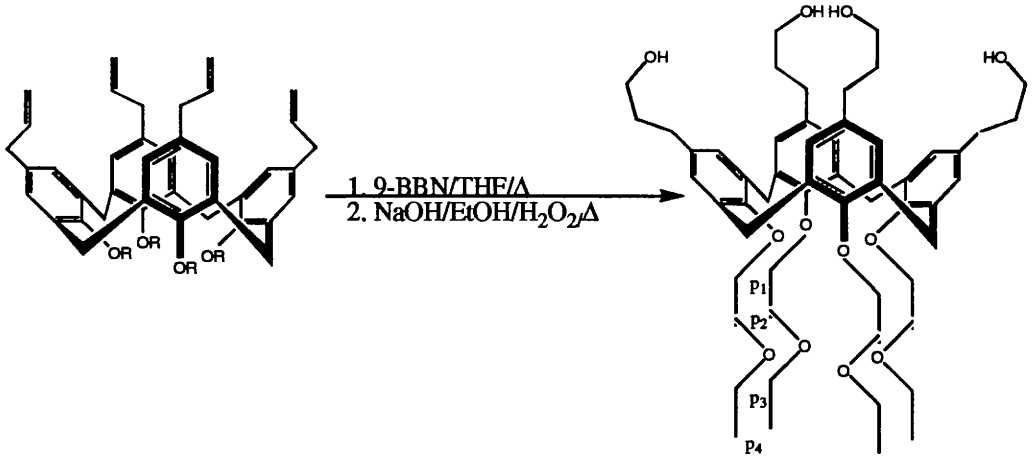
4.1.5 Synthesis of 5, 11, 17, 23-tetraallyl-25, 26, 27, 28-tetraethoxyethyl-calix[4]arene 5



5

As seen in spectrum 5, the newly synthesized calix[4]arene **4** still has some rotation about the methylene groups, therefore the next step is to "lock" the compound into the cone conformation. Since the pathway for conformational inversion involves the rotation of the aryl groups in a direction that brings the OH groups through the annulus of the macrocyclic ring, the most obvious way to halt this motion is to replace the hydroxyl groups with functional groups that are too large to move through the annulus. When calix[4]arene **4** is reacted with an excess of NaH and 2-bromoethyl ethyl ether in DMF, an ether is formed once again on the lower rim. After separation by column chromatography on silica gel, the reaction produces calix[4]arene **5** in 58% yield. This produces a possible binding site for cationic species.[22]

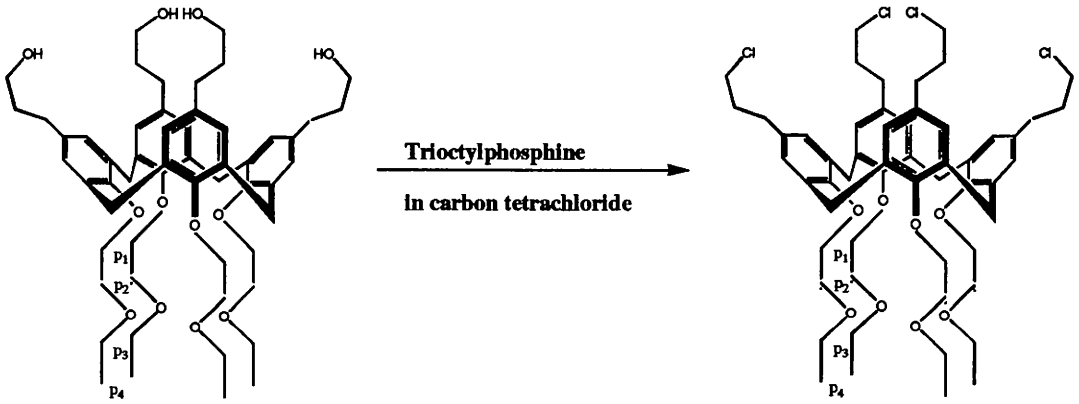
4.1.6 Synthesis of 5, 11, 17, 23-tetra(1-hydroxylpropyl)-25, 26, 27, 28-tetraethoxy-ethyl calix[4]arene 6



6

The next step of the synthesis was to introduce an alcohol at the site of the allyl groups on the upper rim. The hydroboration reaction was accomplished by refluxing a solution of calix[4]arene **5** and 9-BBN in THF overnight. Once the reaction mixture had cooled, sodium hydroxide, ethyl alcohol and 30% hydrogen peroxide were added in that order. It is important to add the hydrogen peroxide very slowly to avoid violent reflux. The tetra-ol calix[4]arene **6** was purified by column chromatography. Due to the increased polarity of the species, alumina oxide was used over silica gel. The calix[4]arene was produced in 28% yield.

4.1.7 Synthesis of 5, 11, 17, 23-tetra(1-chloropropyl)-25, 26, 27, 28-tetraethoxy-ethyl calix[4]arene 7



7

A different approach to the chloride was taken initially. The calix[4]arene **X** was dissolved in chloroform and then reacted with thionyl chloride. When this reaction was examined by TLC, several products were revealed, making this method less desireable. By reacting calix[4]arene **6** with trioctylphosphine in carbon tetrachloride, the tetra-

chloro-calix[4]arene **7** was produced in 82% yield. The product was purified by column chromatography on silica gel.

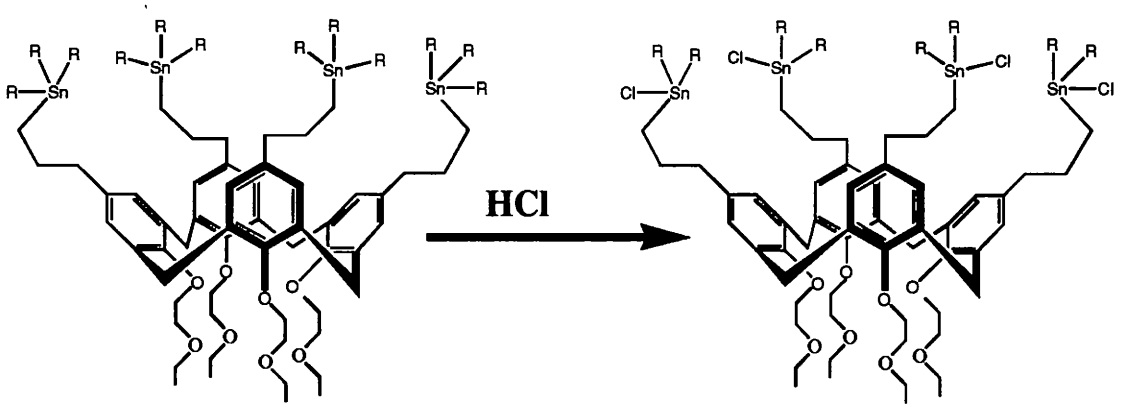
4.1.8 Synthesis of 5, 11, 17, 23-tetra-[1-(triphenylstannyl)-*n*-propyl]-25, 26, 27, 28-tetraethoxyethylcalix[4]arene 8

The introduction of Lewis acidic sites, specifically tin, was attempted by three methods. The first two methods attempted to add the tin atoms directly to the allyl groups on the calix[4]arene **4.** The first attempt was by way of sonochemical initiation. This method is based on using a sonicator bath to create localized superheated cavities with maximum temperatures over 2000 K. These "hot pockets" are intended to initiate a free radical reaction. In our case, this method was unsuccessful.

The second attempt was similar to the first, but differed in the form of initiation. This method attempted to create a free radical reaction by way of using AIBN and ultraviolet light as the initiators. Once again this method was unsuccessful.
Finally, the third attempt was successful. This method utilized a two step process. The first step created a triphenyltin anion by reacting hexaphenylditin with an excess of lithium metal in THF.[23] Once the reaction refluxed overnight, the solution changed color to an olive green, indicating completion. This tin anion was then transferred to another reaction vessel containing a solution of calix[4]arene **7** dissolved in THF. The resulting calix[4]arene **8** was recrystallized in hot hexane in 40% yield. The ^{13}C-NMR of the compound shows a peak at 10.53 δ (spectrum 14) which corresponds to the methylene

carbon next to the tin atom. This peak will become important in the next reaction. The ^{119}Sn NMR showed one peak at –101.29 δ (spectrum 15).

4.1.9 Synthesis of 5, 11, 17, 23-tetra-[1-(diphenylchlorostannyl)-*n*-propyl]-25, 26, 27, 28-tetraethoxyethylcalix[4]arene 9



9

An anhydrous HCl solution was prepared in the manner described in the experimental section (section 3.2.9). The anion receptor was created by reacting a solution of calix[4]aren **8** in methylene chloride with the HCl solution. It was important to use no more than 4 eq of HCl to prevent the removal of more than one phenyl group from each of the Sn atoms. Once the reaction mixture was allowed to stir overnight, its completion was examined by way of ^{13}C-NMR. When examined, a new peak at 16.90 δ (spectrum 16) had appeared which represented the methylene carbon next to tin atom that had had one of the phenyl groups removed. The peak at 10.53 δ had decreased in

intensity, but still remained. Therefore, there was still unreacted calix[4]arene **8** in the mixture. The heights of the two peaks were measured and the ratio of reacted to unreacted was determined. The reaction was repeated based on the mmol of unreacted material using 4 eq of HCl . This procedure was continued until the ^{13}C-NMR revealed the complete disappearance of the peak at 10.53 δ (spectra 17 and 18). Completion of the reaction could also be determined by ^{119}Sn NMR. Before the reaction was complete, two peaks were visible (spectrum 19). The peak at –101.27 δ corresponded to the starting material, calix[4]arene **8,** while the peak at 14.75 δ corresponded to the newly formed calix[4]arene **9.** Once the ^{13}C-NMR showed completion, it was confirmed by the presence of only the peak at 14.75 δ on the ^{119}Sn-NMR spectrum (spectrum 20).

4.2.0 Anion Binding Studies

Complexes formed between the anion receptor and the chloride ions were examined in solution. Since the chemical shift of the ^{119}Sn is sensitive to the geometry of the tin atom and its ligands, ^{119}Sn-NMR spectroscopy was used to examine the complexation between the guest and host molecule. For example, the free host, calix[4]arene **9,** the tin atoms are tetrahedral stannane types which produces a peak at 14.75 ppm, while the guest-host complex gives rise to pentavalent stannate tin atoms which have a chemical shift about 200 ppm downfield.[25]

The stoichiometries of the anionic complexes were determined by the method of continuous variations.[21] In this method, solutions of the host and guest were mixed so that the mole fractions changed but the total concentration of all species in solution was

constant. The solutions were then examined using ^{119}Sn-NMR. The chemical shifts were recorded, and the following table reports the data collected (see Table 1).

Table 1

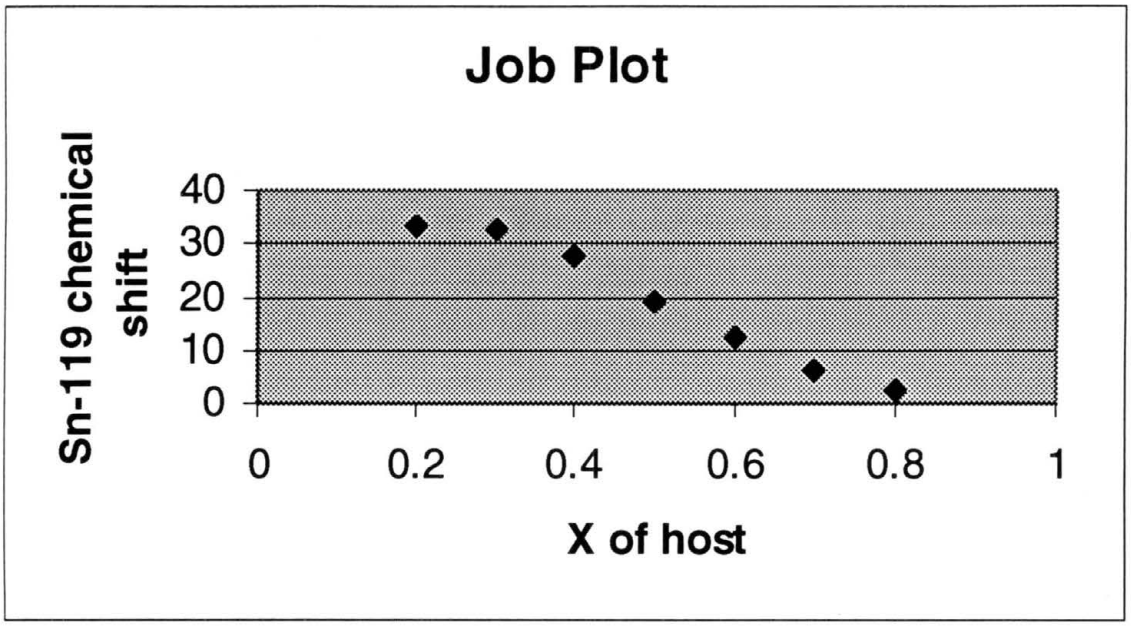
Job Plot Data

X_H	$\Delta\delta$	$\Delta\delta \cdot X_H$
0.8	3.12	2.49
0.7	9.05	6.34
0.6	20.51	12.30
0.5	38.19	19.09
0.4	69.20	27.68
0.3	109.29	32.79
0.2	166.26	33.25

The data was then plotted with the mole fraction of the host (X_H) against the observed chemical shift ($\Delta\delta$) multiplied by the mole fraction of the host (X_H vs $\Delta\delta \cdot X_H$) to reveal the stoichiometry of the complex. If the plot had shown a maximum value at the 0.5 mole fraction, this would have indicated a 1:1 stoichiometry which would have meant that the four tin atoms were working cooperatively to bind one chloride ion. This was not the case for the complexation of Host **9**. The Job plot revealed a maximum value at 0.25 mole fraction of host which relates to a 4:1 stoichiometry (see Figure 16). This meant

that each tin atom worked independently with a total of four chloride ions being bound by the host.

Figure 16



Once the stoichiometry was determined, the association constants (K_a) were determined at different temperatures. To determine these values a large excess of the guest species was present relative to the amount of host. In the ^{119}Sn titration experiments, aliquots of a 1.72 M solution of guest were added to 0.780 mL (0.071 mmol) of a 0.091 M solution of host in 1 mL volumetric flasks. The observed chemical shifts were recorded at four different temperatures (328 K, 295 K, 273 K and 253 K). The following chart (see Table 2) presents the data for the series of samples at room temperature (295 K). Using the Benesi-Hildebrand method, this data can be evaluated to determine the end chemical shift of the complex as well as the association constant.[21]

Table 2

Data for Benesi-Hildebrand Plot

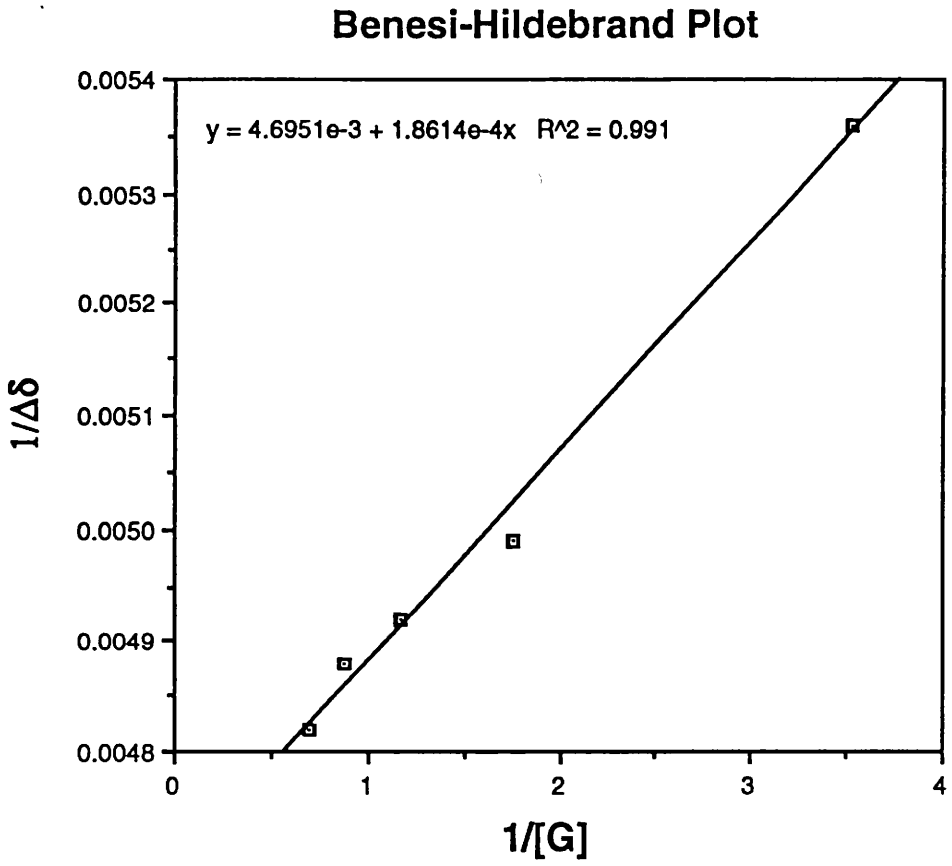
$\Delta\delta$	$1/\Delta\delta$	1/[G]	Ratio G:H
186.68	.00536	3.52	4
200.34	.00499	1.76	8
203.42	.00492	1.17	12
204.86	.00488	0.88	16
207.35	.00482	0.70	20

This data was then graphed using a double reciprocal plot with 1/[G] as the x-axis and $1/\Delta\delta$ as the y-axis (see Figure 17). By way of linear regression, the slope and y-intercept were both determined. Using the Benesi-Hildebrand relationship,

$$(\delta_{obs} - \delta_H)^{-1} = (\delta_C - \delta_H)^{-1} + (K_{eq}(\delta_C - \delta_H))^{-1}\,[G]^{-1}, \qquad \text{equation 1}$$

the chemical shift of the complex and the association constant were both determined (see equation 1). In the above equation, $(\delta_C - \delta_H)^{-1}$ is set equal to the y-intercept and $(K_{eq}(\delta_C - \delta_H))^{-1}$ is set equal to the slope. The chemical shift of the complex was determined to be –277.9 ppm and the K_a was determined to be 25 M^{-1}.

Figure 17



The same procedure was repeated at 328 K, 273 K and 253 K. The complex chemical shifts and association constants were determined and reported in the following table (see Table 3). The K_a values ranged from 13 M^{-1} to 52 M^{-1}. These values were small, suggesting weak binding, and similar to those of tributyltin chloride.[12]

Table 3

Data for van't Hoff Plot

Temp	1/T	K_a	Ln K	δ_{guest}	$-\Delta G°$
328 K	.00305	13	2.56	-234.95	1.66
295 K	.00339	25	3.22	-227.9	1.88
273 K	.00366	33	3.49	-210.73	1.89
253 K	.00395	52	3.95	-205.76	1.98

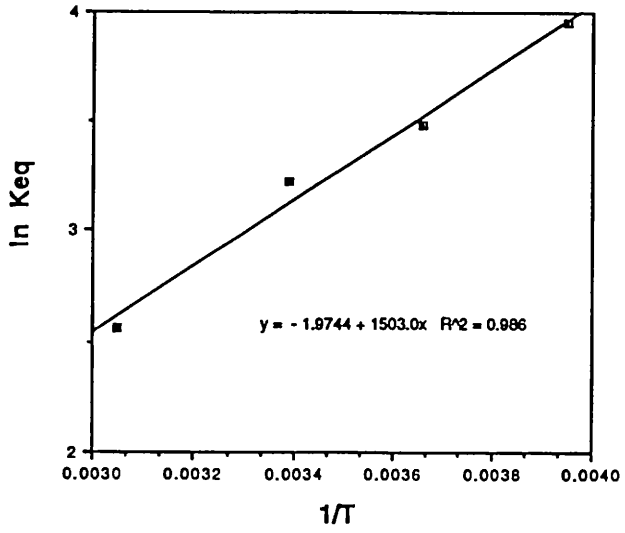
Using the relationship,

$$\Delta G° = -RT \ln K, \qquad \text{Equation 2}$$

the Gibbs free energy was determined for each temperature. Using a van't Hoff plot, 1/T was plotted against ln K which made it possible to determine the enthalpic (ΔH) and entropic (ΔS) contributions to the binding interactions using the relationship: $\ln K = -\Delta H/RT + \Delta S/R$ (R = 1.98 e-3 kcal/mol)(see Figure 18). ΔH and ΔS were determined to be –2.98 and 3.9 e-3 respectively.

Figure 18

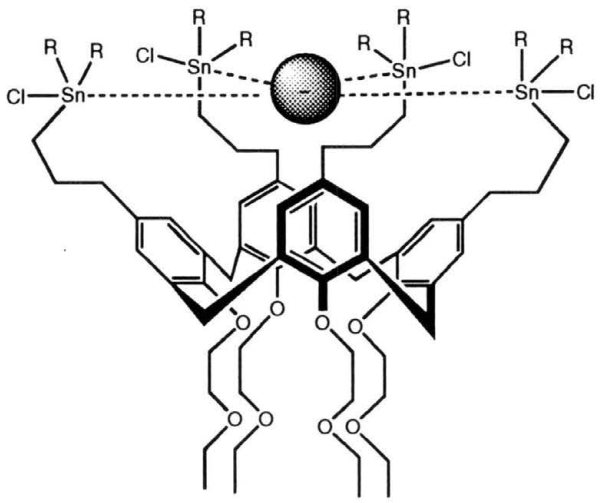
van't Hoff Plot of Association Constants



5.0 SUGGESTIONS FOR FUTURE RESEARCH

The results of this research indicate that the calix[4]arene can be selectively functionalized to create an anion binding cavity on the upper rim which contains Lewis acidic atoms. This receptor molecule was determined to bind chloride ion at 4:1 stoichiometry.

The lower rim of the target molecule creates a possible binding site for cations. Therefore a good avenue for future studies would be to explore the possibility of simultaneously binding cations and anions by this ditopic molecule. Also, the exploration of different guests in order to achieve a 1:1 stoichiometry would make for a much more novel anion receptor.



REFERENCES

1. Zinke, A; Kretz, E. Leggewie. *Monatsh. Chem.* **1952,** 83, 1213.
2. Gutsche, C. D.; Dhawan, B.; No, K. H.; Muthukrishnan, R. *J. Am. Chem. Soc.* **1981,** 103, 3782.
3. Zinke, A.; Ziegler, E. *Ber.* **1941,** 74, 1729.
4. Gutsche, C. D.; Iqbal, M.; Stewart, D. *J. Org. Chem.* **1986,** 51, 743.
5. Gutsche, C. D., Calixarenes, monographs in Supramolecular Chemistry, Vol. 1; The Royal Society of Chemistry: Cambridge, **1989.**
6. Atwood, J. L.; Holman, T.; Steed, W. S. *Chem. Commun.* **1996,** 1401.
7. Staffilani, M.; Hancock, K. S. B.; Steed, J. W.; Holman, K. T.; Atwood, J. L. *J. Am. Chem. Soc.* **1997,** 119, 6324.
8. Park, C. H.; Simmons, H. E. *J. Am. Chem. Soc.* **1967,** 89, 1078.
9. Graf, E.; Lehn, J. M. *J. Am. Chem. Soc.* **1976,** 98, 6403.
10. Schmidtchen, F. P.; Berger, M. *Chem Rev.* **1997,** 97, 1624.
11. Dietrich, B.; Fyles, T. M.; Lehn, J. M.; Pease, L. G.; Fyles, D. L. *J. Chem. Soc., Chem. Commun.* **1978,** 934.
12. Blanda, M. T.; Horner, J. H.; Newcomb, M. *J. Org. Chem.* **1989,** 54, 4626.
13. Scheerder, J.; Mariacristina, F.; Engbersen, J. F. J.; Reinhoudt, D. N. *J. Org. Chem.* **1994,** 59, 7816.
14. Pearson, R. G. *J. Am. Chem. Soc.* **1963,** 85, 3533.
15. Pelizzi, N.; Casnati, A.; Ungaro, R. *Chem. Commun.* **1998,** 2608.
16. Beer, P. D.; Drew, M. G. B.; Hesek, D.; Nam, K. C. *Chem. Commun.* **1997,** 107.

17. Gutsche, C. D.; Levine, J. A.; Sujeeth, P. K. *J. Org. Chem.* **1985,** 50, 580

18. Arduini, A.; Casnali, A.; Fabbi, M.; Minaii, P.; Pochini, A.; Sicuri, A. R.; Ugaro, R. *Supramolecular Chem.* **1993,** 1, 235.

19. Brown, H. C.; Knights, E. F.; Scouten, C. G.; *J. Am. Chem. Soc.* **1974,** 96, 7765.

20. Tamborski, C.; Ford, F. E.; Soloski, E. J. *J. Am. Chem Soc.* **1963,** 28, 181.

21. Conners, K. A.; *Binding Constants, The Measurement of Molecular Complex Stability;* Wiley-Interscience: New York, **1987,** 24-28.

22. Shinkai, S.; Koreishi, H.; Ueda, K.; Manabe, O. *J. Chem Soc., Chem Commun.* **1986,** 233.

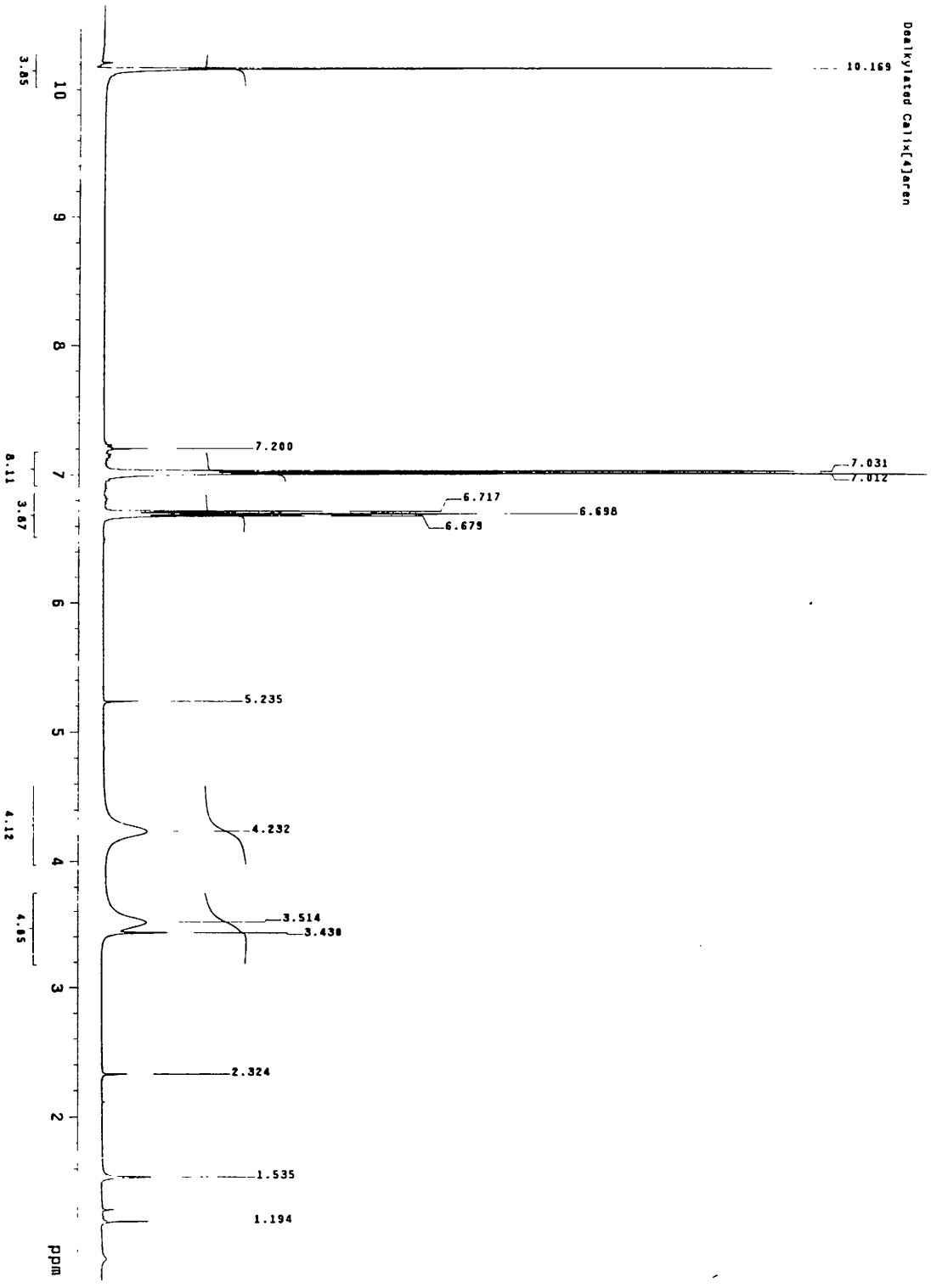
23. Nakamura, E.; Imanishi, Y.; Machii, D. *J. Org. Chem.* **1994,** 59, 8178.

24. Sommer, R.; Kuivial, H. G. *J. Org. Chem.* **1968,** 33, 802.

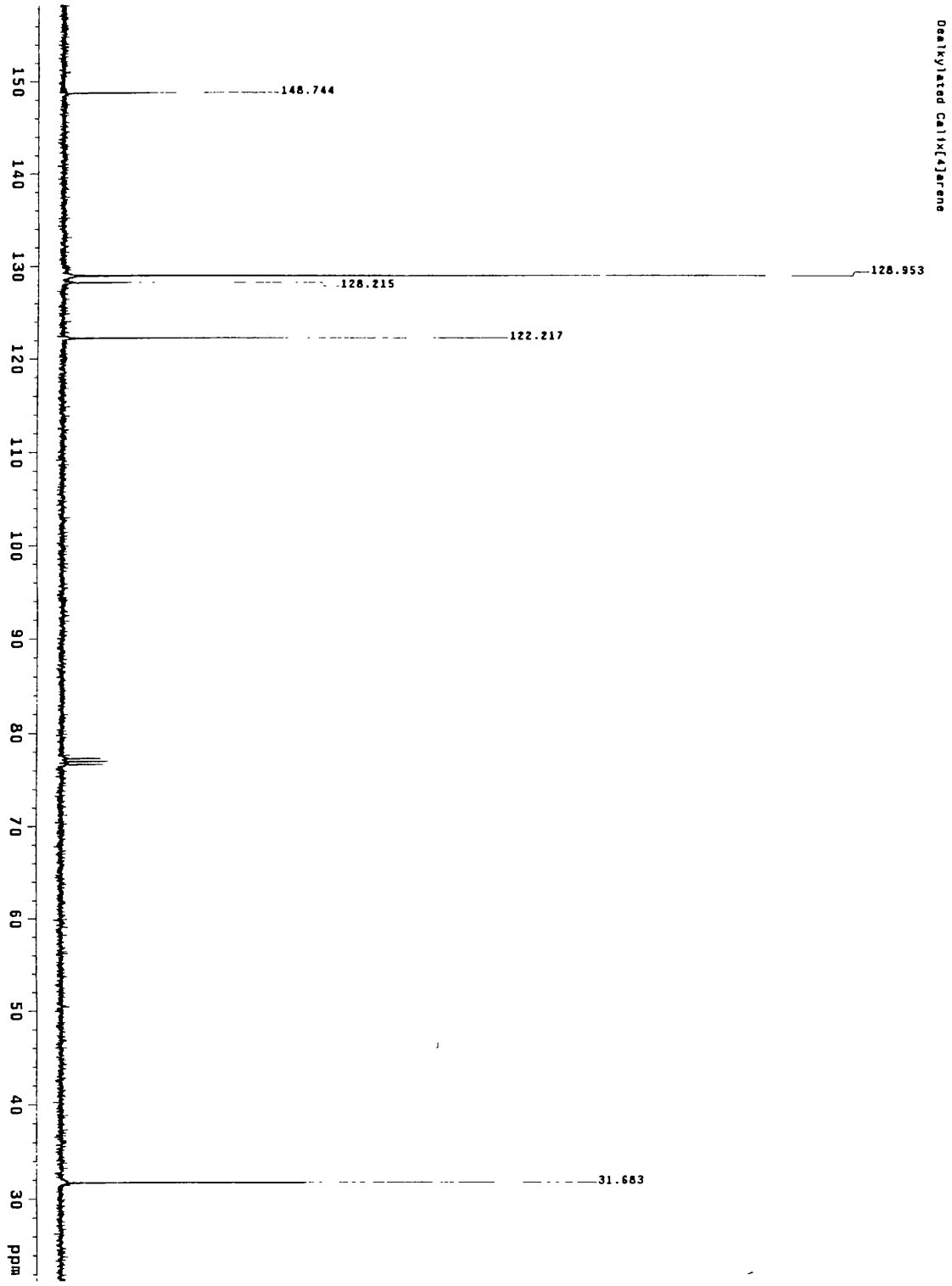
25. Sandstrom, J. *Dynamic NMR Spectroscopy.* Academic Press: New York, **1982,** 12-15.

APPENDIX: SPECTRA

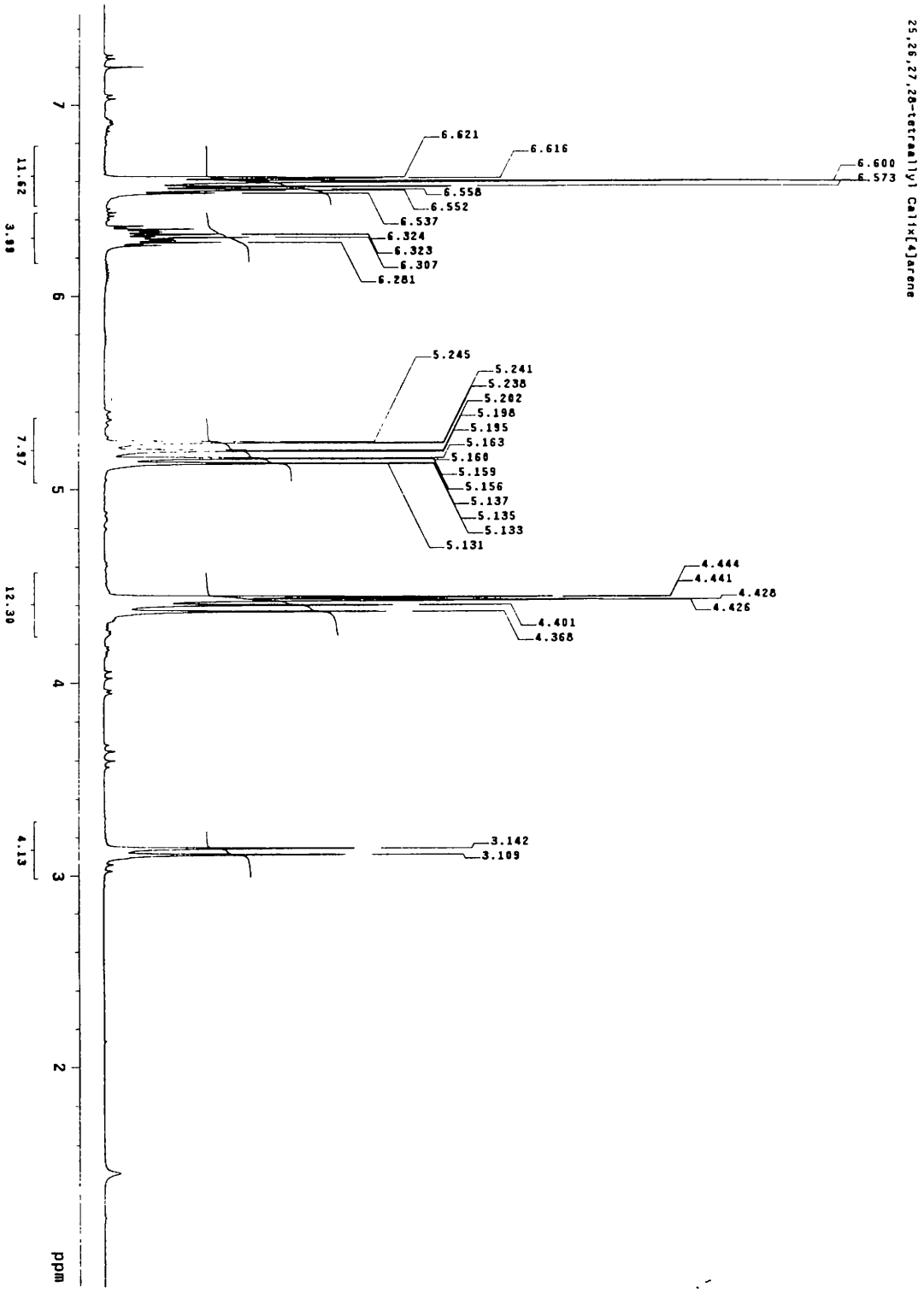
Spectrum 1. ^{1}H-NMR of Compound 2



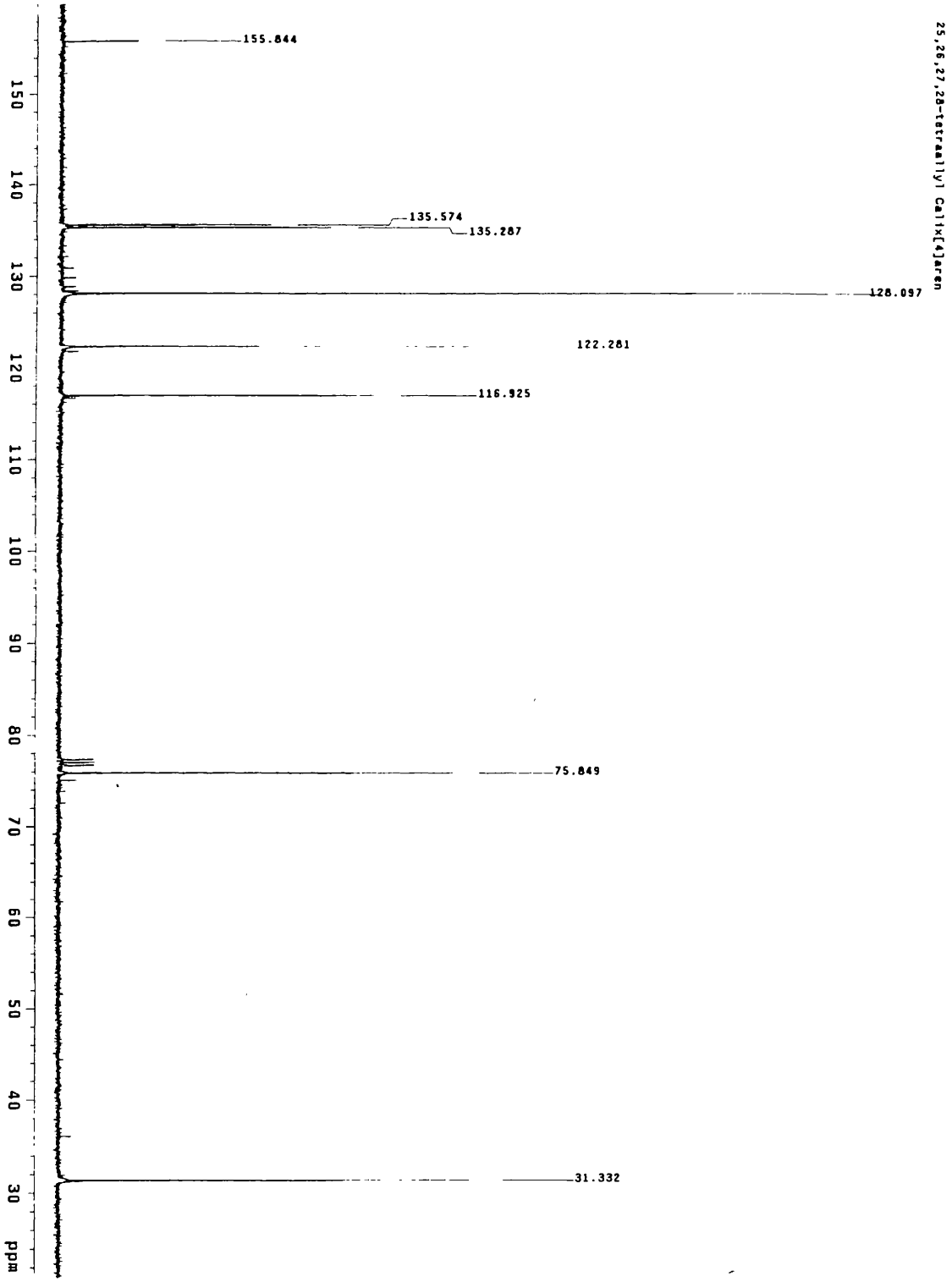
Spectrum 2. ^{13}C-NMR of Compound 2



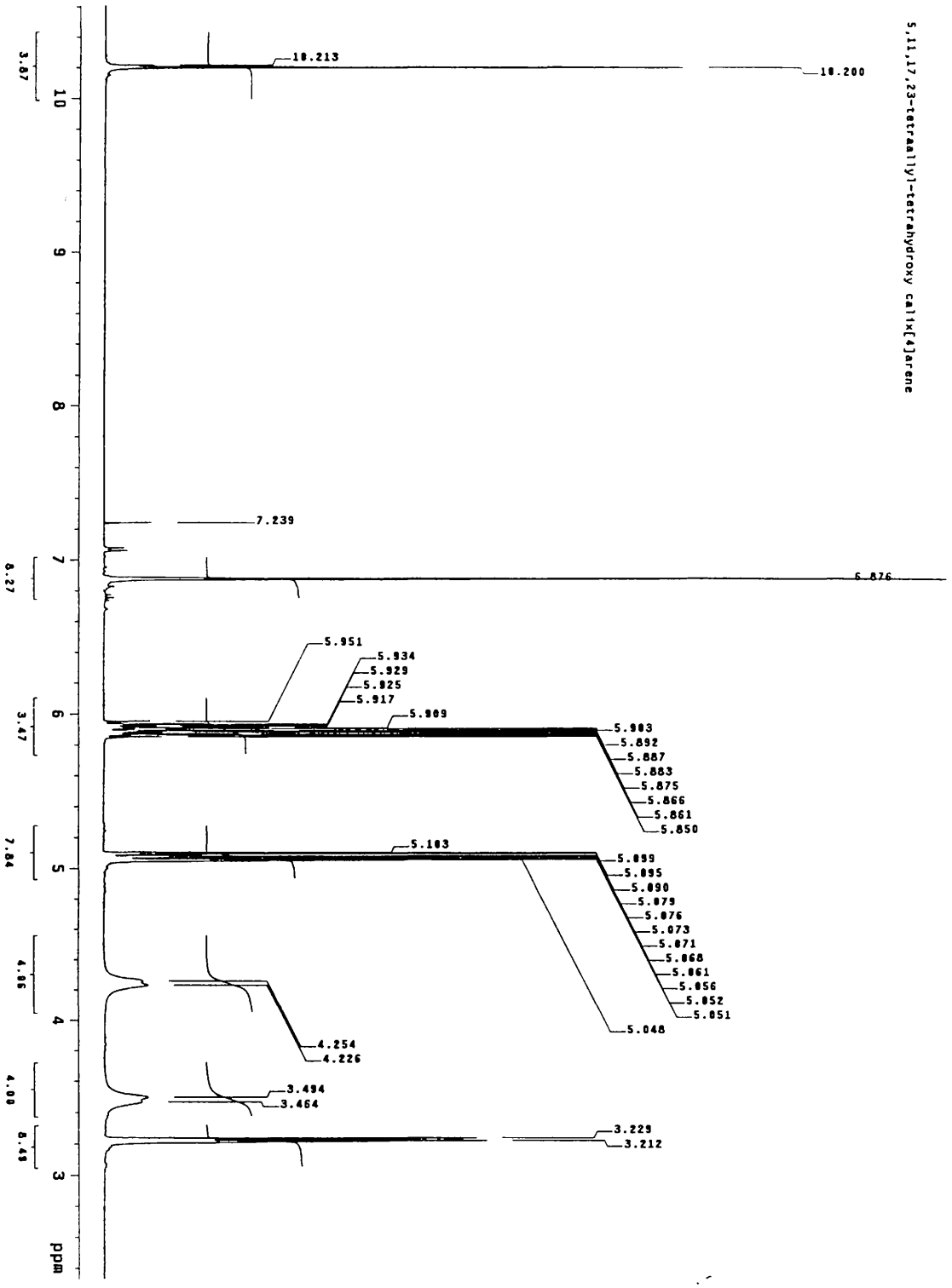
Spectrum 3. ^{1}H-NMR of Compound 3



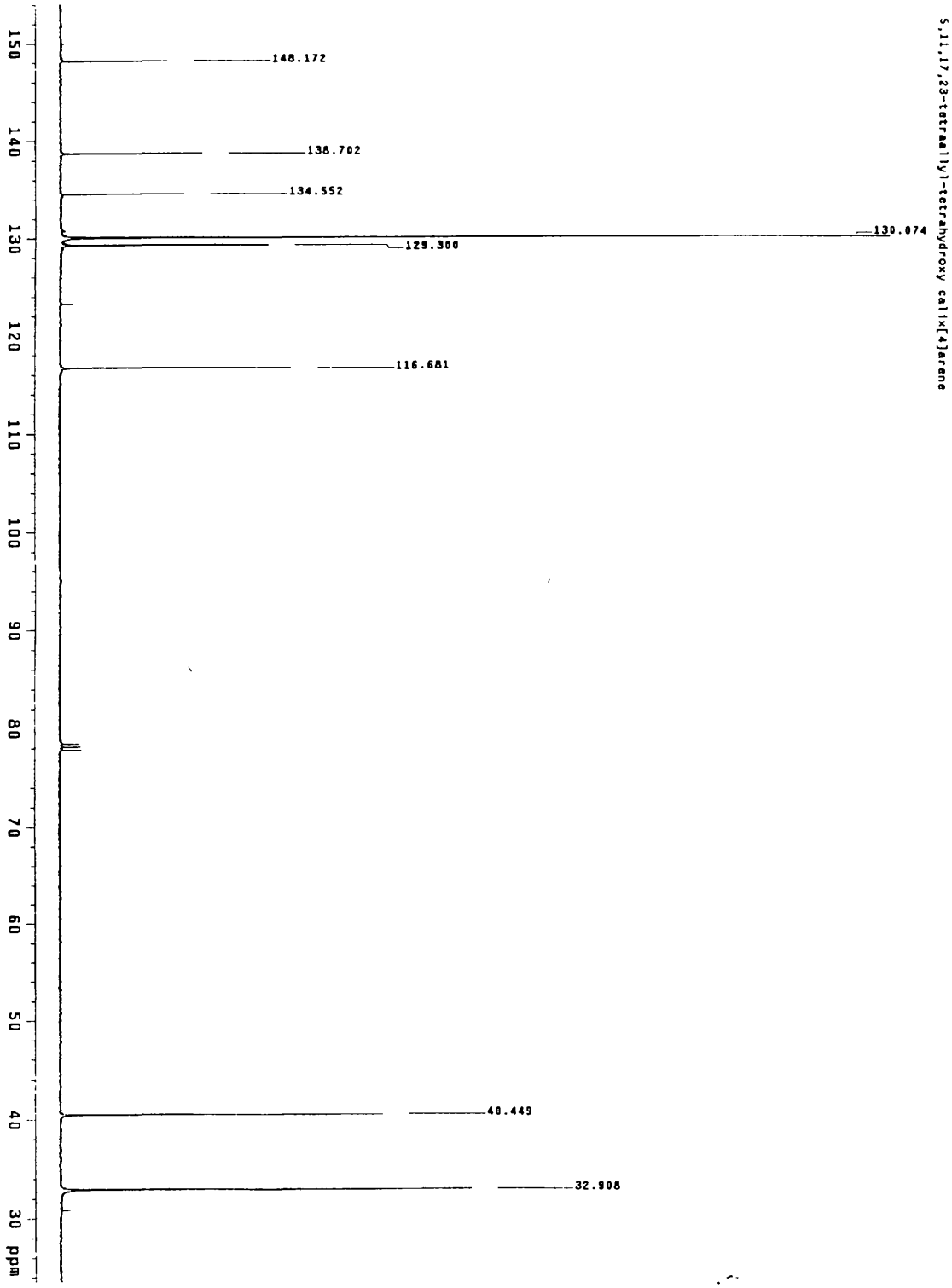
Spectrum 4. ^{13}C-NMR of Compound 3



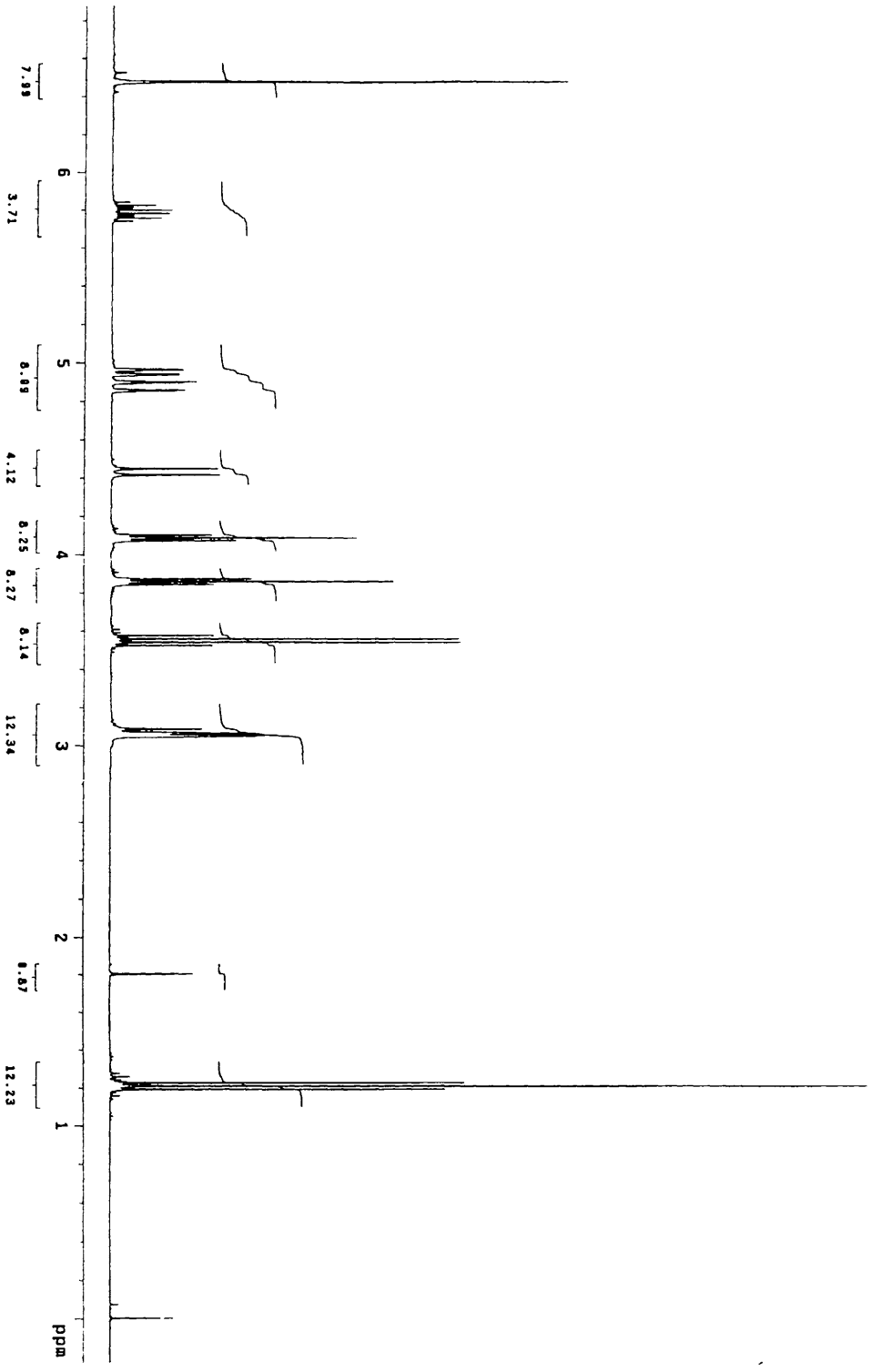
Spectrum 5. ^{1}H-NMR of Compound 4



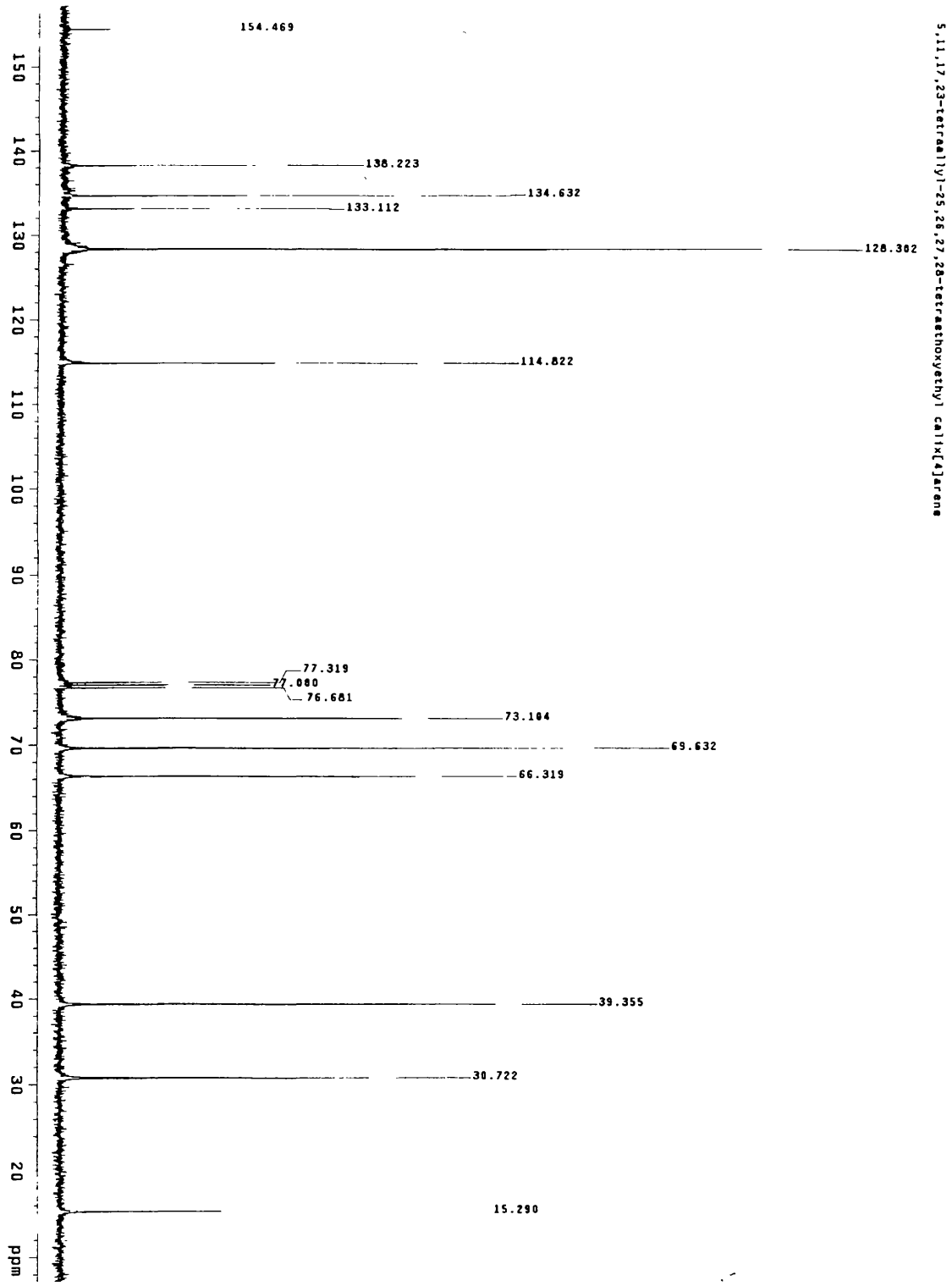
Spectrum 6. ^{13}C-NMR of Compound 4



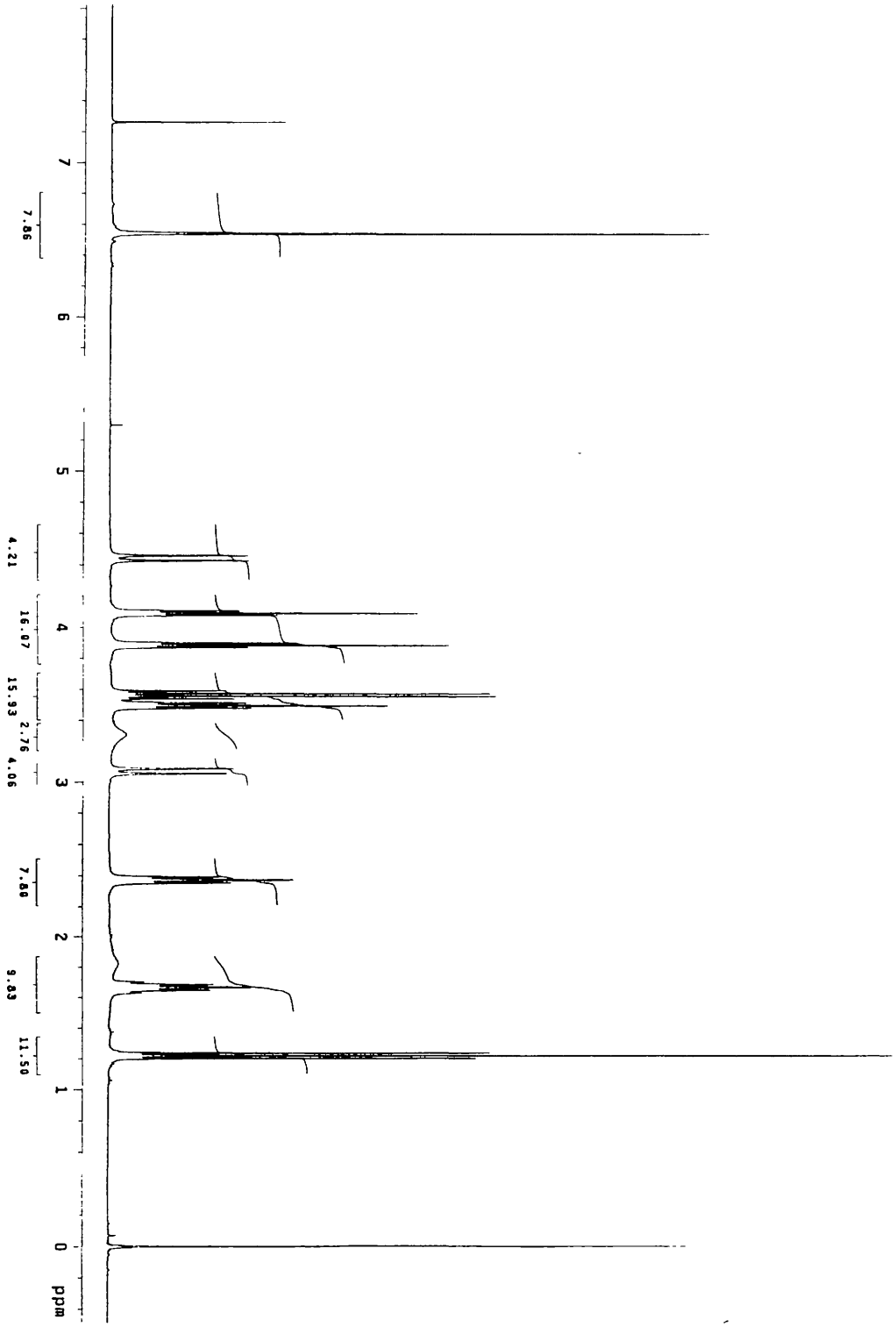
Spectrum 7. ^{1}H-NMR of Compound 5



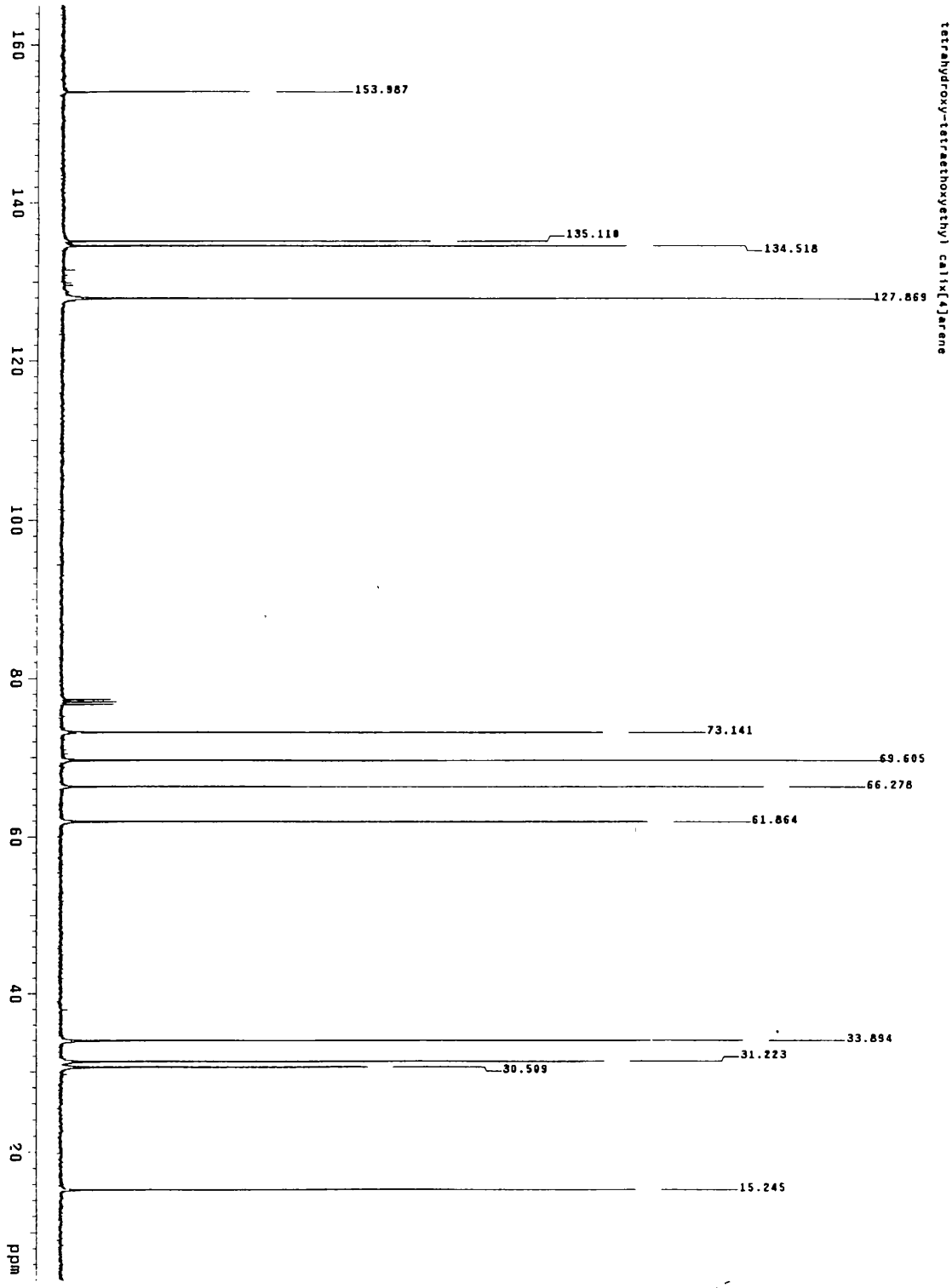
Spectrum 8. ^{13}C-NMR of Compound 5



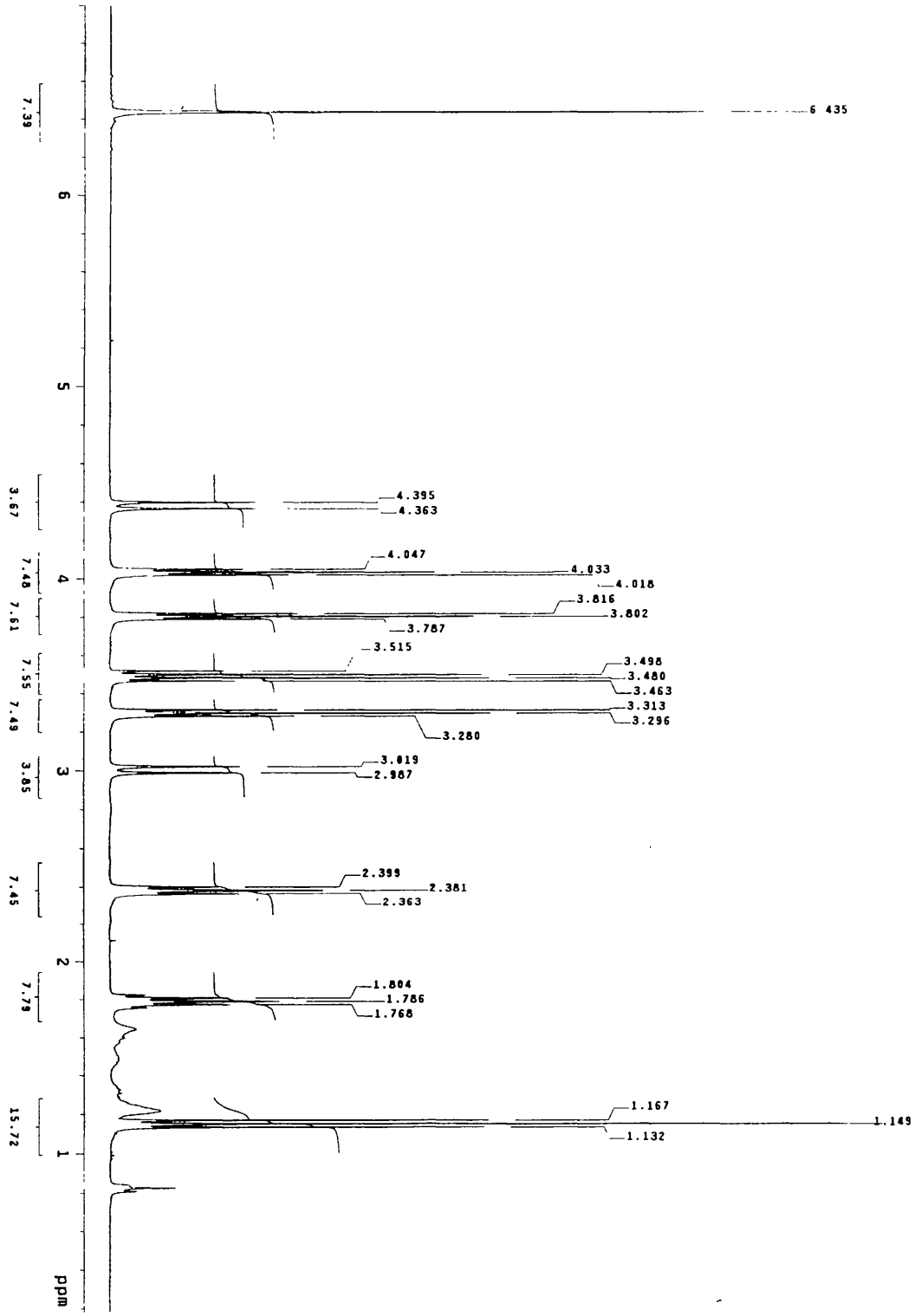
Spectrum 9. ^{1}H-NMR of Compound 6



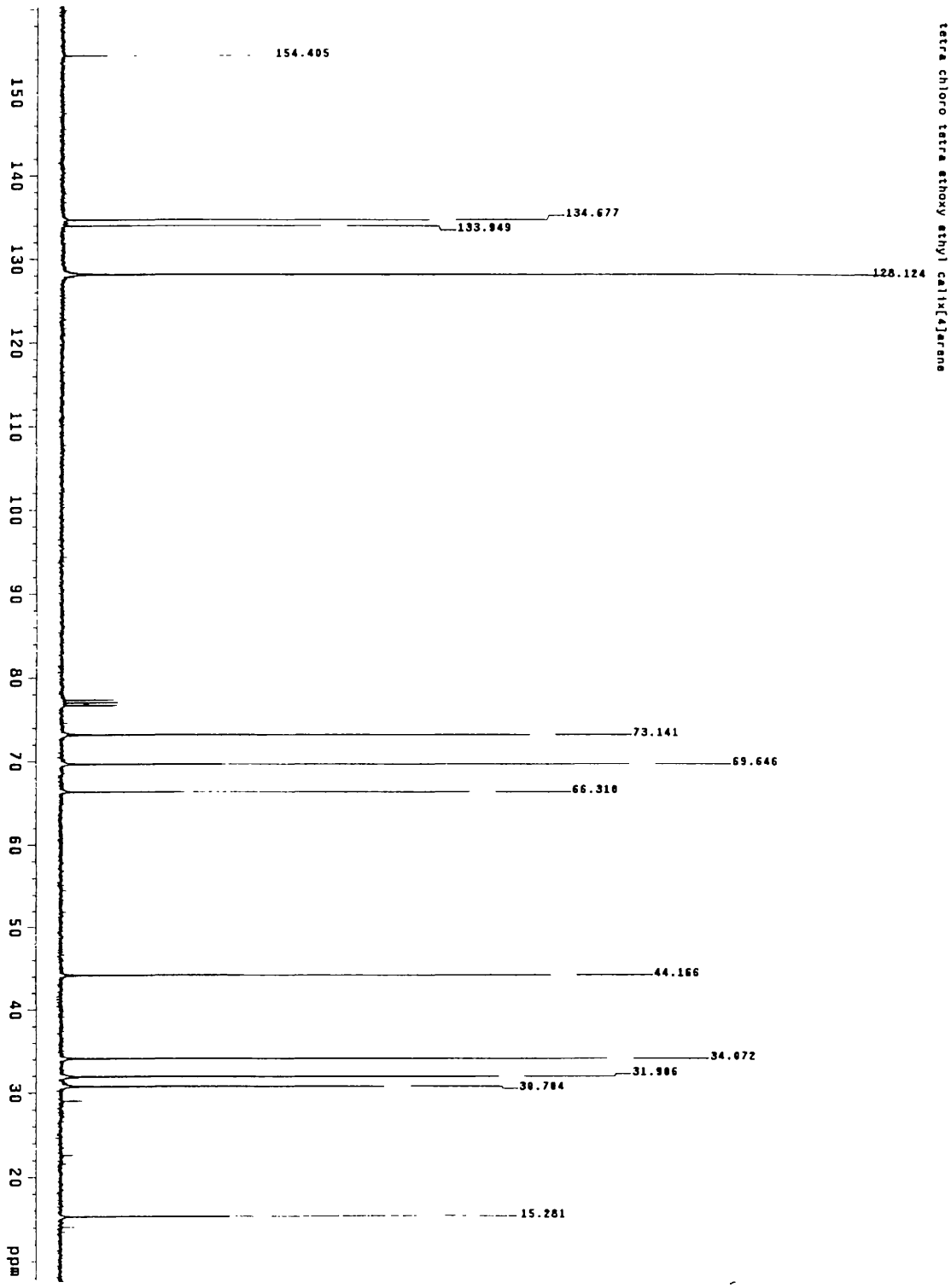
Spectrum 10. ^{13}C-NMR of Compound 6



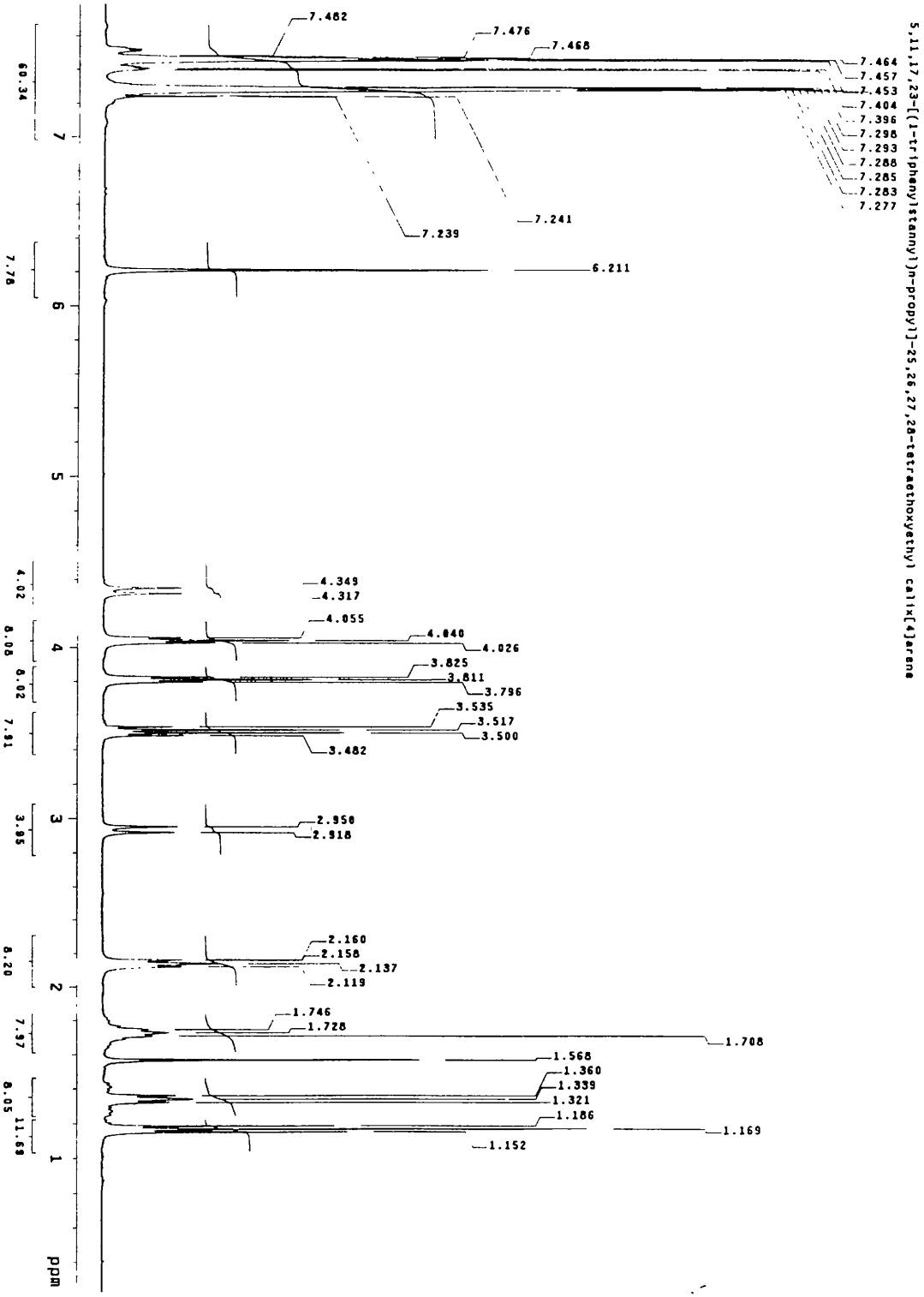
Spectrum 11. ^{1}H-NMR of Compound 7



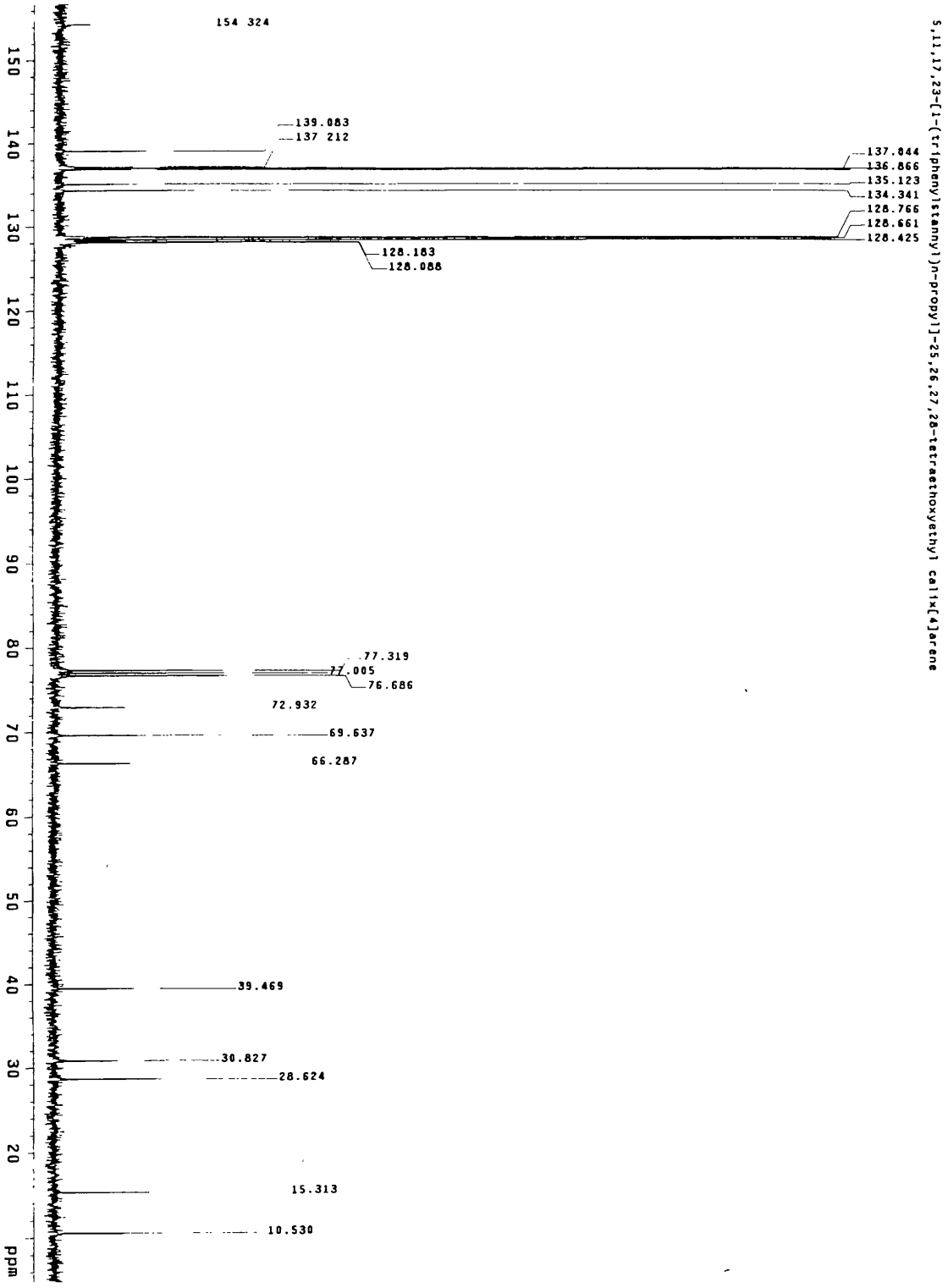
Spectrum 12. ^{13}C-NMR of Compound 7



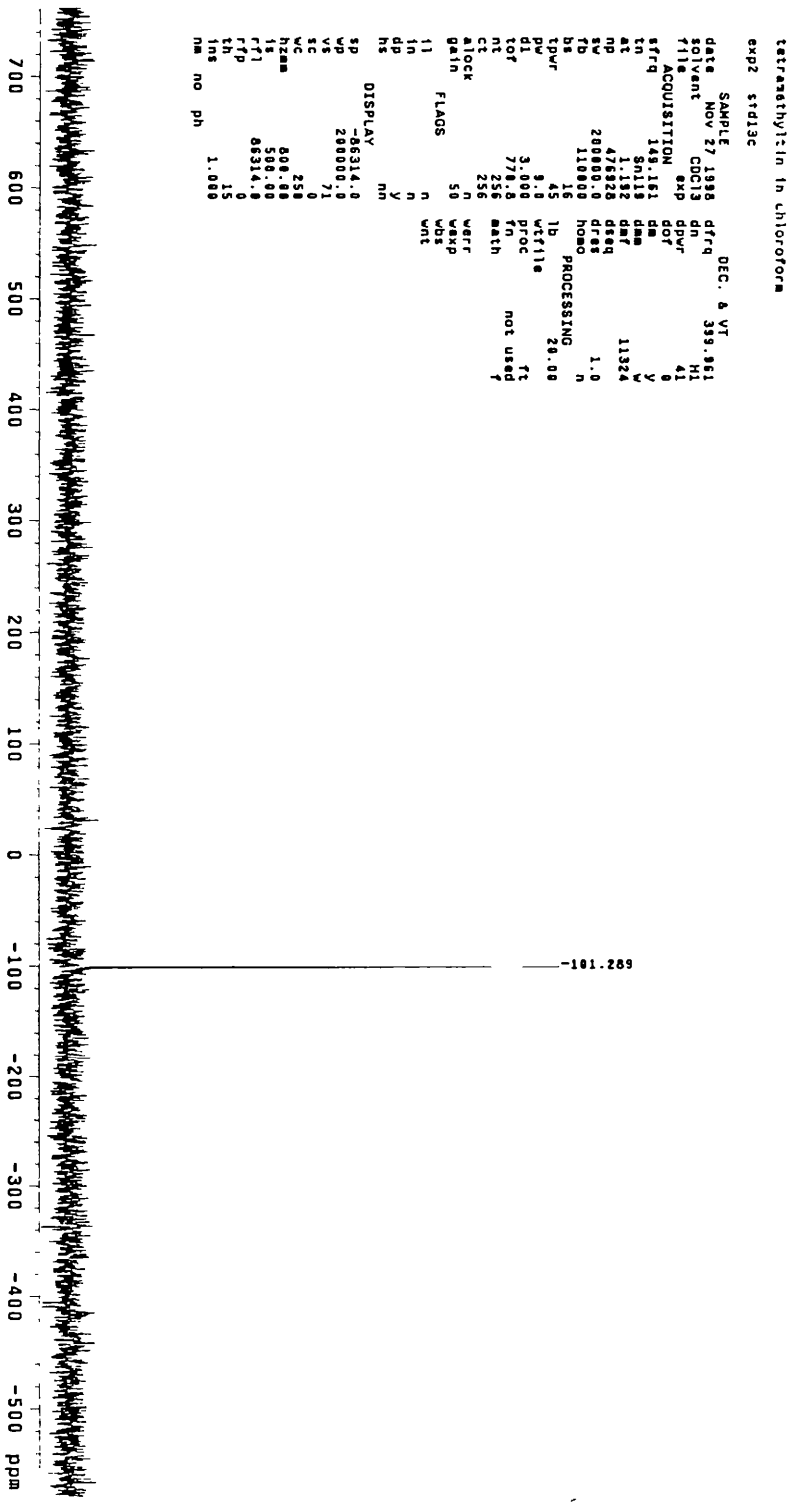
Spectrum 13. ^{1}H-NMR of Compound 8



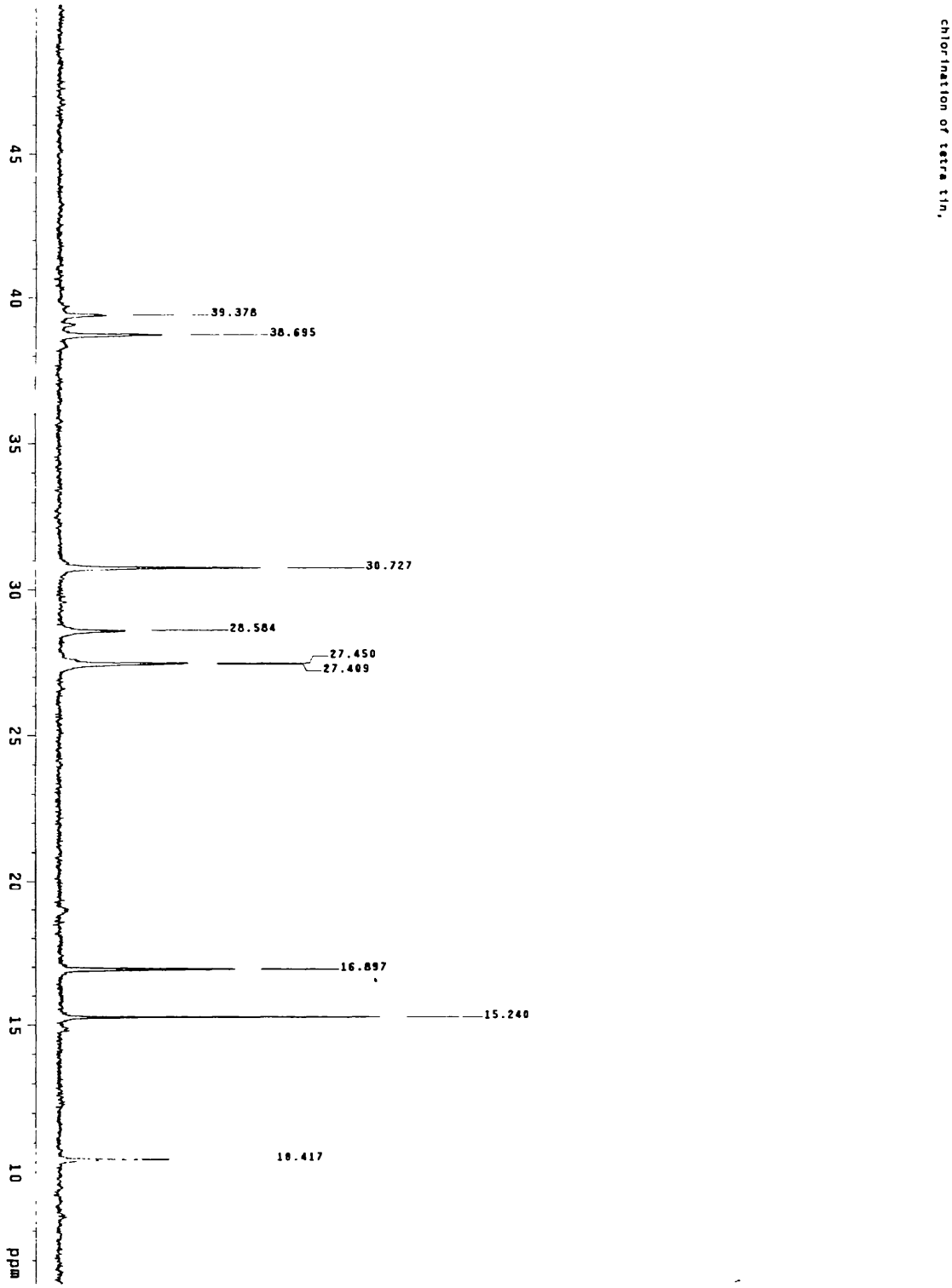
Spectrum 14. ^{13}C-NMR of Compound 8



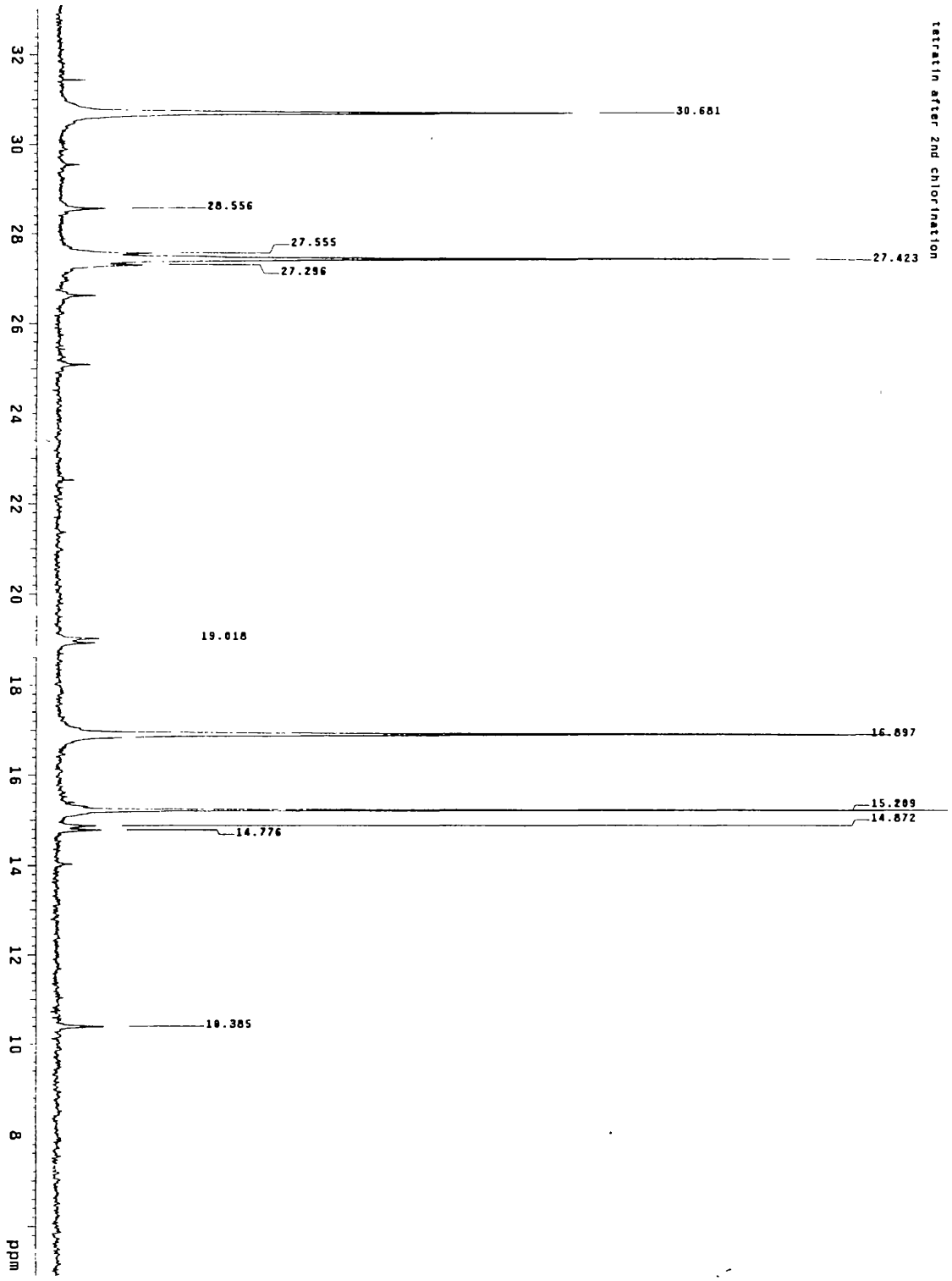
Spectrum 15. ^{119}Sn-NMR of Compound 8



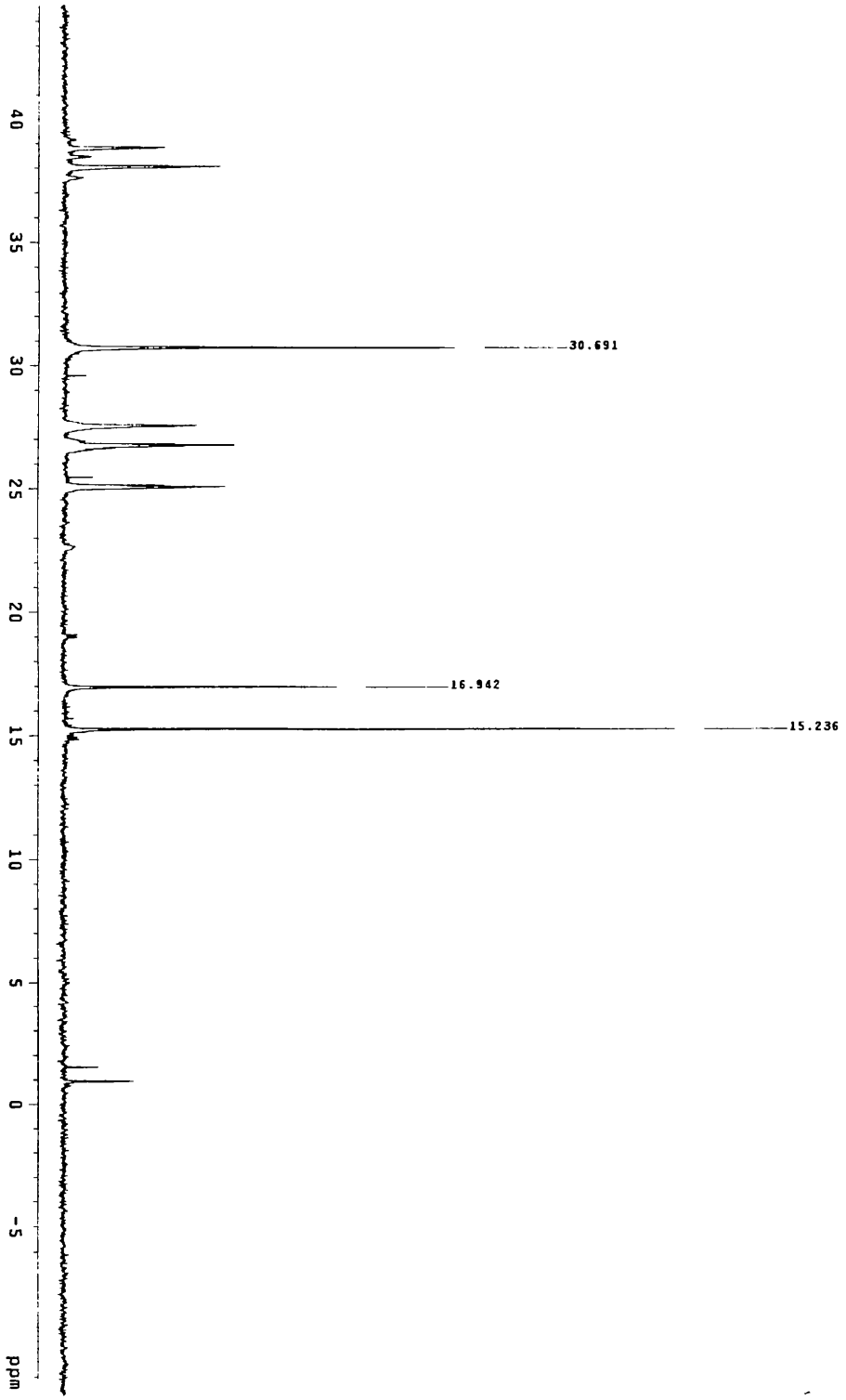
Spectrum 16. ^{13}C-NMR of Compound 9



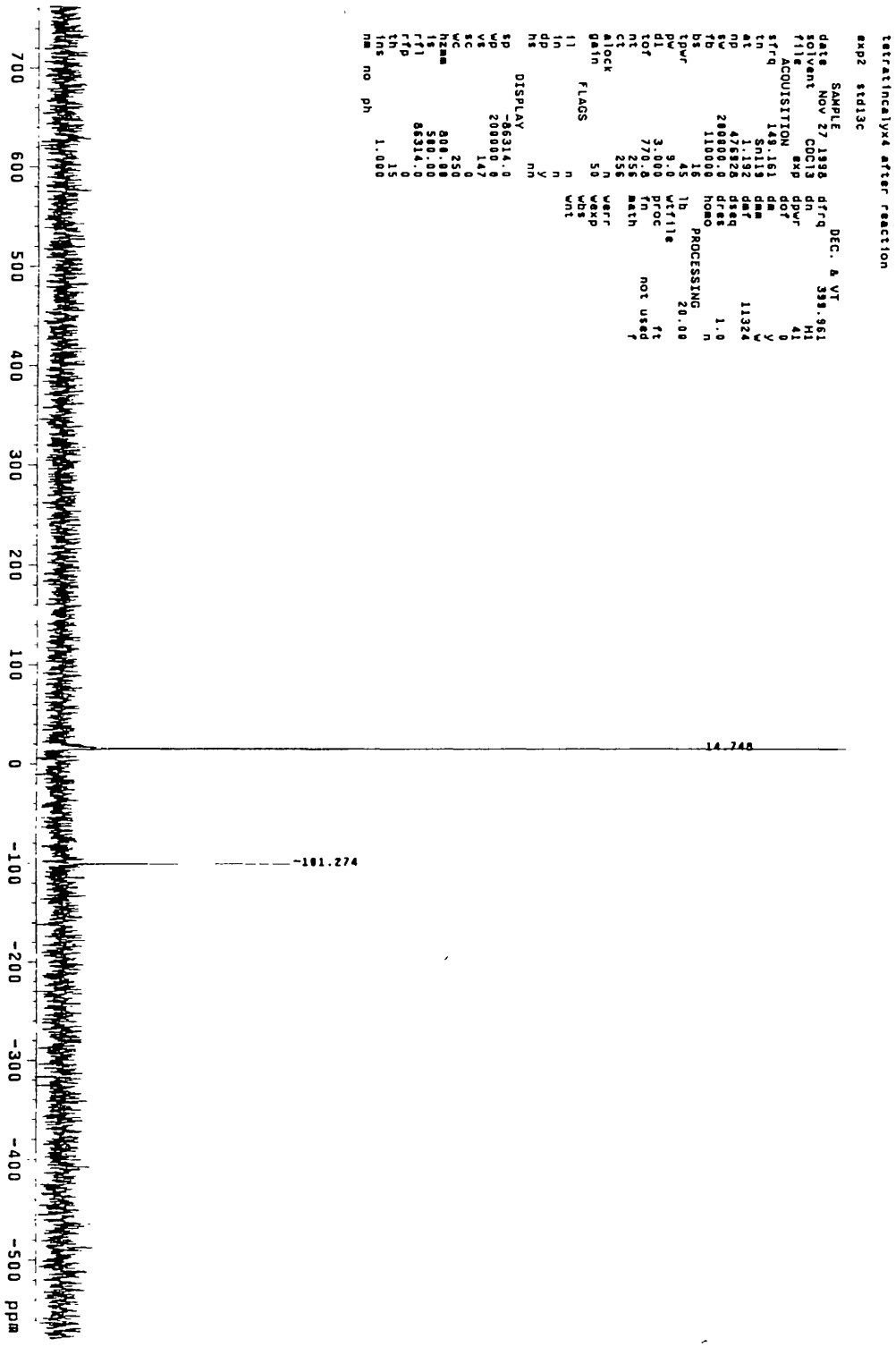
Spectrum 17. ^{13}C-NMR of Compound 9



Spectrum 18. ^{13}C-NMR of Compound 9



Spectrum 19. ^{119}Sn-NMR of Mixture of Compound 8 and 9



Spectrum 20. ^{119}Sn-NMR of Compound 9