



Synthesis of novel homochiral phosphine ligands  
by Meiqun Jiang

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in  
Chemistry

Montana State University

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Abstract:

Chiral phosphine ligands are of key importance in development of transition-metal catalysts for enantioselective reactions. Yet, despite the critical importance of P-chiral phosphines, the methodology for their enantioselective synthesis in high enantiomeric excess and without resolution or separation of diastereomers remains relatively undeveloped. We describe herein an effective enantioselective synthesis of chiral tertiary phosphines. This methodology shows promise for the synthesis of a wide range of monophosphines and diphosphines of high enantiomeric purity and could be useful for the asymmetric reactions,

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A thesis submitted in partial fulfillment  
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in

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April 1994

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**APPROVAL**

of a thesis submitted by  
Meiqun Jiang

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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**ABSTRACT**

Chiral phosphine ligands are of key importance in development of transition-metal catalysts for enantioselective reactions. Yet, despite the critical importance of P-chiral phosphines, the methodology for their enantioselective synthesis in high enantiomeric excess and without resolution or separation of diastereomers remains relatively undeveloped. We describe herein an effective enantioselective synthesis of chiral tertiary phosphines. This methodology shows promise for the synthesis of a wide range of monophosphines and diphosphines of high enantiomeric purity and could be useful for the asymmetric reactions.

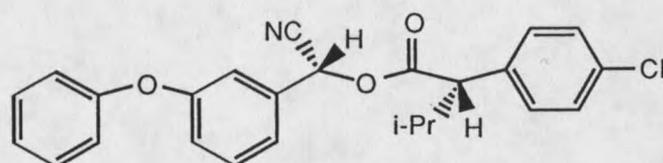
## INTRODUCTION

### Introduction to Enantioselective Catalysis

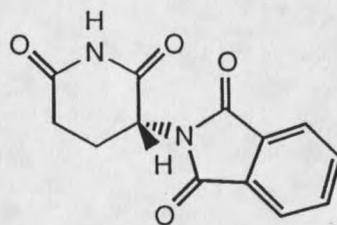
Chirality plays a central role in science and technology. A wide range of significant physical, chemical, and biological functions are generated through precise molecular recognition which requires strict matching of chirality. For a long time, access to enantiomerically pure compounds, at least in a practical sense, was thought to be nature's monopoly. Living organisms are masters of enantioselective catalysis. In general, when a living cell manufactures a chiral organic molecule, it selectively produces only one of the two non-superimposable mirror-image forms (enantiomers). To do otherwise is at best inefficient. Biocatalyst (enzymes and ribozymes) promote the chemistry of life with exquisite efficiency and selectivity.

Synthetic chemists have been slow to learn from nature's model. Creation of optically active organic molecules by chemical means is challenging and difficult. Only optical resolution and structural modification of naturally occurring chiral substances provide in this respect. Until recently, it was common practice for a pharmaceutical company to market a chiral drug as the racemate.<sup>1</sup> As recently as 1985, more than 75% of chiral drugs were sold as the racemates. This approach in effect meant that each dose of a drug was contaminated with an equal weight of an isomer, which usually had no therapeutic value but had the potential to cause unsuspected deleterious side effects. For example, the sedative thalidomide (**1**) was marketed as a

racemate,<sup>2</sup> the desired sedative activity resides in the R-isomer, but the contaminant S-isomer is a teratogen, causing profound birth defects in babies born to mothers using the drug. The issue of enantiomeric purity is by no means limited to the field of pharmaceuticals. A case in point is ASANA (i-Pr=isopropyl),<sup>3</sup> a synthetic pyrethroid insecticide which contains two asymmetric centers(2).



ASANA 2



Thalidomide 1

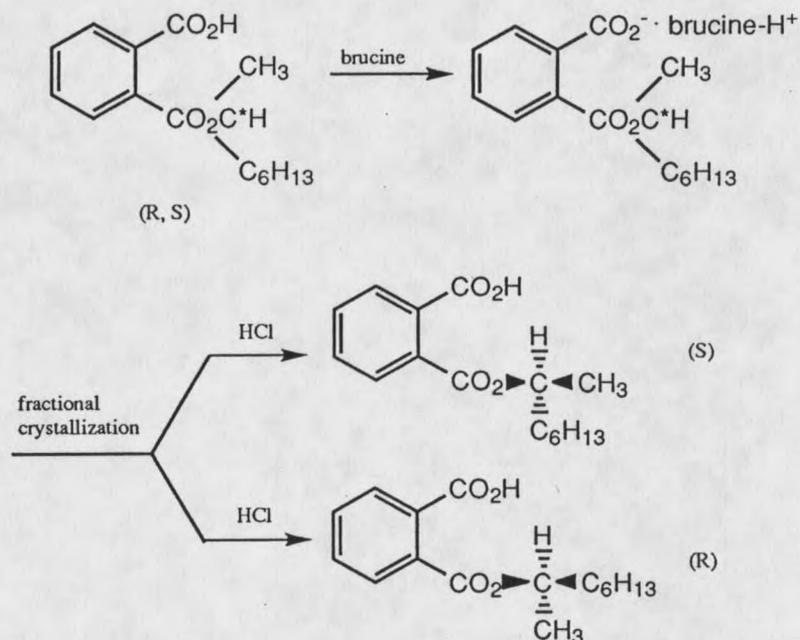
The potent insecticide activity overwhelmingly resides in just one of the four possible stereoisomers. Moreover, the non-insecticidal stereoisomers exhibit significant cytotoxicity toward certain plant species. Thus ASANA, which is sold as a single stereoisomer, can be registered and used for crops whereas the mixed stereoisomers are not suitable. Due to the need for chiral liquid crystals, enantiomerically pure polymers, and membrane components with applications in such diverse areas as drug delivery, separation technology, and

optoelectronics, it is easy to understand the growing demand for efficient methods of producing enantiomerically pure compounds.

Assiduous efforts made by synthetic organic chemists in the last two decades are converting the chemist's dreams into reality. In order to maximize synthetic efficiency, it is obviously desirable to utilize a catalytic amount of chiral source for "multiplication of chirality", namely, stereoselective production of a large quantity of a chiral target compound. Enantioselective catalysis is bringing about a revolution in asymmetric synthesis. Seldom has there been an area of chemistry where the scientific goals are so challenging and the economic benefits so obvious.

In the past, the selling of a racemic product could be defended on the grounds that the cost of manufacturing a single isomer could be prohibitive. Today, improvements in the technology for asymmetric synthesis, including the development of enantioselective catalysts based on metal complexes, make the development of new racemic drugs unacceptable. Asymmetric synthesis has advanced to the point where it should be possible to manufacture any drug as a single enantiomer.

Conventional methods of asymmetric synthesis rely on the stoichiometric use of enantiomerically pure starting materials or reagents. In resolution by differential crystallization,<sup>4</sup> a racemic-product mixture can be converted into a separable mixture of diastereomers by the use of a stoichiometric amount of an optically pure resolving agent (Scheme 1). This method, however, requires recovery of the resolving agent and wastefully consumes precious starting materials to make the wrong enantiomer, which must then be racemized or discarded.



Scheme 1. Conventional methods of making the chiral molecules

Perhaps the most important advantage of enantioselective catalysis, versus conventional stoichiometric procedures, is the feature of chiral multiplication. Under the right conditions, thousands of chiral product molecules can be produced by one molecule of catalyst.

Chiral multiplication is a characteristic of both biocatalysis and catalysis by chiral metal complexes. Recently, enantioselective catalysis using metal complexes has advanced to the point where it can often provide a viable alternative to biocatalysis. The strengths of metal catalysts tend to complement those of enzymes:

- (i) metals can promote reactions not known to occur in nature;
- (ii) the chirality of the catalyst is easily modified by appropriate changes in the ligands;
- (iii) one can use substrates not accepted by enzymes;
- (iv) separation and recovery of products are relatively easy (enzymes

most often work in aqueous or near aqueous environments);

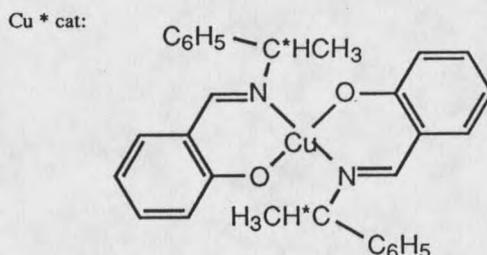
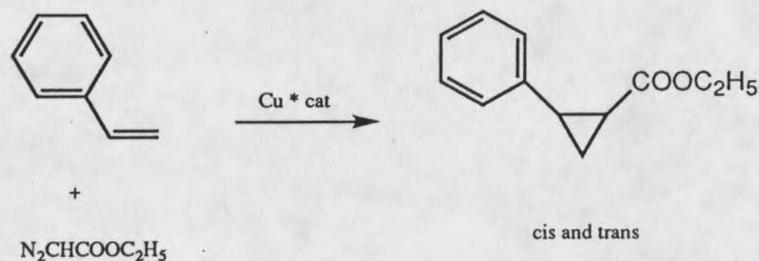
- v) organometallic reagents are generally less capricious than enzymes, which are often susceptible to degradation caused by heat, oxidation, and pH.

Enantioselective catalysis using metal complexes, provides one of the most general, flexible methods for asymmetric reactions. Metallic elements possess a variety of catalytic activities, and permutation of organic ligands, or auxiliaries, that direct the steric course of the reaction is practically unlimited. Besides the choice of central metal, molecular design of the chiral modifier is a particularly significant task. Efficient ligands must be endowed with a suitable functionality, an appropriate element of symmetry, substituents capable of differentiating space either sterically or electronically, skeletal rigidity or flexibility (depending on the nature of the reaction) etc. - all of which contribute to accomplish highly enantioselective catalysts.

### Chiral Phosphine Ligands

The first example of asymmetric synthesis from prochiral compounds catalyzed by homogeneous chiral metal complexes appeared in the literature in 1966.<sup>5</sup> A chiral Schiff base-Cu(II) complex was formed to catalyze decomposition of ethyl diazoacetate in styrene to give cis- and trans-1-carboethoxy-2-phenylcyclopropane in <10% e.e, proving the existence of reactive Cu carbenoid placed in a chiral environment (Scheme 2).

Later, extensive systematic screening of chiral Schiff bases resulted in a dramatic improvement of the optical yield of cyclopropanation, allowing for asymmetric synthesis of chrysanthemic acid derivatives in up to 94% e.e.<sup>6</sup>

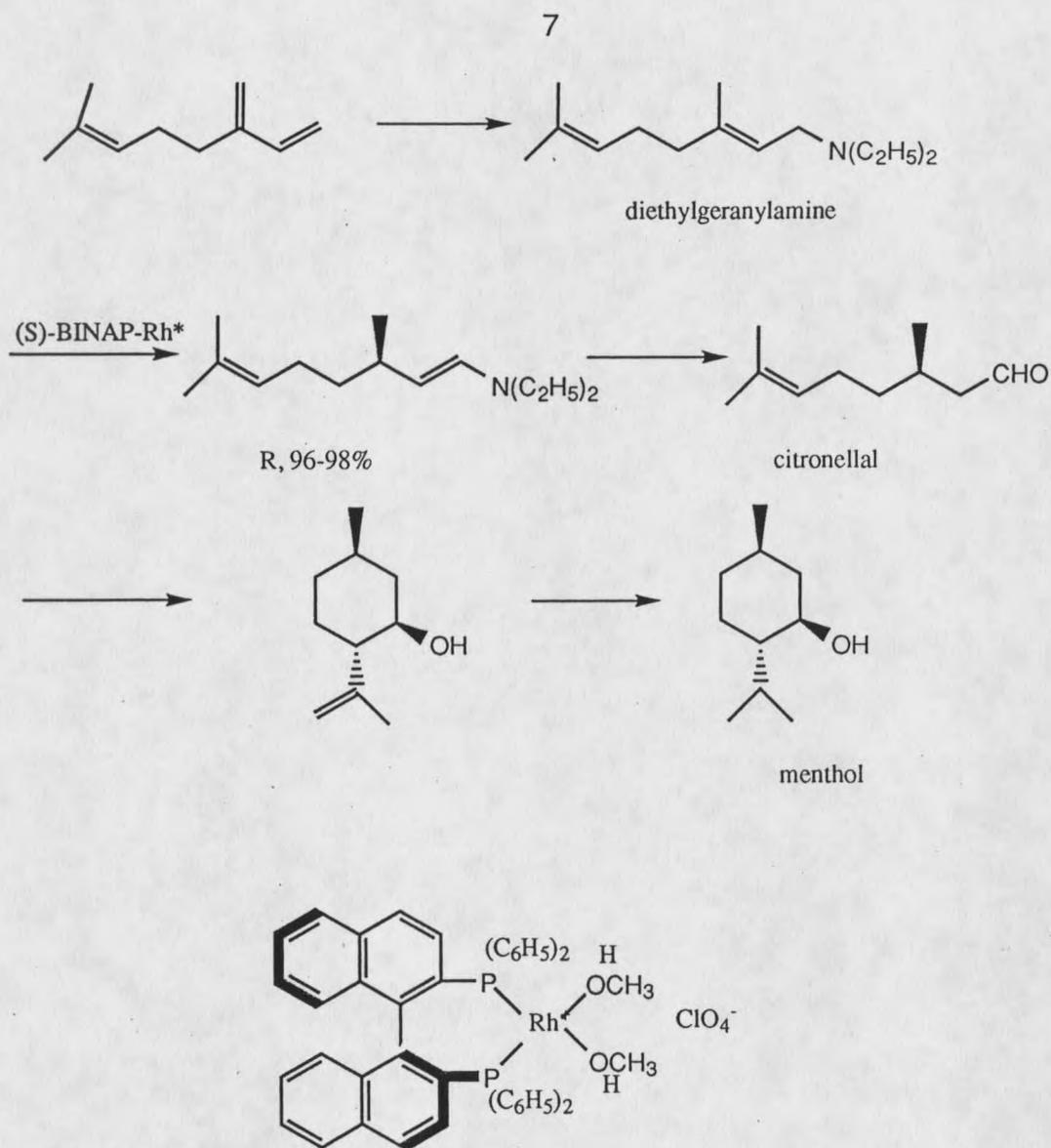


Scheme 2. Chiral Schiff base-Cu(II) complex

Perhaps the most common asymmetric catalyst used by industry at this time is utilized in the synthesis of (-)-menthol (Talasage International CO, Japan)<sup>7</sup> (Scheme 3). The key step is the Rh-BINAP catalyzed enantioselective isomerization of diethylgeranylamine to citronellal diethylenamine proceeding in 96-98% optical yield. Here, use of an atropisomeric BINAP ligand has played a key role in the successful asymmetric transformation.

Another significant development in organotransition-metal chemistry is the discovery of soluble complexes which catalyze the asymmetric hydrogenation of prochiral olefins<sup>8</sup> (Scheme 4). These asymmetric reactions are achieved by homogeneous catalysts bearing chiral phosphine ligands.

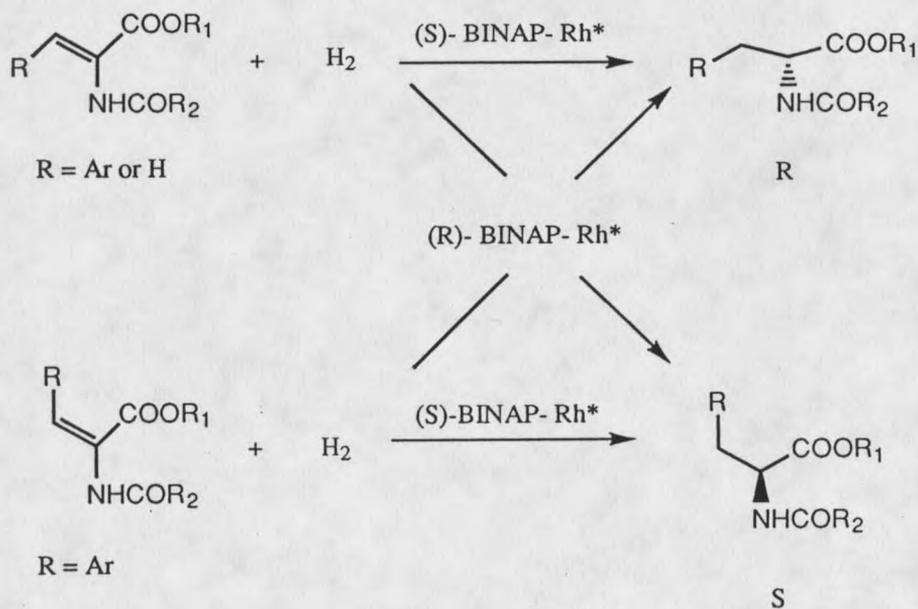
Chiral phosphines have been widely used as ligands for transition metals such as nickel, cobalt, rhodium, ruthenium, platinum, palladium and copper. These metal-chiral phosphine complexes have been used in the study of asymmetric reactions, such as reductions of ketones,<sup>9</sup>



Scheme 3. Synthesis of (-)-menthol using the BINAP

hydrosilylations,<sup>10</sup> hydroformylations,<sup>11</sup> hydrocyanations,<sup>12</sup> and [4+2] cycloadditions.<sup>13</sup> The synthesis of well designed phosphine ligands is crucial to the development of efficient asymmetric catalysis by chiral transition-metal complexes.

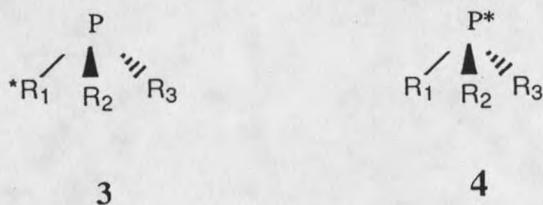
Chiral phosphines can be divided into two broad classes: monophosphine and bidentate phosphine ligands.



Scheme 4. Asymmetric hydrogenation of olefins by Rh-BINAP

### A. Monophosphines

There are basically two ways to design chiral monophosphines; the chirality can be located on either the side chain (**3**) or on phosphorus (**4**) (P-chiral) (Scheme 5).

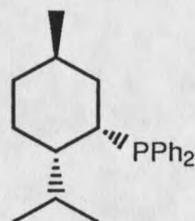


Scheme 5. Main types of chiral monophosphines

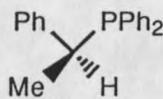
#### A1. Monophosphines with a Chiral Side Chain

Phosphines of the general type (**3**) (Scheme 5) are the easiest to obtain because their syntheses typically begin from a chiral natural product. Some

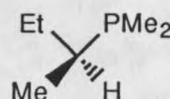
examples are depicted below (5)<sup>14</sup> (6)<sup>15</sup> (7)<sup>16</sup>:



5 (nmdpp)



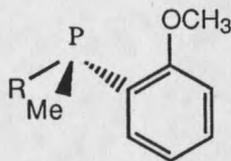
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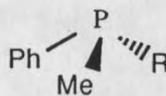
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### A2. Monophosphines with an Asymmetric Phosphorus Center

Optically active phosphines of type (4) (Scheme 5) were first used in asymmetric hydrogenation.<sup>17</sup> Representative P-chiral phosphines are as follows (8)<sup>18</sup> and (9)<sup>19</sup>:



8 R = Ph (pamp)

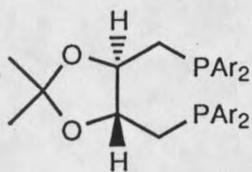


9 R = Et, n-Pr, CH<sub>2</sub>Ph,  
CH<sub>2</sub>CHCH<sub>2</sub>, t-Bu

### B. Bidentate Phosphines

The chelation of the ligand on a metallic center can occur through a chiral group connecting two achiral phosphorus atoms (10)<sup>20</sup> and (11)<sup>21</sup>. Within this class, the majority of members possess a stereogenic center, plane, or axis as an intrinsic component of the P-P linking backbone. Normally the two remaining substituents at phosphorus are aryl residues (commonly PPh<sub>2</sub>),

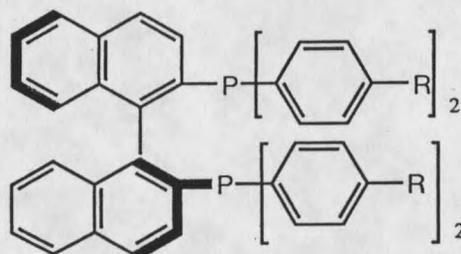
although other combinations including alkylphosphines<sup>22</sup>, alkyl(aryl)phosphines<sup>23</sup> and phospholanes<sup>24</sup> have been utilized to good effect.



**10** Ar = Ph (R,R-diop)

Ar = 2-anisyl

Ar = 3,5-dimethylphenyl

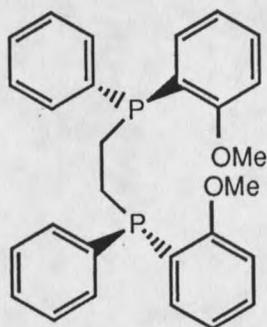


**11** R = H (binap)

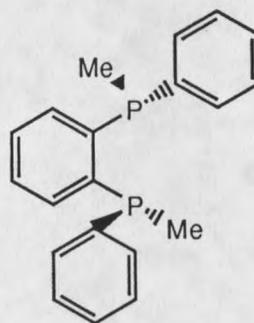
R = Me

R = t-Bu

Another type of bidentate chiral phosphine consists of two chiral phosphorus atoms connected by achiral backbone (**12**)<sup>25</sup> and (**13**)<sup>26</sup>. Examples of this class are relatively rare, due to the synthetic difficulty of controlling stereogenicity at phosphorus.



**12** (dipamp)



**13**

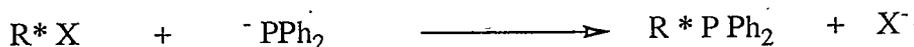
One important objective in designing bidentate chiral phosphine ligands is to keep a suitable distance between the two chelating points in order to obtain a suitable chelate ring size. If the chelate ring is too large, the ligand will have a tendency to complex in a monodentate fashion or form a bridge between metals.

### Preparation of Chiral Phosphines

#### A. Monophosphines

##### A1 Monophosphines with a Chiral Side Chain

Phosphines of the general type (3) (Scheme 5) are among the most easy to obtain because the synthesis can start from a chiral natural product (e.g. a terpene, sugar, etc.). The most frequent way to introduce phosphorus is to treat the tosylate (or halide) of the optically active compound (available from the chiral pool) with the diphenylphosphide anion,  $^-PPh_2$  (Scheme 6):



Scheme 6. Route to monophosphines with a chiral side chain

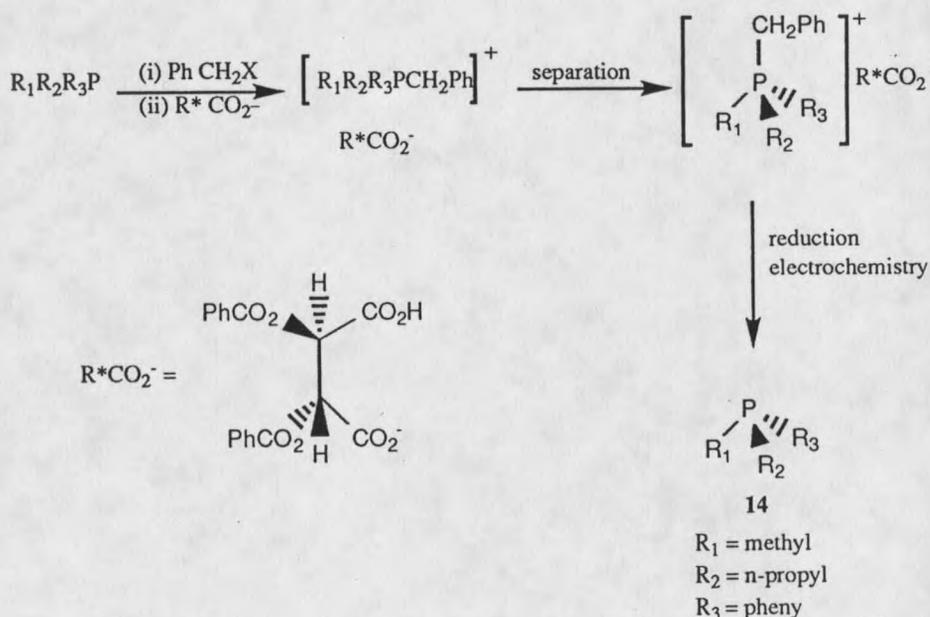
##### A2 Monophosphines with an Asymmetric Phosphorus Center

Optically active phosphines of type (4) (Scheme 5) were first used in asymmetric hydrogenation.<sup>17</sup> There are three main transformation methods giving access to P-chiral phosphines:

- electrolytic hydrogenolysis of chiral phosphonium salts;
- reduction of chiral phosphine oxides;
- displacement of diheterocyclic phosphines

### 1. Electrolytic Hydrogenolysis of Chiral Phosphonium Salts

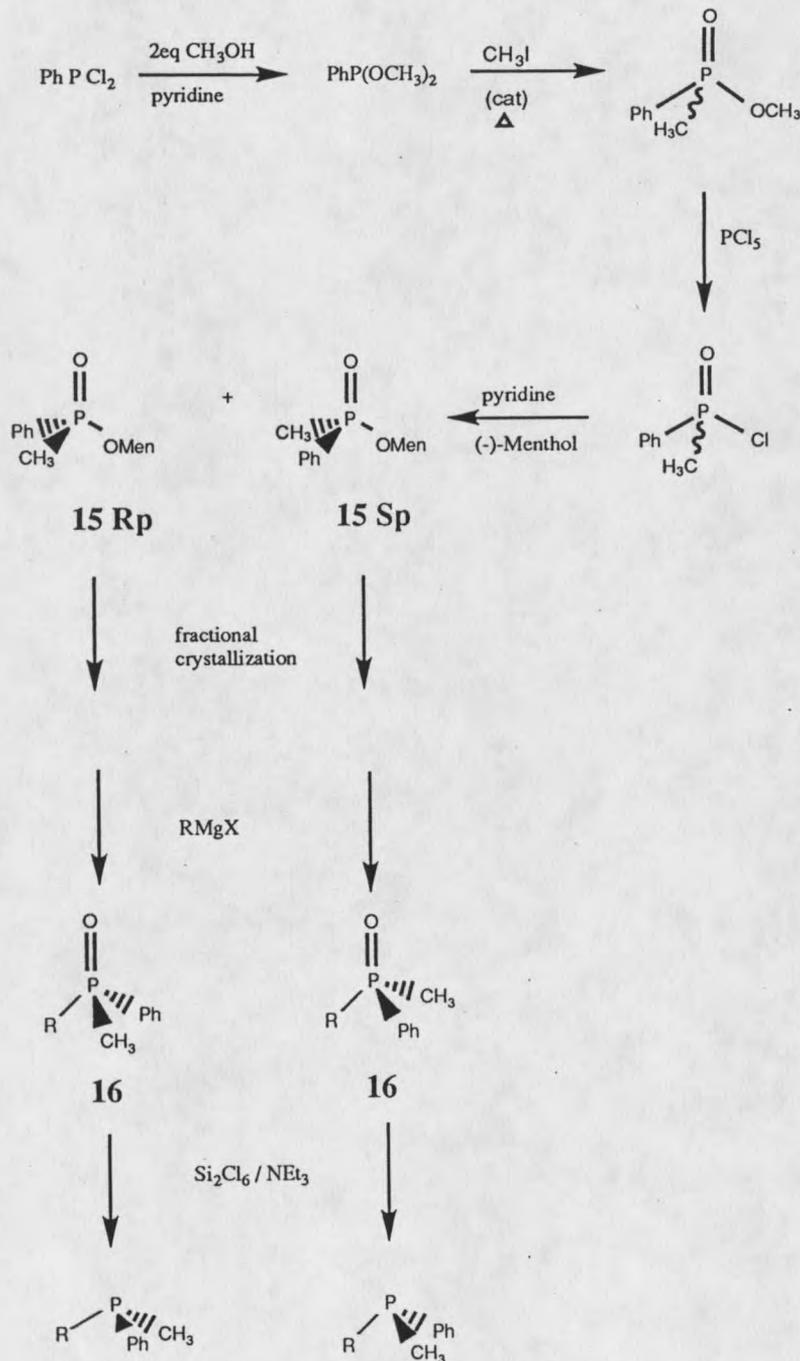
The first optically active phosphine in which the phosphorus atom is the asymmetric center in the molecule was described in 1911 by Meisenheimer and Lichtenstadt.<sup>27</sup> It was not until 50 years later that optically active phosphines could be routinely prepared, due to the efforts of Horner and Mentrup.<sup>28</sup> For example, methyl n-propylphenylphosphine **14** was obtained by electrolytic hydrogenolysis of its optically active benzylphosphonium salt (Scheme 7).



Scheme 7. Electrochemical preparation of chiral phosphines

### 2. Reduction of Phosphine Oxides

In 1968, a new method to create asymmetric phosphorus atoms was introduced by Mislow.<sup>29</sup> This approach was based on a simple observation that the diastereomeric O-menthylphosphinate **15** (*Rp*) and **15** (*Sp*) could be separated by fractional crystallization (Scheme 8).

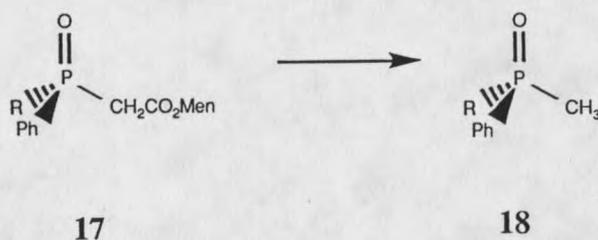


Scheme 8. Synthesis of chiral phosphines by Mislow and coworkers

The two diastereomeric phosphinates derived from the esterification of

(-)-menthol with  $\text{Ph(R)PCl}$  were separated (the most tedious step of the method). Displacement of the menthol group by an arylmagnesium halide occurred with inversion of configuration, giving (16) and its diastereomer. Reduction of the phosphine oxide by  $\text{Si}_2\text{Cl}_6$  produced the related optically active phosphine with complete inversion of configuration.<sup>29b</sup> It had been observed that the combined reagent  $\text{HSiCl}_3\text{-Et}_3\text{N}$  was not stereoselective for phosphine oxide reduction whereas  $\text{PhSiH}_3$  gave mainly retention of configuration.<sup>29c</sup> Therefore,  $\text{Si}_2\text{Cl}_6$  seemed to be the most useful reagent for the stereospecific transformation of a phosphine oxide into a phosphine. This work led directly to the synthesis of the ligand DIPAMP {(*R,R*)-1,2-bis-[O-methoxyphenyl(phenyl)phosphino] ethane} **12** by Monsanto.<sup>25</sup>

Pietrusiewicz<sup>30</sup> and Imamoto<sup>31</sup> prepared the vinyl and tert-butyl phosphine oxide (**18**) by separation of (**17**) followed by decarboxylation (Scheme 9).

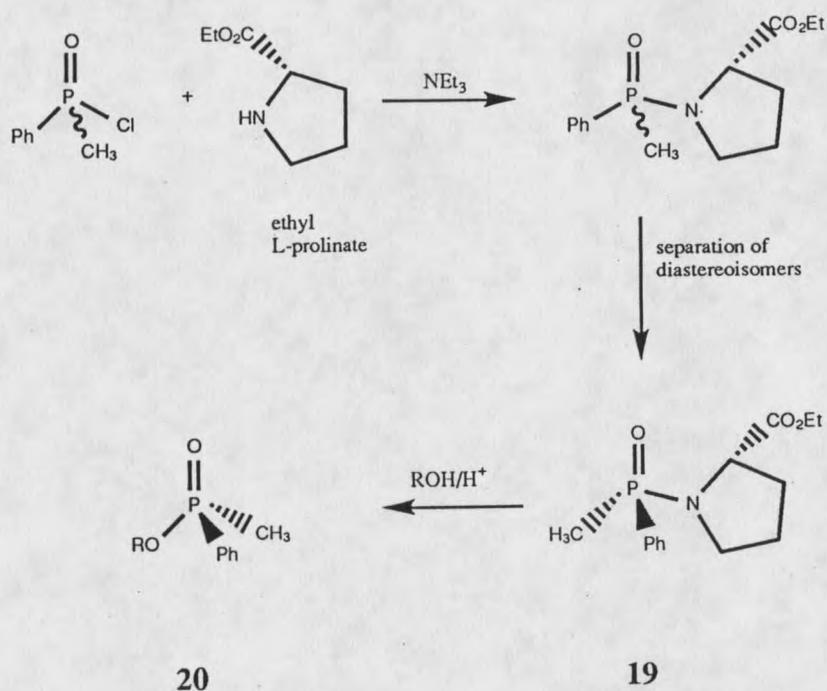


a) R = vinyl: (LiCl; H<sub>2</sub>O; DMSO)/180°C

b) R = t-Bu: (i) KOH (ii) 160°C

Scheme 9. Synthesis of phosphine oxides by Pietrusiewicz and Imamoto

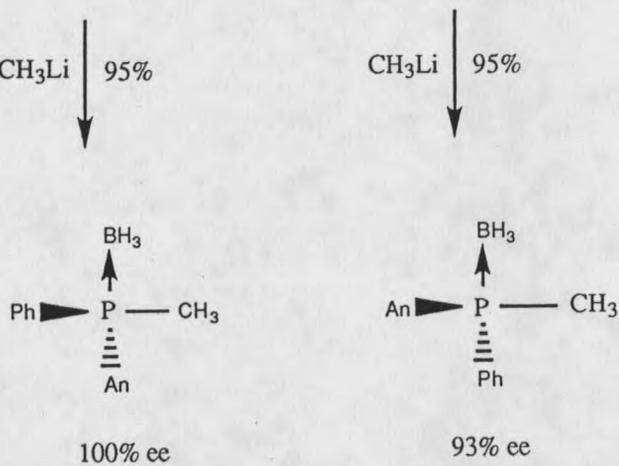
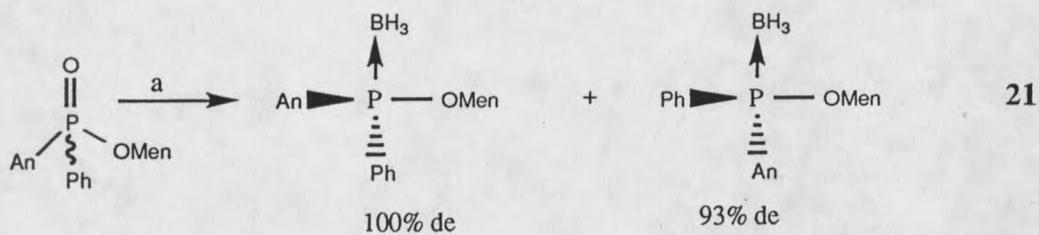
In 1979, Koizumi and Coll<sup>32</sup> used this method to synthesize the phosphinate (**20**) by methanolysis of intermediate phosphinamide (**19**), derived from ethyl L-prolinate (Scheme 10).



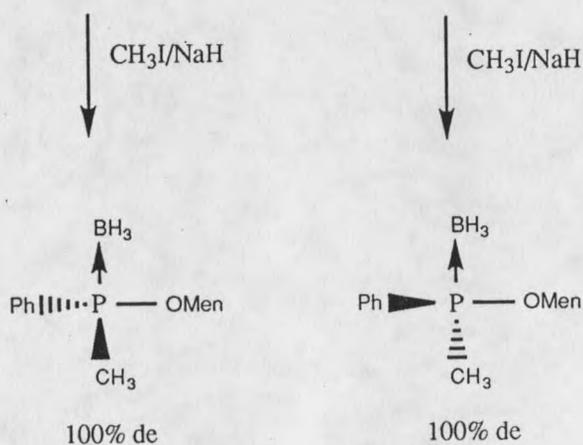
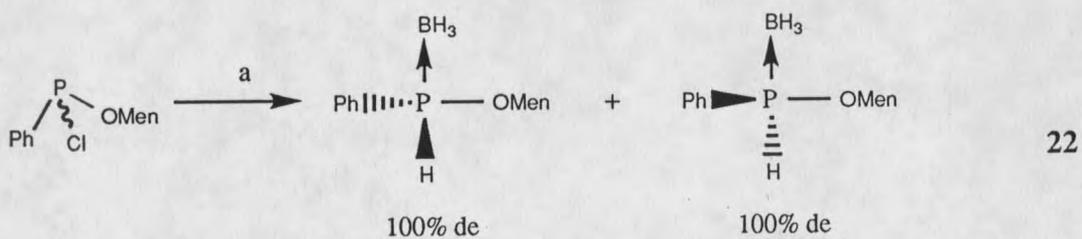
Scheme 10. Synthesis of phosphinates by Koizumi and Coll

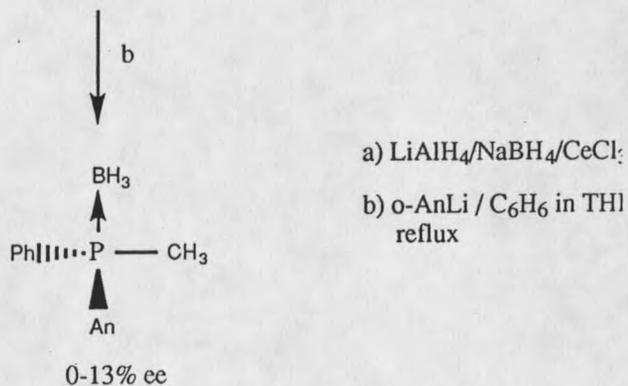
Recently, Imamoto<sup>33</sup> described a new approach to prepare chiral phosphines. The diastereomerically pure menthyloxyphenylphosphineboranes (**21**) and (**22**) were prepared from their phosphine oxides on treatment with  $\text{LiAlH}_4\text{-NaBH}_4\text{-CeCl}_3$  (Scheme 11).

The method for the preparation of optically pure phosphines via reduction of a phosphine oxide generally involves a diastereomeric separation, low overall yields, and is not adaptable to the modification of substituents on the phosphorus atom.



a)  $\text{LiAlH}_4/\text{NaBH}_4/\text{CeCl}_3$

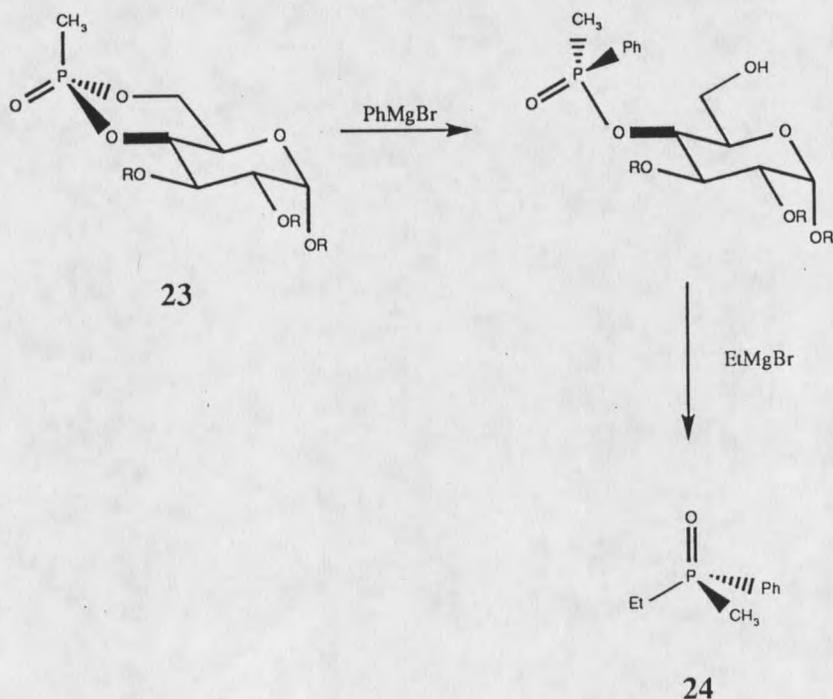




Scheme 11. Synthesis of phosphine borane complexes

### 3. Displacement of Diheterocycle Phosphines (Oxazaphospholidine, Oxaphosphorinane)

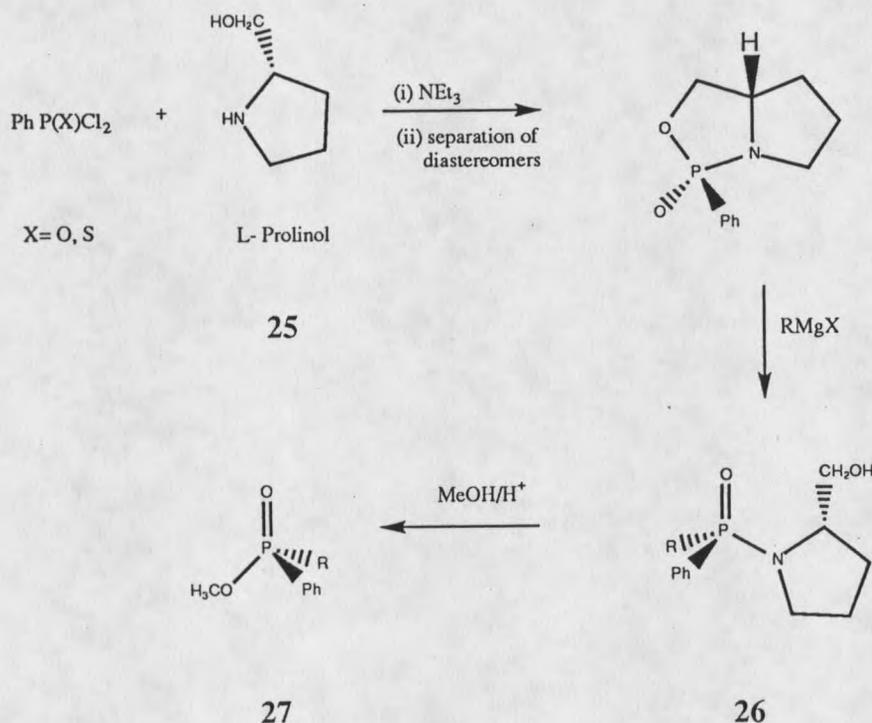
In 1974, Inch and Coll<sup>34</sup> proposed a new way to synthesize chiral phosphine oxides (Scheme 12).



Scheme 12. Synthesis chiral phosphine oxides by Inch and Coll

The dioxaphosphorinane (**23**) was diastereoselectively formed by starting with a carbohydrate derivative. Sequential addition of phenylmagnesium bromide and ethylmagnesium bromide afforded phosphine oxide (**24**), which illustrated the utility of carbohydrates for stereospecific synthesis of optically active phosphates.

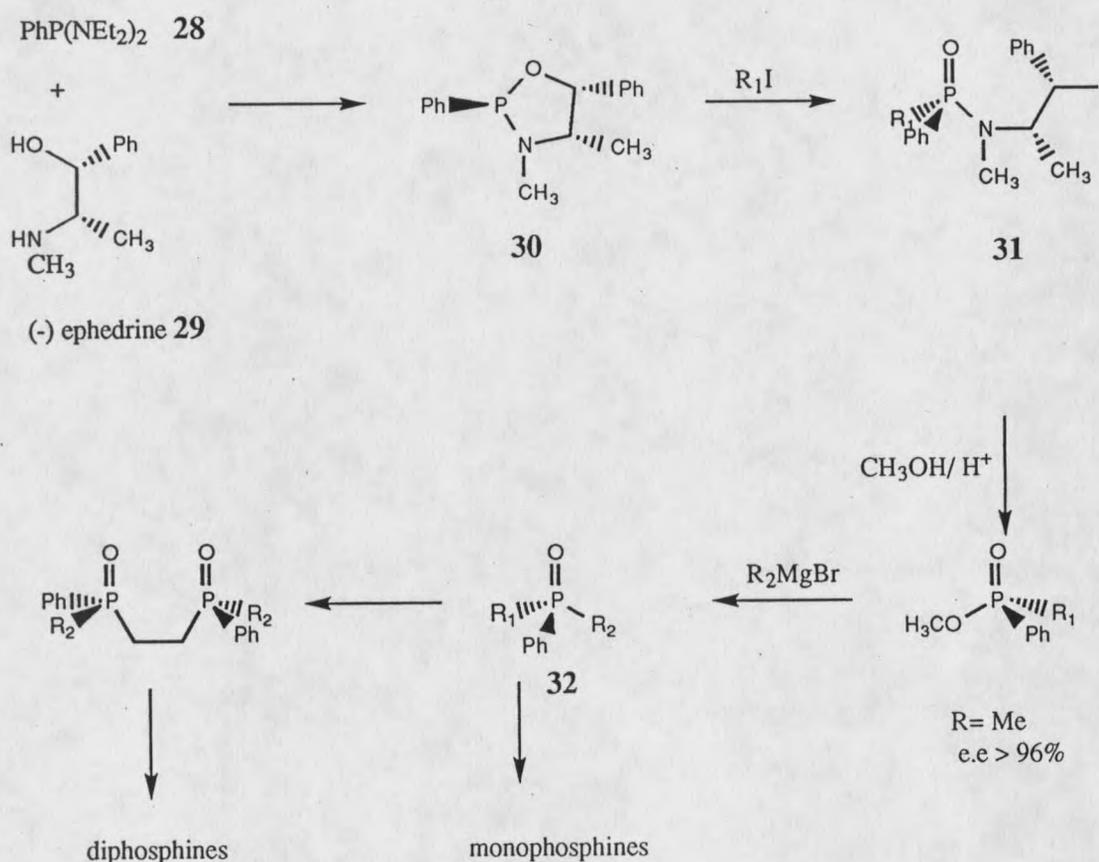
Using a related method, Koizumi and Coll<sup>35</sup> synthesized chiral phosphinate (**27**) by acid methanolysis of the phosphinamide (**26**), prepared by regio and stereoselective opening of oxazaphospholidine derived of L-prolinol **25** (Scheme 13).



Scheme 13. Synthesis of chiral phosphates from oxazaphospholidines

In the 1980's, Juge<sup>36</sup> and Brown<sup>37</sup> developed a new method for making

optically active phosphines (Scheme 14). This approach was based on the high diastereoselectivity observed in the formation of oxazaphospholidine (**30**) from ephedrine. Thus (**30**) reacted with MeI, EtI, or PrI to give (**31**) in a 9:1 ratio of diastereomers. The product (**31**) could be converted into diarylalkylphosphine oxides by successive acid-catalyzed methanolysis and Grignard displacement to give (**32**) in 95% e.e.

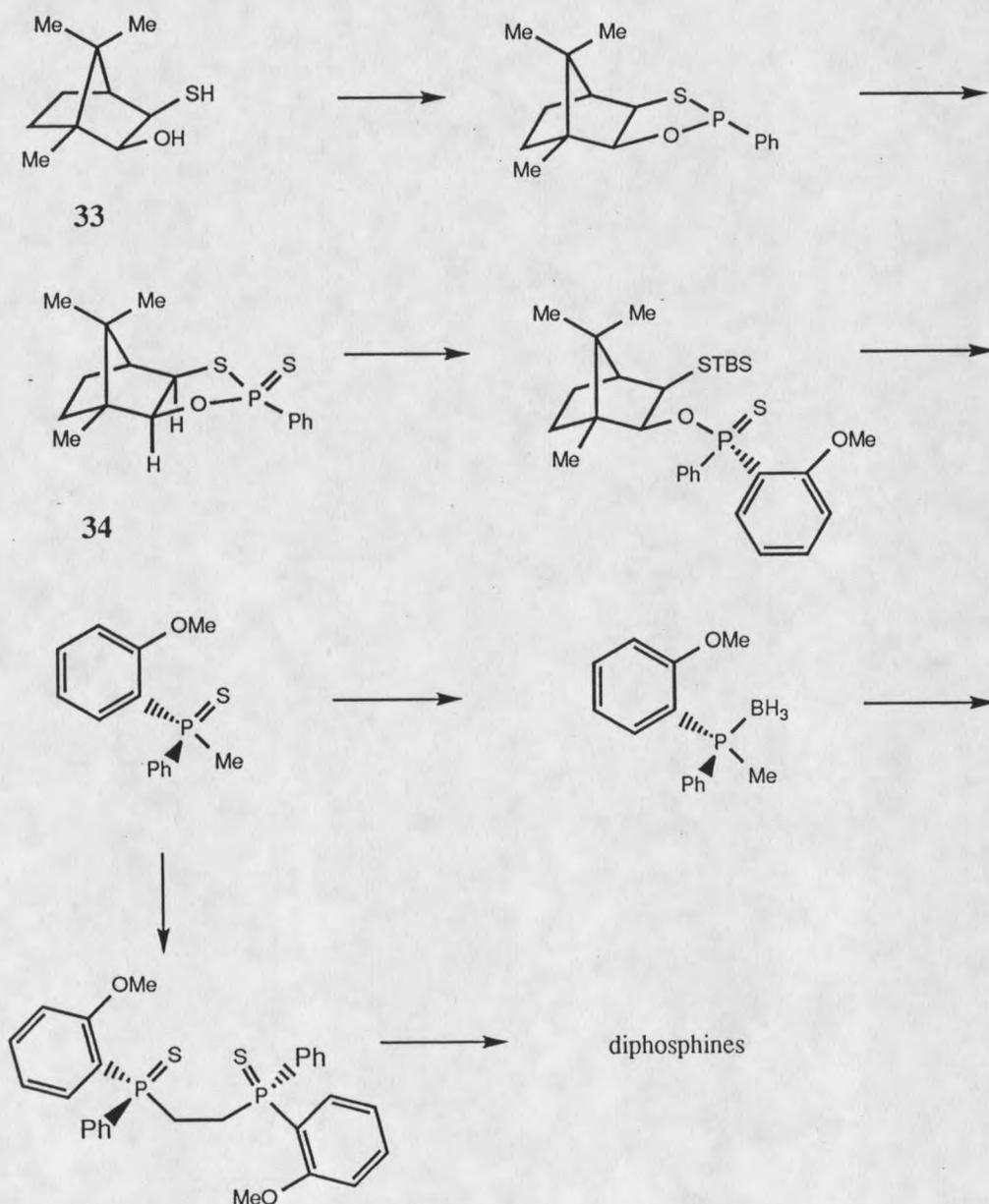


Scheme 14. Synthesis of chiral phosphine oxides by Juge and Brown

A crucial transformation that is commonly used in this method involves the thermal condensation of bis[diethyl(amino)phenyl] phosphine with (-)-ephedrine to give the corresponding oxazaphospholidine. It was quickly

determined, however, that the direct thermal condensation reaction involving (28) and (29) was a highly capricious and non-general reaction, it also gave poor yields (15-30%) along with large amounts of polar by-products.

Very recently, Corey<sup>38</sup> used a camphor derivative (33) formed a cyclic phospholidine intermediate (34) (Scheme 15).

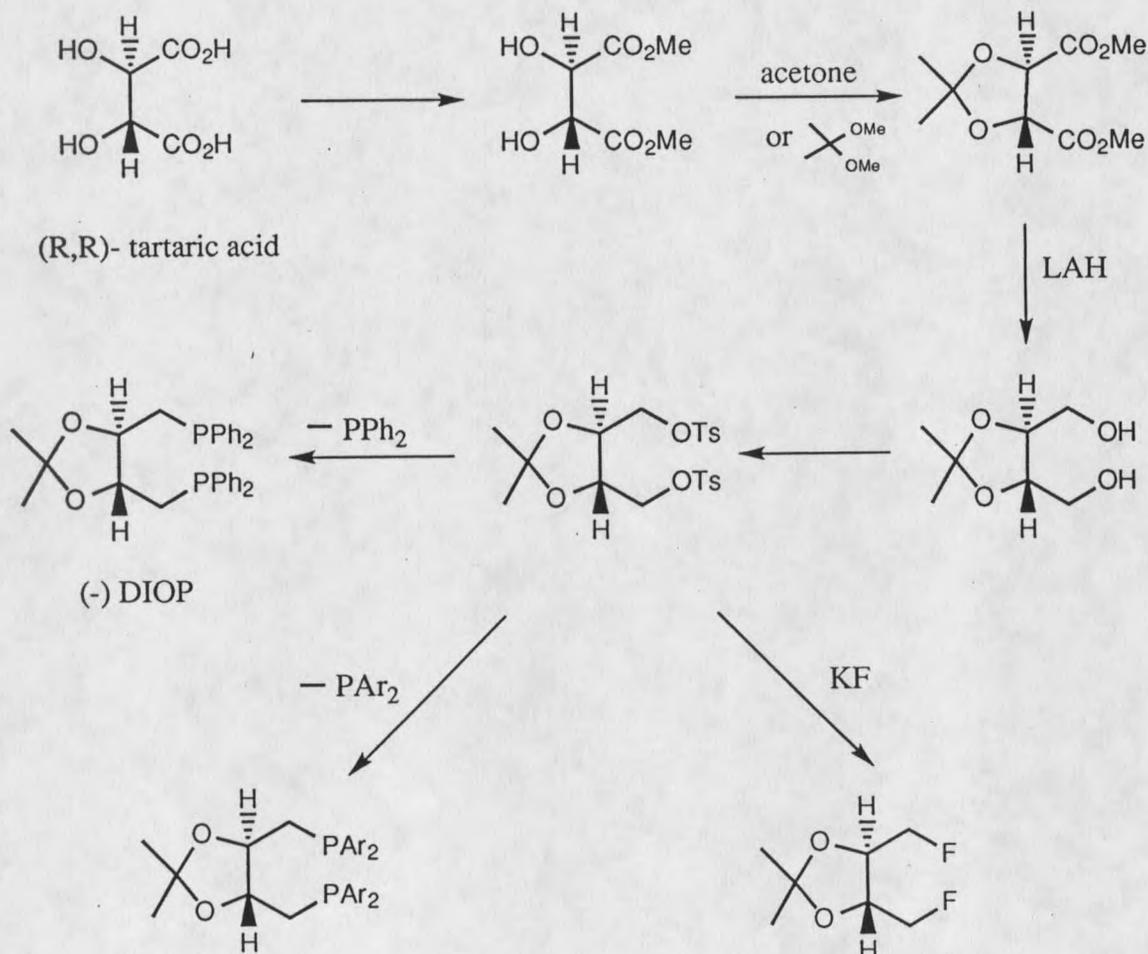


Scheme 15. Synthesis of chiral phosphine ligands by Corey

In this case, two heteroatoms attached to phosphorus can be displaced stereospecifically by nucleophilic aryl or alkyl groups.

### B. Diphosphines with a Chiral Group Connecting Two Achiral Phosphorus Atoms

This family of chelating ligands expanded rapidly during the last decade because of the very high enantiomeric excess often observed in various catalytic reactions that used them. They are also relatively easy to synthesize (Scheme 16).

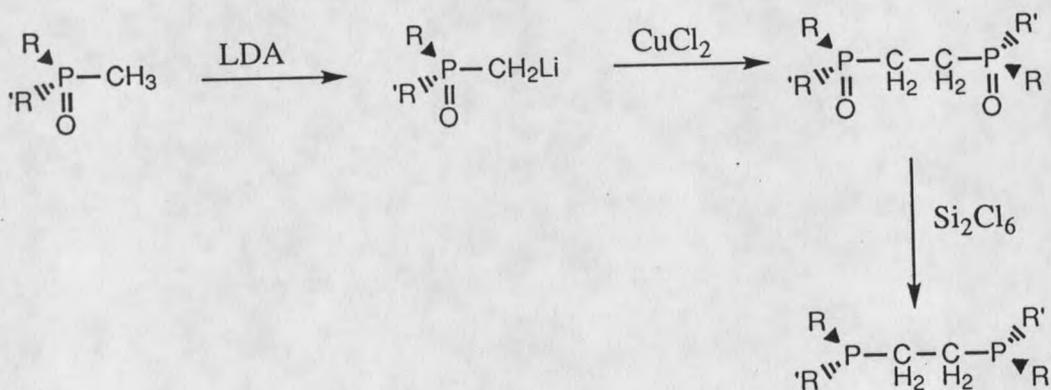


Scheme 16. Preparation of diphosphines with chiral carbon backbone

In many cases tedious resolutions could be avoided by starting with optically active natural products. Simple chemistry often allows easy introduction of the  $PR_2$  groups (usually as  $PPh_2$ ). The most common ligands are 1,4-diphosphines, 1,3-diphosphines, and 1,2-diphosphines.<sup>39</sup>

### C. Diphosphines with Chirality on Phosphorus

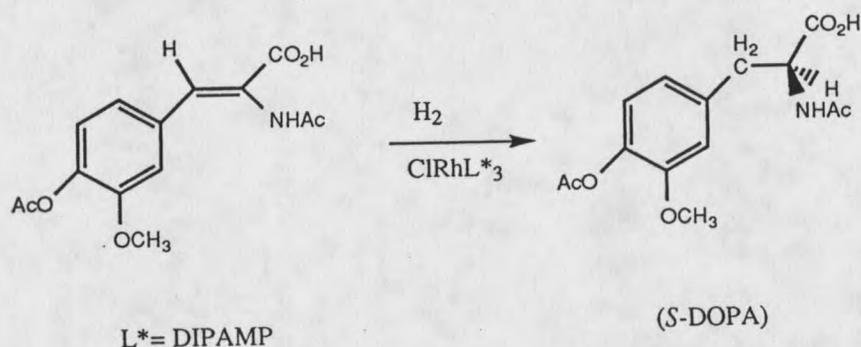
This family of chelating ligands consists of the two chiral phosphorus atoms which are separated by a carbon chain (X) of variable length:  $R(R')PXP(R'')R'''$ . The connecting chain (X) has to be of suitable length and geometry to allow chelation. Up to now 1,2-diphosphines were synthesized in which  $X = (CH_2)_2$ , 1,2- $C_6H_4$ , or *cis*- $CH=CH$ . In many cases the two phosphorus atoms are equivalent ( $R = R''$ ,  $R' = R'''$ ). The most general way to prepare chiral 1,2-diphosphines stereoselectively is the oxidative coupling of two chiral phosphine oxides<sup>40</sup> (Scheme 17).



Scheme 17. Preparation of diphosphine ligands by oxidative coupling

The stereochemistry at phosphorus during metallation and coupling is retained. By this method, Knowles made (*R, R*)-DIPAMP (**12**),<sup>25</sup> which is a very efficient rhodium catalyst for asymmetric hydrogenation and is used in industrial

asymmetric synthesis of (*S*)-DOPA, a drug for the treatment of Parkinson's disease (Scheme 18).



Scheme 18. Industrial use of Rh-DIPAMP to make (*S*)-DOPA

Hence, the immense potential that structurally varied homochiral mono- and biphosphine ligands hold for transition metal based asymmetric synthesis has recently stimulated renewed investigation into the synthesis of these compounds.

## RESULTS AND DISCUSSIONS

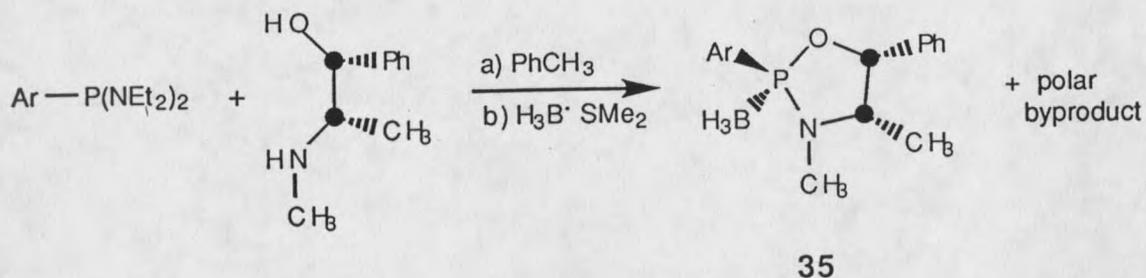
### Preparation of Homochiral Oxazaphospholidine Boranes

Progress in the development of transition-metal catalysts for enantioselective reactions, especially hydrogenation processes, heavily depends on the availability of suitable chiral phosphine or diphosphine ligands. Yet, despite the critical importance of P-chiral phosphines, the methodology for their enantioselective synthesis in high enantiomeric excess and without resolution or separation of diastereomers remains relatively undeveloped. Our goal is to develop an effective methodology for the synthesis of a wide range of chiral phosphines and diphosphines.

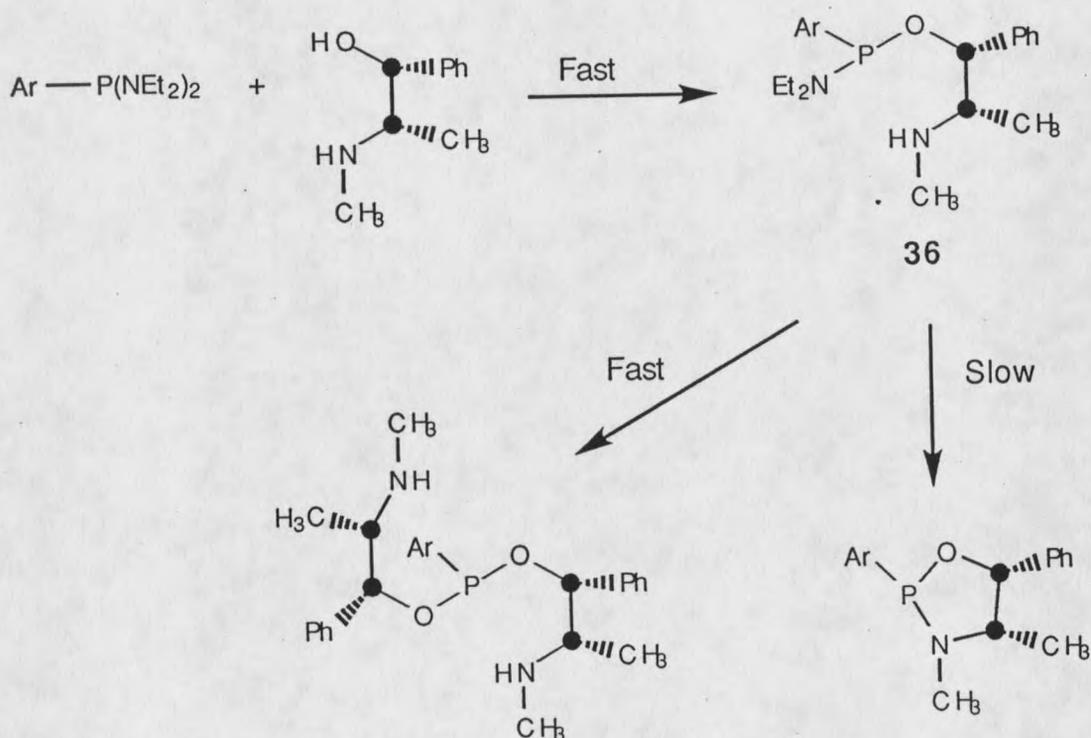
In 1990, Juge and coworkers reported a new approach for making chiral phosphine ligands.<sup>36</sup> One of the crucial steps in this approach is the diastereoselective synthesis of oxazaphospholidine boranes (**35**).

The diastereomerically pure complex (**35**) was prepared in one step from bis(diethylamino)phosphine, (-)-ephedrine and  $\text{BH}_3\text{-SMe}_2$  (Scheme 19). A direct thermal condensation was involved in this step. For most cases we studied, this reaction gave low yields (15-30%) along with large amounts of polar by-products.

We reasoned that the polar by-product was formed because the formation of the phosphorus-nitrogen bond was relatively slow, and the non-cyclized intermediate (**36**) can react with another (-)-ephedrine molecule to give dioxaphosphine products (Scheme 20).

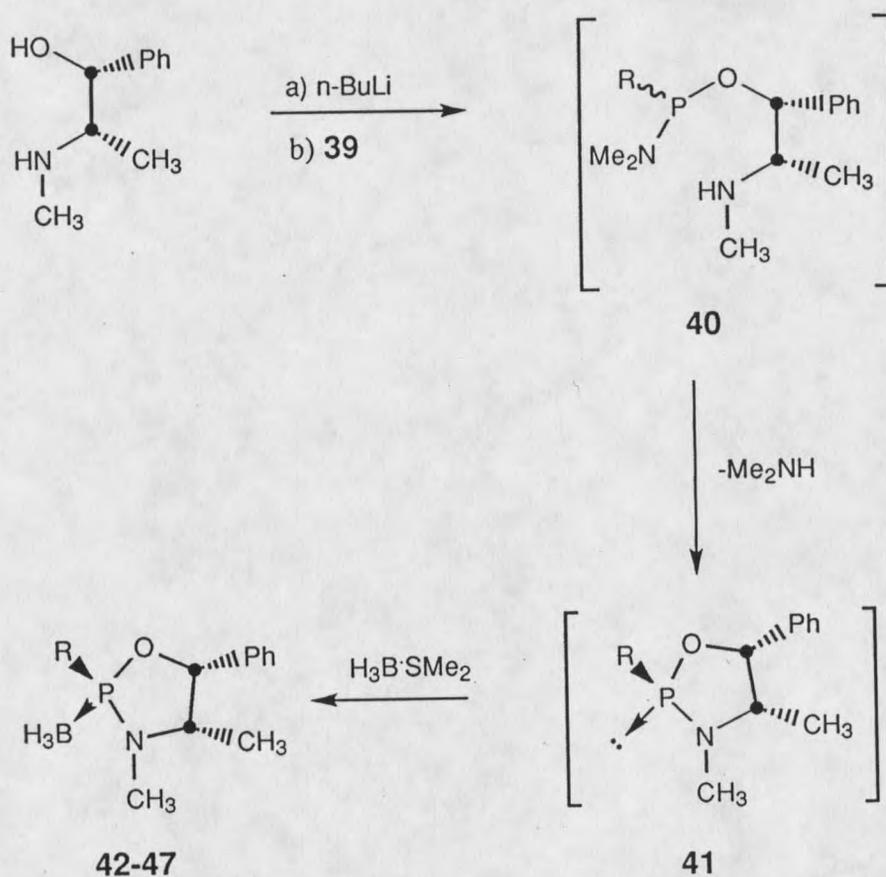
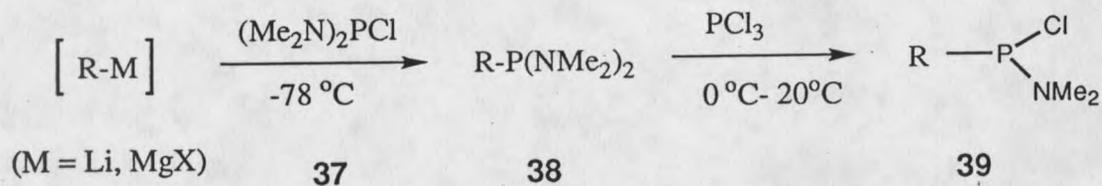


Scheme 19. Preparation of oxazaphospholidine boranes by Juge



Scheme 20. Formation of the polar by-products

In our strategy, an efficient “ionic” coupling reaction was employed to give the initial phosphorus-oxygen bond, followed by thermolytic ring closure. Using this strategy, we have made a range of electronically and sterically differentiated oxazaphospholidine boranes (**42-48**) (Scheme 21).



R = 2-(CF<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>; (**42**)

R = C<sub>6</sub>F<sub>5</sub>; (**43**)<sup>41</sup>

R = 4-(OCH<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>; (**44**)

R = 2-(CH<sub>3</sub>)-4-(OCH<sub>3</sub>)C<sub>6</sub>H<sub>3</sub>; (**45**)<sup>41</sup>

R = 2-(5-methylthienyl); (**46**)

R = cyclohexyl; (**47**)<sup>41</sup>

R = Ph; (**48**)

Scheme 21. Preparation of oxazaphospholidine boranes

Chloro-bis(dimethylamino)phosphine (37) was treated with an organolithium (or Grignard) reagent to give the bis(dimethylamino)phosphines (38). Exposure of (38) to 1.0 equiv of  $\text{PCl}_3$  gave the chloro(dimethylamino)phosphine (39). The addition of (39) to a solution of monolithiated (-)-ephedrine (in THF or 1,2-DME) afforded the non-cyclized phosphonamidates (40) which the P-O bond was formed by "ionic coupling". The reaction mixture was then heated at reflux for 12 h to furnish the cyclized products (41). Addition of 1.1 equiv of BMS *in situ* provided the desired complexes (42-48).

The amine exchange reaction that results in cyclization is acid catalyzed (in the form of ammonium salts). In cases where cyclization is sluggish, as shown by the absence of copious  $\text{Me}_2\text{NH}$  evolution, a few  $\mu\text{l}$  of  $\text{Me}_3\text{SiCl}$  may be added as a more powerful Lewis acid catalysis.

An indication of the preparative scope of the foregoing procedure is provided by the examples in Table 1.

Table 1. Isolated yields and melting points of oxazaphospholidine derivatives

compound	42	43	44	45	46	47	48
yield (%)	77	72	78	70	82	76	80
mp(°C)	106	104	82	100	76	99	107

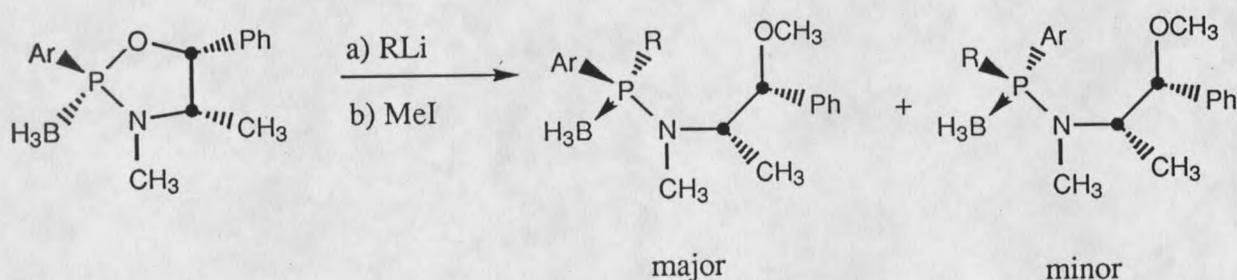
As can be seen from Table 1, the overall yields for this procedure are all in the range 70-82%, and seem to be relatively insensitive to both the electronic and steric effects of the substituent R. It is particularly worth mentioning that in this reaction sequence the borane group bonding with the phosphorous atom activates the adjacent group and at the same time it protects the phosphine

group which is generally sensitive to oxidation and electrophiles such as alkyl halides.

The new procedure used herein is characterized by its ease of execution and overall chemical efficiency. This new method permits the large scale preparation of a range of electronically and sterically differentiated homochiral monophosphine precursors.

Utilization of Oxazaphospholidine Borane Complexes in the Synthesis of Aminophosphine Boranes

Alkyl and aryllithium compounds reacted with oxazaphospholidine borane complexes at low temperatures (-78 °C) in THF, to give the corresponding aminophosphine boranes (**49-54**), by P-O bond cleavage, with a diastereomeric ratio better than 96:4 (Scheme 22).



Ar = 2-(CF<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>, R = Me; (**49**)

Ar = 4-(CH<sub>3</sub>O)C<sub>6</sub>H<sub>4</sub>, R = Me; (**52**)

Ar = 2-(CF<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>, R = Ph; (**50**)

Ar = Ph, R = Me; (**53**)

Ar = 2-(CF<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>, R = p-An; (**51**)

Ar = Ph, R = 2-(CH<sub>3</sub>O)C<sub>6</sub>H<sub>4</sub>; (**54**)

Scheme 22. Preparation of aminophosphine borane complexes

The complexes (49-54) are highly crystalline so that the separation of diastereomeric impurities at this stage by recrystallization is usually easy (e.g., methylcyclohexane). The reaction conditions and results are shown in Table 2.

Table 2. Results and conditions for preparation of aminophosphine boranes

Entry	Substrate	RM	Product	Temp (°C)	Diastere ratio
1	42	MeLi	49	-78	98:2
2	42	MeLi	49	-40	85:15
3	42	PhLi	50	-78	100:0
4	42	p-AnLi	51	-78	96:4
5	44	MeLi	52	-78	100:0
6	48	MeLi	53	-78	98:2
7	48	o-AnLi	54	-78	100:0

These reactions gave reasonable yields (80%) with high stereoselectivity. However, a lowering of stereoselectivity was observed at higher temperatures. The diastereomeric ratio of complexes (49-54) were determined by <sup>1</sup>H NMR spectroscopy (Figure 1) and HPLC (Figure 2).

Recently, the structure of (*Rp*)-*N*-methyl *N*-[(1*R*, 2*S*)-(1-hydroxyl-1-phenyl 2-propyl)] amino-methyl-phenyl-phosphine borane has been determined by X-ray crystallography<sup>42</sup> in order to determine the absolute configuration around the phosphorus atom (Figure 3). The absolute configuration of the phosphorus atom is *R*. The bond distance for the P-B bond (1.90Å) is longer than the P-N bond (1.65Å). The bond angles for CH<sub>3</sub>-P-BH<sub>3</sub> and CH<sub>3</sub>-P-N are 110°. The N-P-BH<sub>3</sub> and Ph-P-CH<sub>3</sub> bond angles are 115° and 104° respectively.

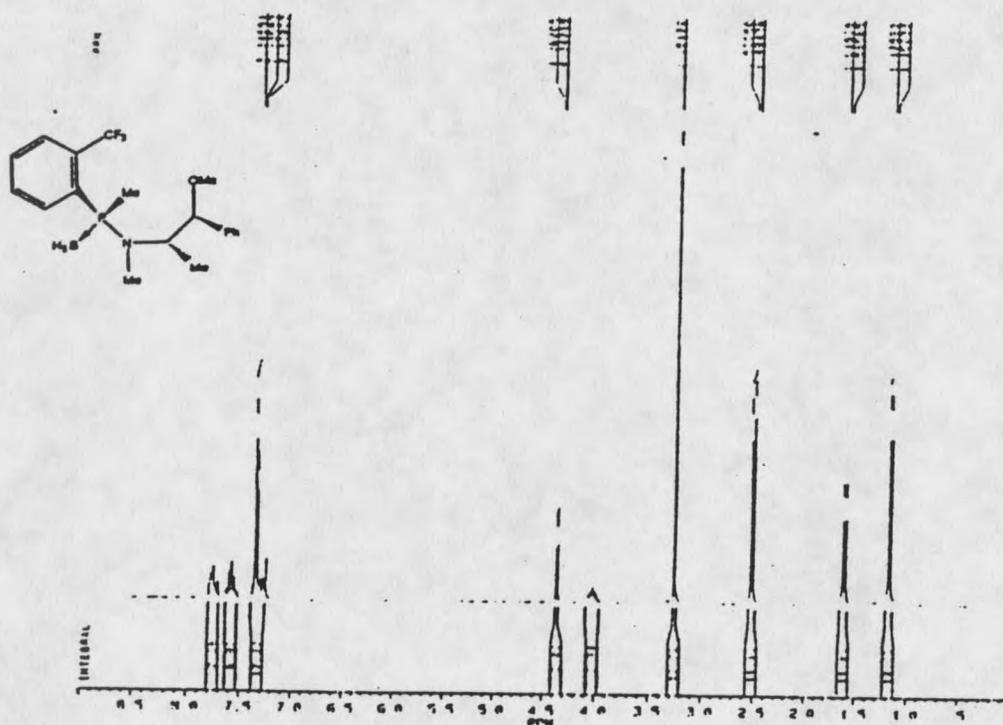


Figure 1.  $^1\text{H}$  NMR of aminophosphine borane complex (49)

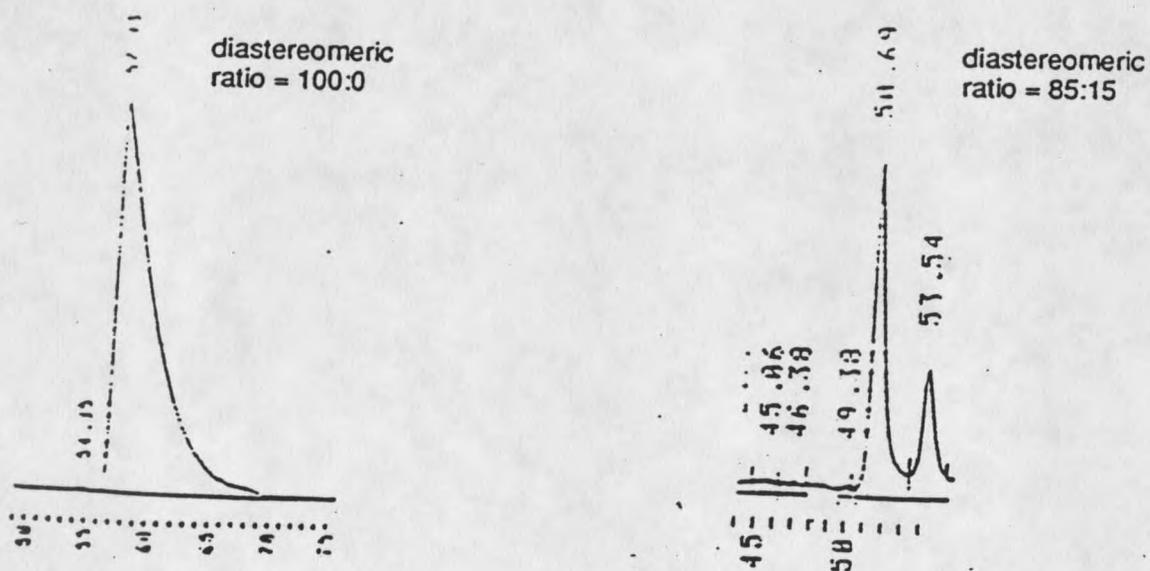
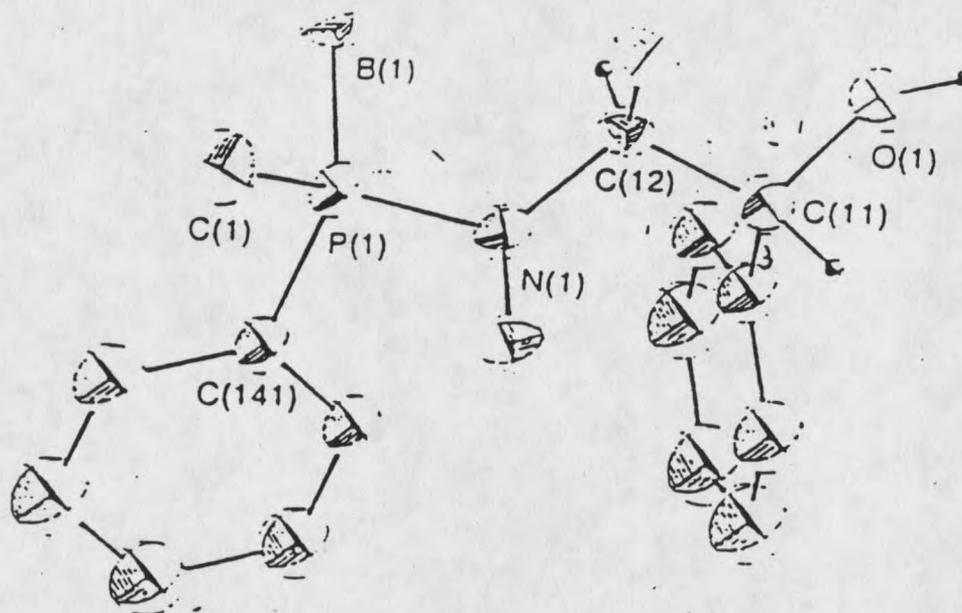


Figure 2. HPLC analysis of aminophosphine borane complex (49)



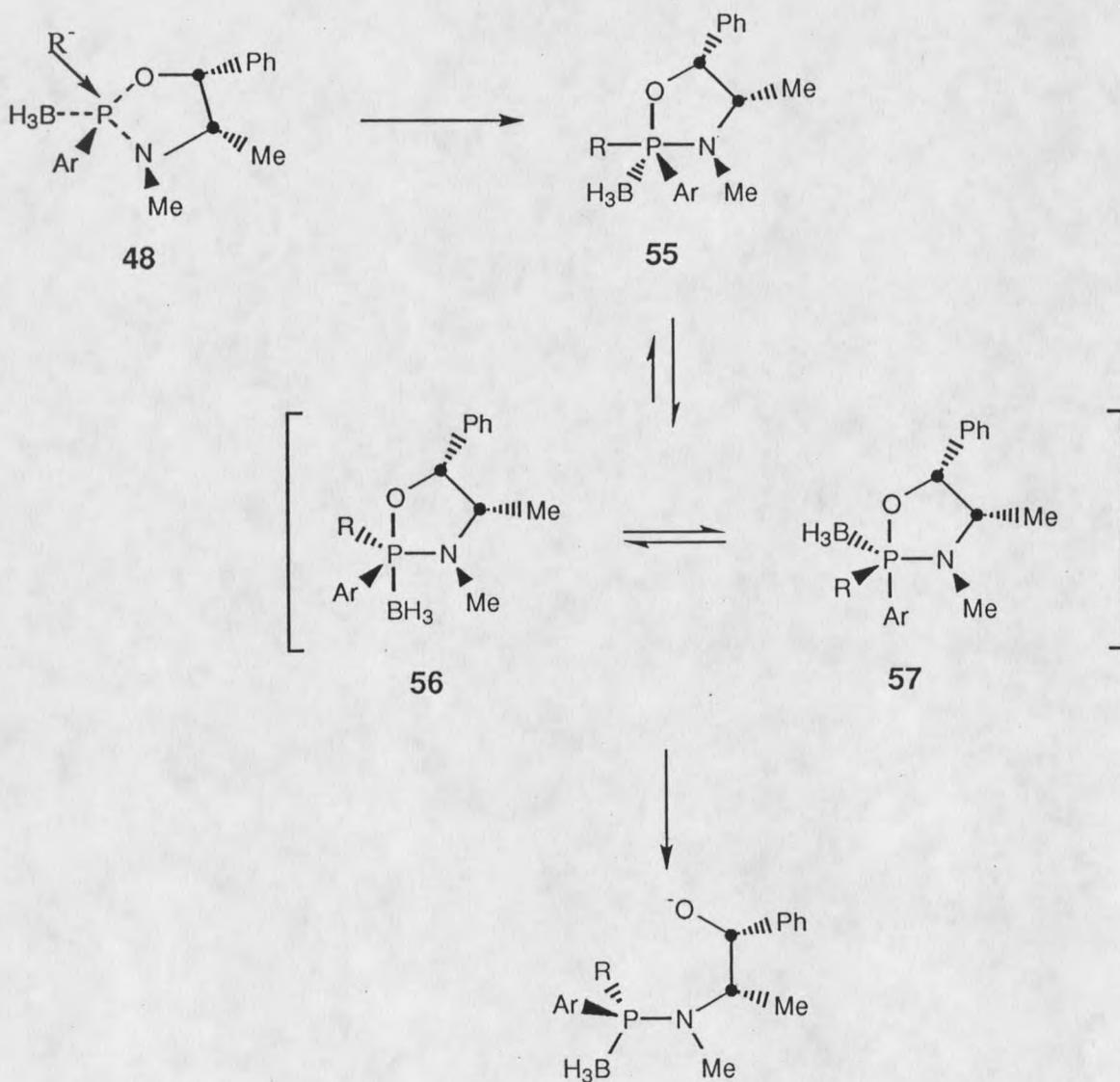
ORTEP projection at the 30% probability level. Selected distances (Å) and angles ( $^{\circ}$ ): P(1)-C(1) 1.81; P(1)-B(1) 1.90; P(1)-N(1) 1.65; P(1)-C(141) 1.81; B(1)-P(1)-C(1) 110.2; N(1)-P(1)-C(1) 109; N(1)-P(1)-B(1) 114.5; C(141)-P(1)-C(1) 104.4; C(141)-P(1)-B(1) 112.2; C(141)-P(1)-N(1) 105.8.

Figure 3. X-ray structure of aminophosphine borane

The absolute configuration of the phosphorus atom demonstrates that P-C bond formation proceeds in this case with retention of configuration. The X-ray structure of starting material (48)<sup>42</sup> shows the methyl substituent of the nitrogen on the back side of the oxygen leaving group. Consequently, the stereochemistry of P-C bond formation is under kinetic control. Nucleophilic attack occurs at the less hindered face of the P-O bond which is opposite nitrogen (Scheme 23).

The mechanism proposed requires the formation of a pentacoordinate intermediate (55) which stereopermutes into another one (56 or 57), having

the substituents on the phosphorus atom in a staggered position with the N-methyl group. The presence of the oxygen group in the apical position of the intermediate (56 or 57) permits the cleavage of the P-O bond and the formation of the ring opened compound with retention of configuration.

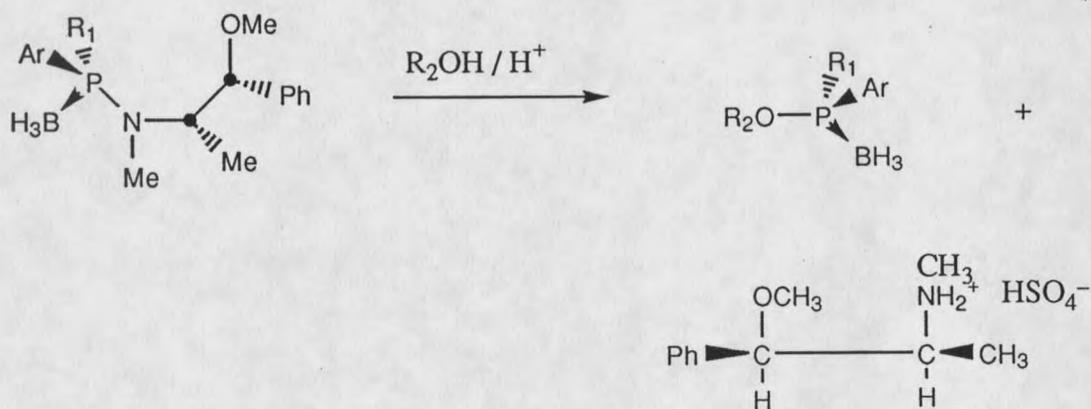


Scheme 23. Mechanism for P-C bond formation

Utilization of Aminophosphine Borane Complexes in the Synthesis of  
Asymmetric Phosphine Derivatives

A. Preparation of Phosphinite Borane Complexes

Aminophosphine borane complexes reacted with alcohol at room temperature in the presence of acid to give the corresponding phosphinite boranes (58-61) with varying degrees of inversion of configuration (Scheme 24).



Ar = 2-(CF<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>, R<sub>1</sub> = CH<sub>3</sub>, R<sub>2</sub> = CH<sub>3</sub>; (58)

Ar = 2-(CF<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>, R<sub>1</sub> = CH<sub>3</sub>, R<sub>2</sub> = CF<sub>3</sub>CH<sub>2</sub>; (59)

Ar = 2-(CF<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>, R<sub>1</sub> = CH<sub>3</sub>, R<sub>2</sub> = H<sub>3</sub>COCH<sub>2</sub>CH<sub>2</sub>; (60)

Ar = Ph, R<sub>1</sub> = 2-(CH<sub>3</sub>O)C<sub>6</sub>H<sub>4</sub>, R<sub>2</sub> = CH<sub>3</sub>; (61)

Scheme 24. Acid alcoholysis of aminophosphine boranes

Juge has found that the enantiomeric excesses of phosphinite boranes depends on the acid concentration during methanolysis.<sup>36</sup> The highest

selectivity is obtained with 0.125M H<sub>2</sub>SO<sub>4</sub>. Our reaction conditions and results are shown in Table 3.

Table 3. Results and conditions of the acid alcoholysis

Entry	Substrate	Product	Acid Conc. (M)	e.e	Yield
1	49	58	0.125	>98%	95%
2	49	58	4.00	84%	90%
3	49	59	0.125	20 %	40%
4	49	60	0.125	30%	60%
5	54	61	0.125	>98%	90%

In general, the acid catalyzed methanolysis of aminophosphine boranes was very efficient, it gave quantitative yields and high stereoselectivities (Table 3, entry 1, 5). The reactions were less efficient in terms of yield and stereoselectivity when 2-trifluoroethanol or 2-methoxyethanol were used (CH<sub>3</sub>SO<sub>3</sub>H as acid). These resulted in 40% and 60% yield respectively. Also the e.e dropped from 98:2 to 52:48 (Table 3, entry 4). All enantiomeric excesses were determined by chiral HPLC (Figure 4) (hexane/isopropanol 90:10)

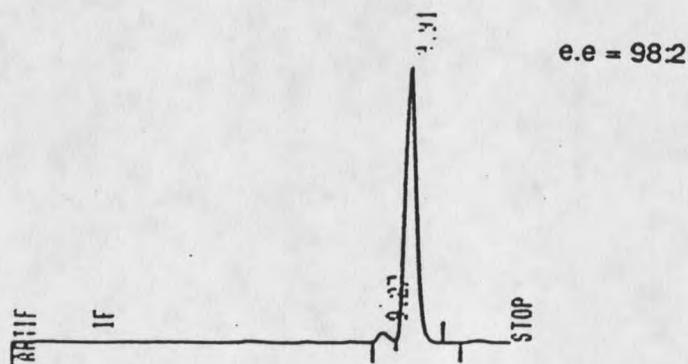
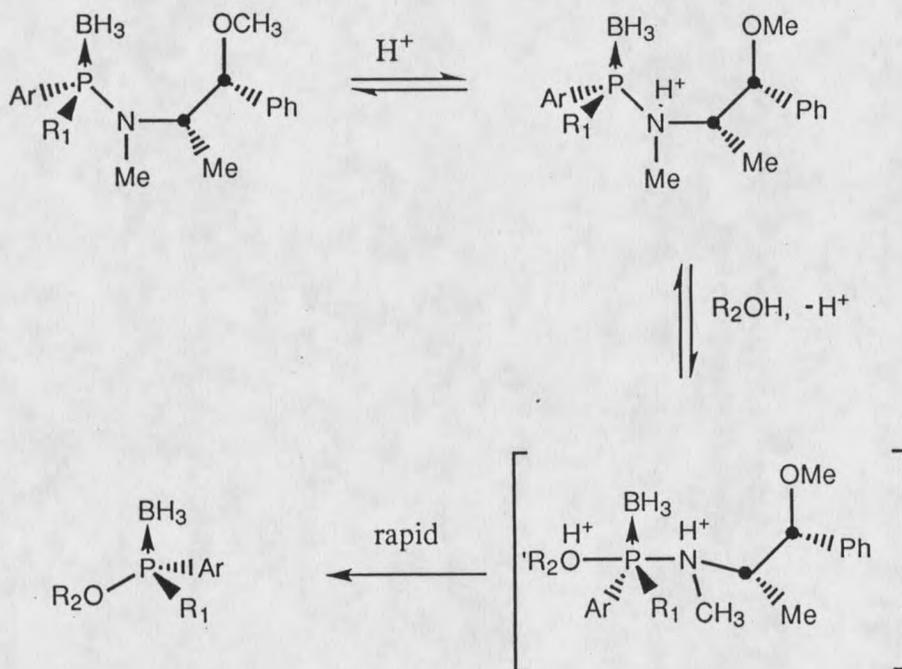


Figure 4. HPLC analysis of the phosphinite borane (49)

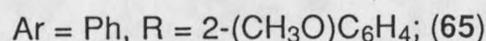
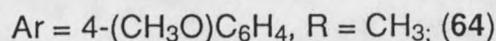
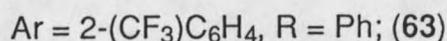
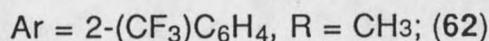
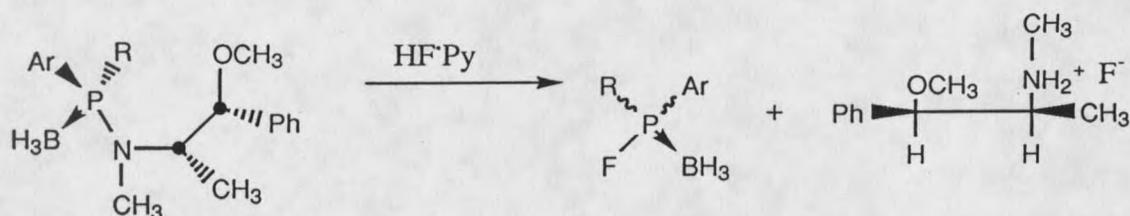
The proposed  $S_N2$  mechanism for alcoholysis of aminophosphine boranes is shown below (Scheme 25). The nitrogen of the aminophosphine borane is first protonated by the acid, then the nucleophile attacks the phosphorus to form a pentacovalent intermediate. At this stage the ammonium group quickly dissociates from the phosphorus, affording the product with inversion of configuration.



Scheme 25. Mechanism for the alcoholysis of aminophosphine boranes

### B. Preparation of Fluorophosphine Borane Complexes

Aminophosphine boranes react with HF-py at  $-25\text{ }^{\circ}\text{C}$  to give the fluorophosphine borane complexes (62-65) (Scheme 26).



Scheme 26. Preparation of fluorophosphine borane complexes

None of the examples we studied gave enantiomerically pure products. The enantiomeric ratios were measured by chiral HPLC (99:1 of hexane:isopropanol). The reaction conditions and results are shown in Table 4.

The reactions of aminophosphine borane complexes with HF·py gave >80% yield, and the corresponding fluorophosphine boranes were stable at 0 °C. Comparing hydrofluorination with acid methanolysis, the former is much faster. The electronic characteristics and steric characteristics of the substituents on the asymmetric phosphorus seemed not to influence the stereoselectivity of hydrofluorination.

Umezawa has demonstrated that HF-amine reagents were in equilibrium with a small amount of free hydrogen fluoride.<sup>43</sup> The concentration of free hydrogen fluoride would increase by lowering the basicity of the amine in an HF-amine reagent ( $i\text{-Pr}_2\text{NH} > n\text{-Bu}_3\text{N} > \text{pyridine}$ ). Fluoride ions are known to be high phosphophilic,<sup>44</sup> and it is this higher reactivity with phosphorus that may cause the racemization. In the two solvent systems:  $\text{CHCl}_3/\text{CH}_3\text{CN}$

Table 4. Results and conditions for hydrofluorination

Entry	Substrate	Solvent	[HF] (M)	Product	e.e
1	49	toluene	>4.0	62	46:54
2	49	toluene	0.1	62	45:55
3	49	CHCl <sub>3</sub> /CH <sub>3</sub> CN	>3.0	62	48:52
4	49	toluene/MTHP	>3.0	62	48:52
5	49	CH <sub>2</sub> Cl <sub>2</sub> /MTHP	>3.0	62	50:50
6	50	toluene	>4.0	63	48:52
7	52	toluene	>4.0	64	46:54
8	54	toluene	> 4.0	65	48:52
9	49	toluene(half done)	0.1	62	46:54
10	49	toluene(over done)	0.1	62	48:52

and CH<sub>2</sub>Cl<sub>2</sub>/2-methyltetrahydropyran (MTHP), the concentration of free hydrogen fluoride could possibly decrease due to "chelation" of the lone pair electrons of the nitrogen (CH<sub>3</sub>CN) and oxygen (MTHP). It was interesting to find that the results obtained with these two solvent systems are almost the same as those with toluene solvent system. It is possible that the ability of CH<sub>3</sub>CN and 2-methyltetrahydrogenpyran to chelate the hydrogen fluoride is not strong enough, so the concentration of fluoride ion in the solution is still high. Currently under investigation in our group, is the utilization of BF<sub>3</sub>·OEt<sub>2</sub> which may lower the concentration of fluoride ion more effectively (Scheme 27).

Scheme 27. Reaction of BF<sub>3</sub>·OEt<sub>2</sub> with F<sup>-</sup>

A hydrofluorination reaction that consumed 50% of aminophosphine borane complexes was performed in order to see whether the racemization rate is faster than the reaction rate or not. Chiral HPLC showed that the product was a mixture of enantiomers of this half done reaction and the enantiomeric ratio was almost the same as the ratio in overtime reaction (Figure 5). Hence it appears that the rate of racemization is at least as fast as reaction rate.

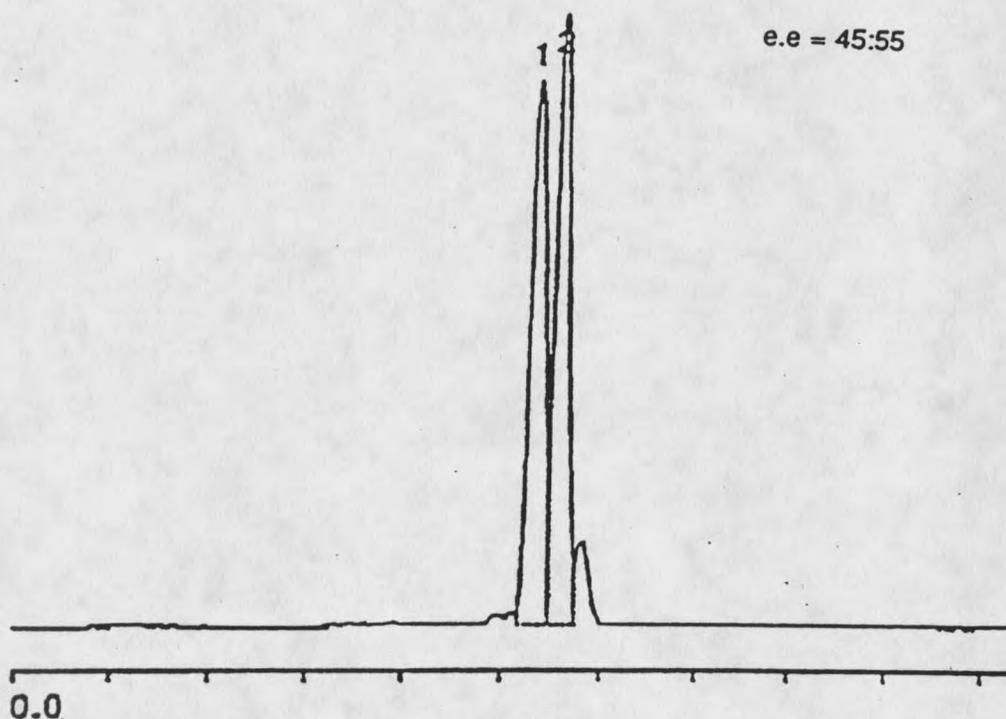
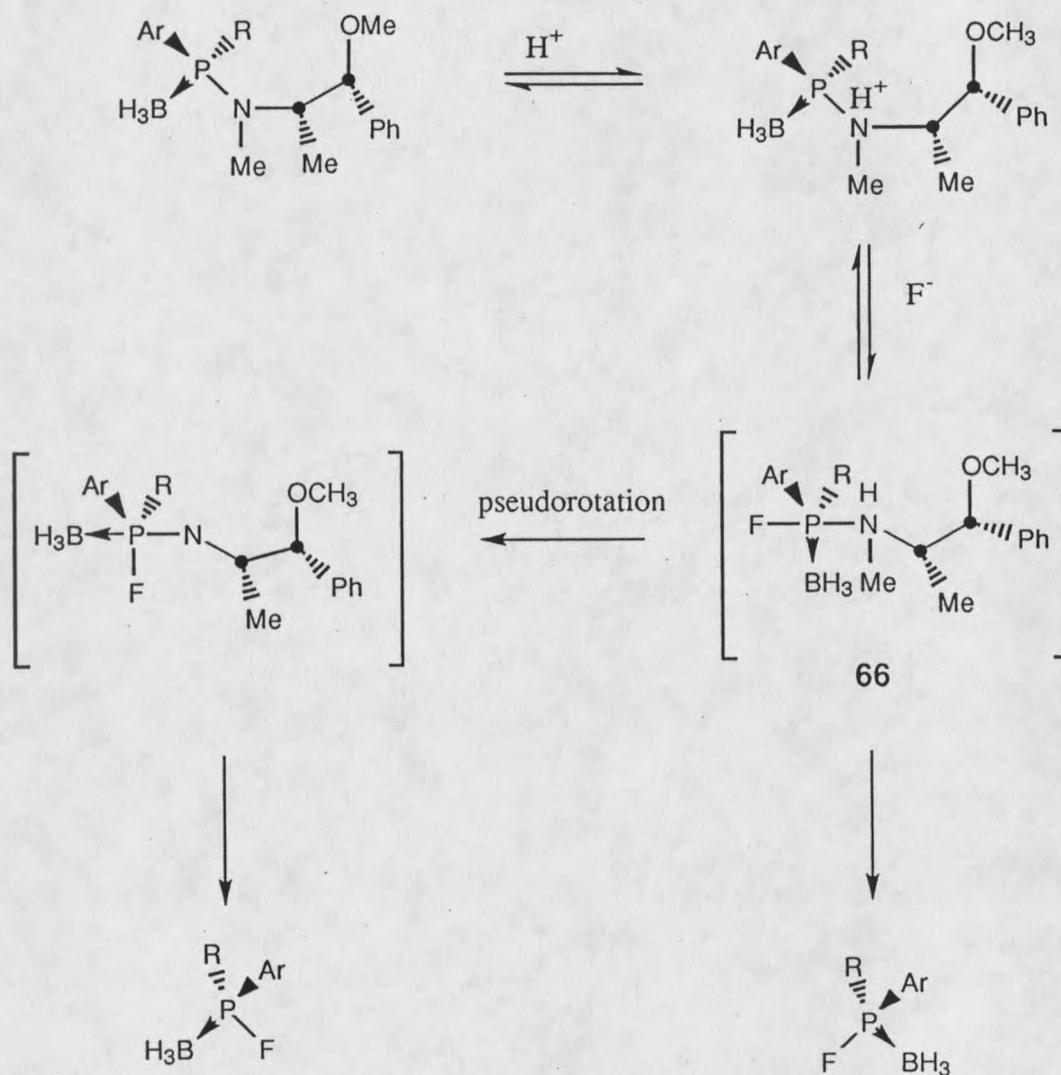


Figure 5. HPLC analysis of the hydrofluorination reaction

Thus, it has been clearly demonstrated that the conversion of phosphinite boranes into fluorophosphine boranes under the action of HF results in the mixture of enantiomers. Assuming that the first step involves the protonation of the aminophosphine nitrogen atom, the most probable structure for the

transition state or short-lived intermediate (**66**) involves a trigonal bipyramid (Scheme 28).



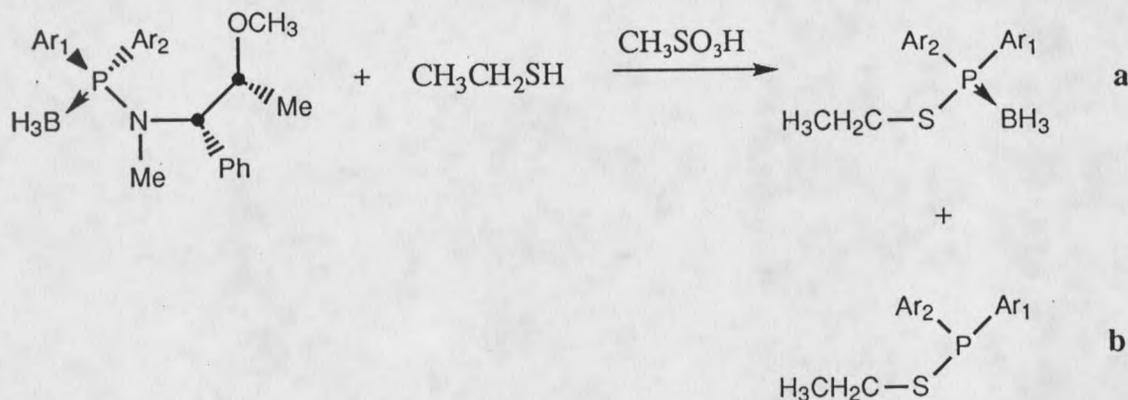
Scheme 28. Proposed mechanism for hydrofluorination

The intermediate (**66**) collapse leads to a product with inversion of configuration. However, the pentacoordinate intermediate can undergo pseudorotational isomerization, and then collapse to give the retention product. Since fluorine is the most electronegative element, the N-P bond of the

fluorophosphine borane is relatively stronger than the N-P bond of phosphinite borane. Hence the dissociation of ammonium ion from fluorophosphine borane may be slower than that in the phosphinite borane, so the intermediate (66) has more time to undergo the pseudorotation isomerization. As a result, this reaction affords the mixture of enantiomers. It is also possible that the highly phosphophilicity of the fluoride may form a difluoro pentacoordinated intermediate,<sup>44</sup> then collapse to the mixture of enantiomers. The exact mechanism of this reaction will require more study.

### C. Preparation of Thiophosphines and Thiophosphine boranes

Aminophosphine boranes reacted with ethanethiol under acidic conditions to give the corresponding thiophosphines and thiophosphine boranes (67-70) (Scheme 29).



Ar<sub>1</sub> = 2-(CF<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>, Ar<sub>2</sub> = Me; (67)<sup>47</sup>

Ar<sub>1</sub> = 2-(CF<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>, Ar<sub>2</sub> = Ph; (68)

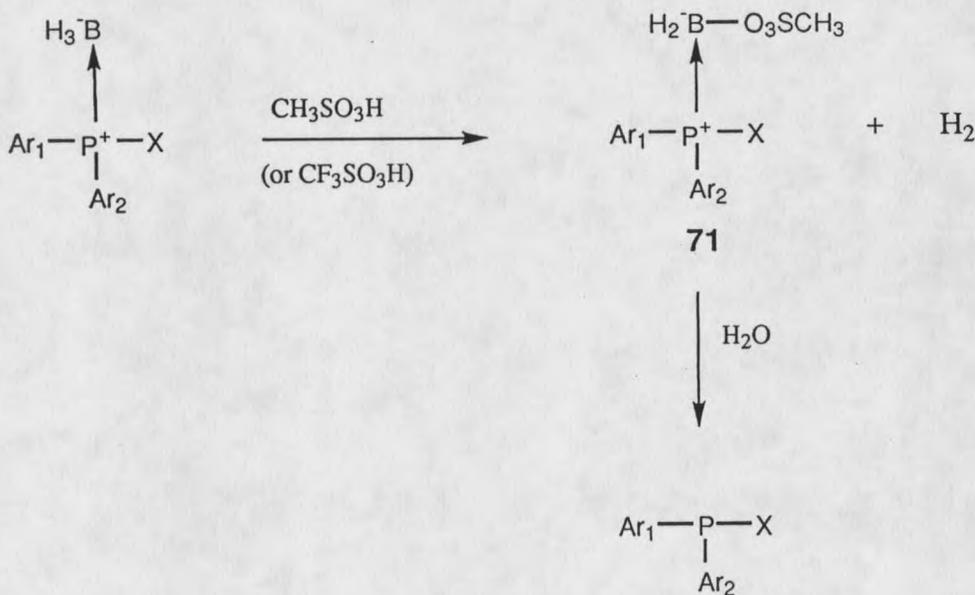
Ar<sub>1</sub> = Ph, Ar<sub>2</sub> = 2-(CH<sub>3</sub>O)C<sub>6</sub>H<sub>4</sub>; (69)

Ar<sub>1</sub> = Ph, Ar<sub>2</sub> = Me; (70)<sup>47</sup>

Scheme 29. Preparation of thiophosphines and thiophosphine boranes

Upon reaction with methanesulfonic acid or trifluoromethane sulfonic acid, in dichloromethane, an evolution of hydrogen gas occurred and the corresponding B-sulfonate (**71**) was formed.<sup>45</sup> Hydrolysis of (**71**) on workup gave the thiophosphines without a borane protecting group (Scheme 30).

These reactions were also conducted in dimethoxyethane (1,2-DME), tetrahydrofuran (THF) and ethyl acetate. In these solvent systems, the oxygens can "chelate" with  $H^+$  in different scale, but the reaction also resulted in the free phosphines.



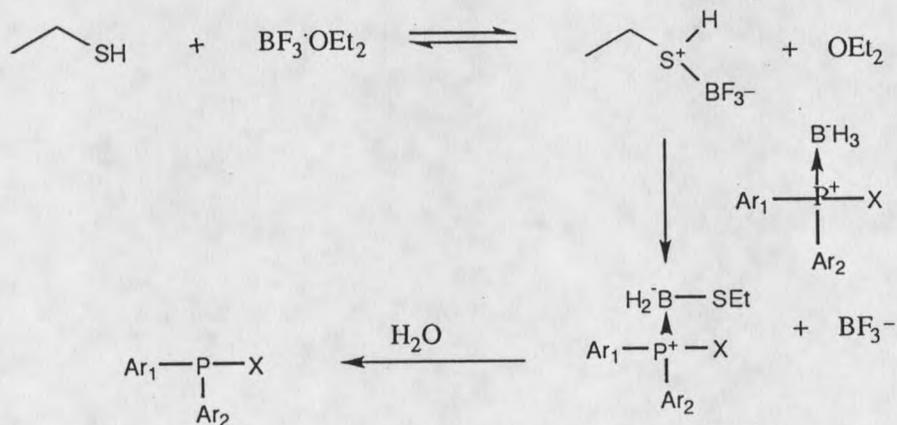
Scheme 30. Formation of the thiophosphines

Under the Lewis acid conditions ( $BF_3 \cdot OEt_2$ ), the similar reaction happened between the Lewis acid and the phosphine boranes, so the free thiophosphine also was obtained (Scheme 31).

The reaction conditions and results are shown in Table 5.

Table 5. Results and conditions for reaction of aminophosphine boranes with ethanethiol.

Entry	Substrate	Solvent	[H <sup>+</sup> ] (M)	Product (a:b)
1	54	CH <sub>2</sub> Cl <sub>2</sub>	0.4	69 (~50:40)
2	54	CHCl <sub>3</sub> /MTHF	0.2	69 (~55:45)
3	54	ethyl acetate	0.4	69 (~55:45)
4	54	toluene	0.2	69 (~50:40)
5	63	CH <sub>2</sub> Cl <sub>2</sub>	0.4	68 (0:100)
6	63	CHCl <sub>3</sub> /MTHF	0.4	68 (0:100)
7	63	THF	0.2	68 (0:100)
8	63	DME	0.083	68 (0:100)
9	63	ethyl acetate	0.2	68 (0:100)
10	63	CH <sub>2</sub> Cl <sub>2</sub> (CF <sub>3</sub> SO <sub>3</sub> H)	0.4	68 (0:100)
11	63	CH <sub>2</sub> Cl <sub>2</sub> (BF <sub>3</sub> ·OEt <sub>2</sub> )	0.25	68 (0:100)
12	53*	CH <sub>2</sub> Cl <sub>2</sub>	0.4	70 (100:0)
13	49*	CH <sub>2</sub> Cl <sub>2</sub>	0.4	67 (70:30)

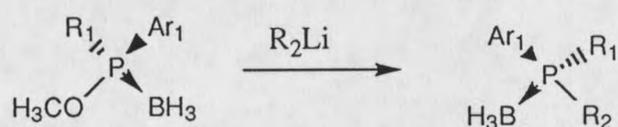
Scheme 31. Formation of thiophosphines in Lewis acid (BF<sub>3</sub>·OEt<sub>2</sub>)

The above results demonstrated that these reactions were substrate dependent. It was shown that electronic withdrawing groups (e.g. 2-trifluoromethylphenyl) on the phosphorus give 100% of free thiophosphine (entry 5-11), while the more hindered substituents (e.g. 2-methoxyphenyl) result in the formation of about 50% of the free thiophosphine (entry 1-4).

The absolute stereochemistry of the thiophosphine and thiophosphine borane complex is still unknown. Studies of these reactions are still ongoing in our laboratories.

#### Preparation of Homochiral Monophosphine Boranes

The reaction of phosphinite boranes (**58**) and (**61**) with 2 equiv of alkyl or aryl lithium in THF led to the optically active phosphine boranes (**71-74**) with inversion of configuration (Scheme 32). The resultant compounds are stable to O<sub>2</sub>.



Ar<sub>1</sub> = 2-(CF<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>, R<sub>1</sub> = Me, R<sub>2</sub> = Ph; (**71**)

Ar<sub>1</sub> = 2-(CF<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>, R<sub>1</sub> = Me, R<sub>2</sub> = p-AnLi; (**72**)

Ar<sub>1</sub> = Ph, R<sub>1</sub> = 2-(OCH<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>, R<sub>2</sub> = Me; (**73**)

Ar<sub>1</sub> = Ph, R<sub>1</sub> = 2-(OCH<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>, R<sub>2</sub> = 4-(OCH<sub>3</sub>)C<sub>6</sub>H<sub>4</sub>; (**74**)

Scheme 32. Preparation of monophosphine boranes from phosphinite boranes

The reaction conditions and results are shown in Table 6. The enantiomeric ratios were determined by chiral HPLC (99:1 hexane/isopropanol).

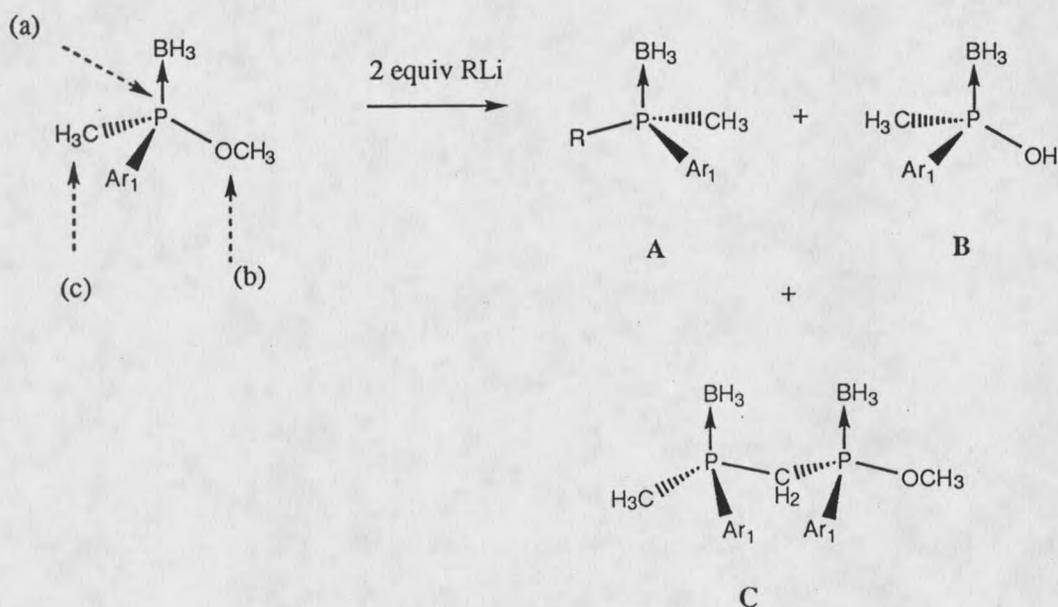
Table 6. Results and conditions for reaction of phosphinite boranes with organometallic reagents

Entry	Substrate	RM	T (°C)	Time (h)	Yield	e.e
1	58	PhLi	20	30	65%	99:1
2	58	p-AnLi	20	48	50%	98:2
3	58	PhMgBr	25	72	20%	/
4	58	p-AnMgBr	25	72	10%	/
5	61	MeLi	-20	15	85%	/
6	58	PhLi (Ni(dppp)Cl <sub>2</sub> )	-40	20	60%	100:0
7	58	p-AnLi(Ni(dppp)Cl <sub>2</sub> )	0	24	46%	100:0
8	61	p-AnLi(Ni(dppp)Cl <sub>2</sub> )	20	30	54%	100:0

For the methyl trifluoromethylphenyl phosphinite boranes, there are three competitive reactions occurring (Scheme 33). These are: (1) displacement of methoxy group by inversion of configuration to give **A** (*via a*), (2) cleavage of the C-O bond to give **B** (*via b*), or (3) formation of the coupling product **C** by condensation (*via c*). Due to the formation of carbanion PCH<sub>2</sub><sup>-</sup>, for P-CH<sub>3</sub> bearing substrates, 2.0 equiv of organolithium are necessary for this reaction. The overall yield is not high because purification of the products from these competing reactions is not efficient.

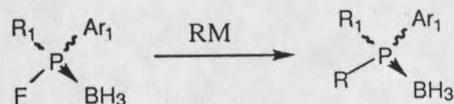
For the methyl trifluorophenyl phosphinite borane substrates, using the Ni(dppp)Cl<sub>2</sub><sup>47</sup> as a catalyst can increase the reaction rate and also increase the

stereoselectivity. The mechanism for the Ni(II) catalyzed reaction is still unknown.



Scheme 33. Competitive reactions for the reaction of RLi with phosphinite boranes

The fluorophosphine boranes can react with different kinds of organometallic reagent to give the corresponding monophosphine boranes (71-72) (Scheme 34).



$\text{Ar}_1 = 2\text{-(CF}_3\text{)C}_6\text{H}_4$ ,  $\text{R}_1 = \text{CH}_3$ ,  $\text{R} = \text{Ph}$ ; (71)

$\text{Ar}_1 = 2\text{-(CF}_3\text{)C}_6\text{H}_4$ ,  $\text{R}_1 = \text{CH}_3$ ,  $\text{R} = p\text{-An}$ ; (72)

$\text{Ar}_1 = 2\text{-(CF}_3\text{)C}_6\text{H}_4$ ,  $\text{R}_1 = \text{Ph}$ ,  $\text{R} = \text{Me}$ ; (71)

Scheme 34. Reactions of fluorophosphine boranes with organometallic reagents

The reaction conditions and results are shown in Table 7.

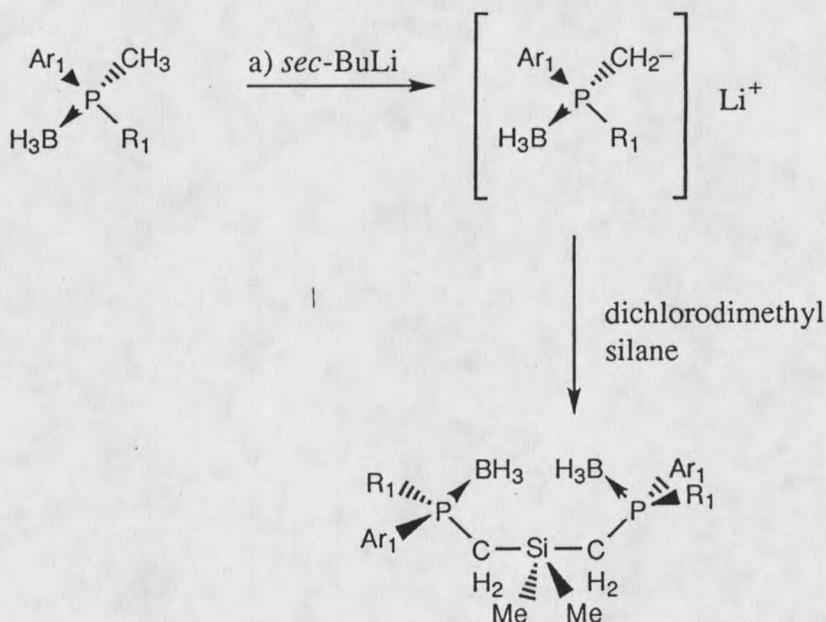
Table 7. Results and conditions for reaction of fluorophosphine boranes with organometallic reagents

Entry	Substrate	RM	Product	T(oC)/time(h)	Yield
1	62	PhLi/THF	71	-110/2	90%
2	62	PhLi/ (PMDETA)	71	-110/2	90%
3	62	PhMgBr	71	-20/8	88%
4	62	p-AnLi	72	20/24	83%
5	62	p-AnMgBr	72	-20/24	85%
6	63	MeMgBr	71	-78/2	92%

Displacement of the fluoro group is a much faster reaction than that of the methoxy group. The fluorophosphine boranes also react with Grignard reagents and give higher isolated yields due to the ease of purification. If one can overcome the problem of racemization in the previous step (Scheme 27), this reaction might be very good for making monophosphine boranes.

#### Preparation of Homochiral Diphosphine Borane Complexes

Homochiral bisphosphine borane complexes have been prepared by lithiating the monophosphine boranes (**71-73**) with *sec*-BuLi (THF, -78 °C) followed by coupling with dichlorodimethylsilane (Scheme 35).



$\text{Ar}_1 = 2\text{-(CF}_3\text{)C}_6\text{H}_4$ ,  $\text{R}_1 = \text{Ph}$ ; (75)

$\text{Ar}_1 = 2\text{-(CF}_3\text{)C}_6\text{H}_4$ ,  $\text{R}_1 = \textit{p}\text{-An}$ ; (76)

$\text{Ar}_1 = \text{Ph}$ ,  $\text{R}_1 = \textit{o}\text{-An}$ ; (77)

Scheme 35. Coupling reactions of the monophosphine boranes

There are two main reasons for coupling the monophosphine borane complexes. These are: (1) homochiral biphosphine boranes are the precursors of many useful ligands (the borane group can be removed by "Ward" procedure)<sup>46</sup> and (2) The coupling products can be used to determine the optical purity of the monophosphine boranes. If the monophosphine borane compounds are racemates, formation of meso coupling products will occur. These differences can be determined by <sup>1</sup>H NMR because the meso coupling products look different than the optically pure compounds (figure 6).

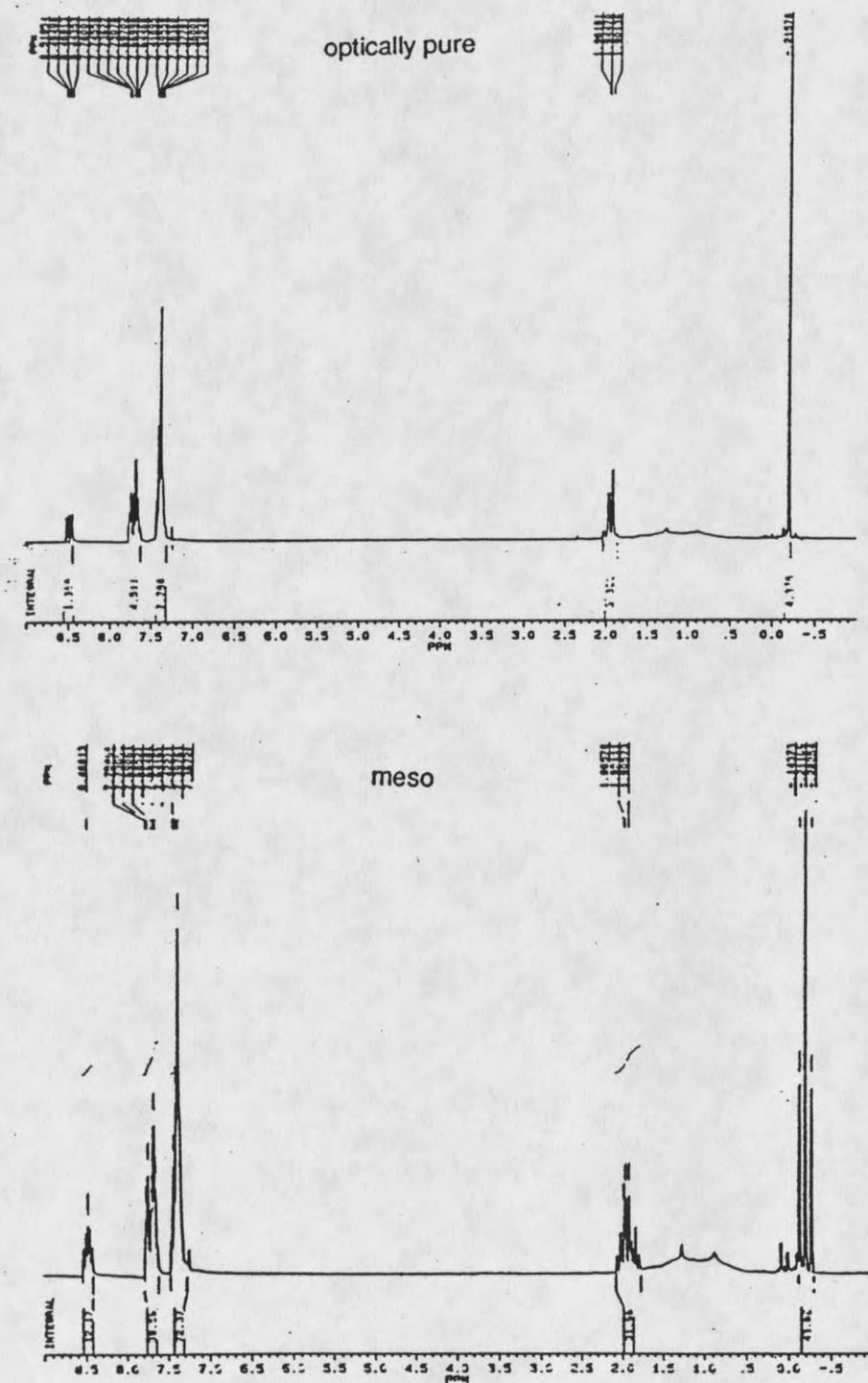


Figure 6. <sup>1</sup>H NMR of the meso and optically pure diphosphine boranes

The results of coupling reaction are shown in Table 8.

Table 8. Results of coupling reactions of the monophosphine boranes

Entry	Substrate	Product	$[\alpha]^{25}_D$	Yield (%)
1	71	75	+58.5	78
2	72	76	+30.0	75
3	73	77	-14.0	80

These three kinds of optically pure diphosphine boranes are electronically different. These ligands will form six membered rings when they chelate with a transition metal. All these homochiral diphosphine ligands will be evaluated as to their utility in various asymmetric reactions.

## EXPERIMENTAL

Physical Data:  $^1\text{H}$  NMR and  $^{13}\text{C}$  NMR were measured at 300 and 75 MHz respectively, with a Bruker AL-300 spectrometer.  $^{31}\text{P}$  NMR were measured at 202 MHz, Bruker AM-500 spectrometer.  $^1\text{H}$  NMR chemical shifts are reported in ppm relative to the residual protons of  $\text{CDCl}_3$  ( $\delta$  7.24) or  $\text{C}_6\text{H}_6$  ( $\delta$  7.15).  $^{13}\text{C}$  NMR chemical shifts are reported in ppm relative to  $\text{CDCl}_3$  ( $\delta$  77.0) or  $\text{C}_6\text{D}_6$  ( $\delta$  128),  $^{31}\text{P}$  NMR chemical shifts are reported in ppm relative to  $\text{H}_3\text{PO}_4$  (85%) ( $\delta$  0.0) or triphenylphosphine ( $\delta$  -6.0).  $^1\text{H}$  NMR coupling constants are reported in Hz and refer to real or apparent multiplicities which are indicated as follows: s (singlet), d (doublet), t (triplet), q (quartet), p (pentet), sx (sextet), br (broad), m (multiplet) and app (apparent). Combinations of these descriptors were also used when appropriate. For example, a signal which appears as a triplet (t) but is truly an unresolved doublet of doublets (dd) would be reported as an apparent triplet (app t).

Infrared spectra were recorded with either a Perkin Elmer 1800 FT-IR or a Bruker IFS 25IR. High resolution mass spectra were measured on a VG Analytical 7070E spectrometer by Dr. L. J. Sears. Melting points were determined with a Me1-Temp II melting point apparatus and are uncorrected. Optical rotations were measured with a Perkins-Elmer 241 MC Polarimeter.

Chromatography: Gas chromatography was performed on a Varian Model 3700 Gas Chromatograph equipped with a flame ionization detector, a Hewlett-Packard 3390A Reporting Integrator and a 15m x 0.54mm ID column

with a SE-54 (or equivalent) bonded phase. The Gas Chromatography (GC) results were reported in time (initial temperature - retention time - progress temperature).

Thin layer chromatography was performed on plates supplied by Alltech Associates (K42-G). Visualization of plates was effected by one or more of the following : a) UV illumination; b) exposure to I<sub>2</sub> vapor; c) KMnO<sub>4</sub> oxidation; or d) anisaldehyde derivitization. All column chromatography was conducted on E. Merck silica gel 60. Solvent systems used for elution are reported in % volume/volume.

High Performance Liquid Chromatography was performed on a IBM LC/9533 Ternary Gradient Liquid Chromatograph equipped with a 250 x 4.6 mm (L x I.D) chiralPak AD column, which analyse tris (3, 5 - dimethylphenyl carbamate) coat on 10 ul silica gel substrate. An IBM LC/9523 Variable UV Detector and a Hewlett-Packard 3390A Reporting Integrator were used for detecting and plotting.

Materials: A listing of the common solvents and reagents purified by distillation is shown in Table 9. Atmospheric pressure distillations were conducted in an inert atmosphere of argon or nitrogen.

Commercially available 10 M n-BuLi was diluted with heptane and then titrated against a standard solution of 2-butanol in ether using 1,10-phenanthroline as indicator. Grignard reagents were titrated in the same manner as n-BuLi. These reagents were also checked periodically for total base content. This was accomplished by adding an aliquot to ice and titration of the resulting mixture with a standard solution of potassium biphthalate using phenolphthalein as the indicator.

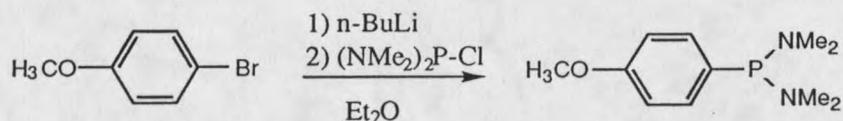
Unless indicated otherwise, reactions were performed in oven or flame dried vessels under an atmosphere of nitrogen or argon. Temperatures reported are bath temperatures unless noted otherwise. Concentrations were performed under reduced pressure with a Büchi rotary evaporator and "drying" of an organic solution was accomplished with anhydrous  $\text{Na}_2\text{SO}_4$  or  $\text{MgSO}_4$ .

Table 9 . Solvent and Reagent Purification

$\text{Et}_2\text{O}^a$	$\text{Na-Ph}_2\text{CO}$
THF	K
$\text{CH}_3\text{CN}$	$\text{CaH}_2$
toluene	$\text{CaH}_2$
DME	K
$\text{CH}_2\text{Cl}_2$	$\text{CaH}^2$
benzene	K
heptane	K
DMSO <sup>b</sup>	$\text{CaH}_2$
DMF <sup>b</sup>	$\text{CaH}_2$
HMPA <sup>c</sup>	$\text{CaH}_2$
$\text{CH}_3\text{OH}$	$\text{Mg}(\text{OCH}_3)_2$
2-butanol	$\text{CaH}_2$
TMS-Cl	$\text{CaH}_2$
xylene <sup>b</sup>	$\text{CaH}_2$
pentane	Na-K
hexane	K
amines <sup>c</sup>	$\text{CaH}_2$

a.  $\text{Et}_2\text{O}$  used in the preparation of  $\text{CH}_3\text{Li}$  was distilled from Na-K<sup>d</sup>. b. reduced pressure. c. vacuum pressure. d. 1:3 Na:K. e.  $\text{Et}_2\text{NH}$ ,  $i\text{-Pr}_2\text{NEt}$ ,  $i\text{-Pr}_2\text{NH}$  and  $\text{PhN}(\text{CH}_3)_2$ .

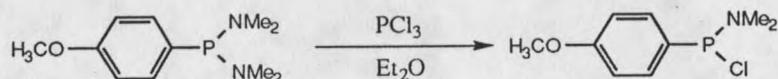
**Bis(dimethylamino)-4-methoxyphenyl phosphine (38)**



4-Bromoanisole (18.7 g, 0.100 mol) was added to a solution of n-BuLi (36.9 mL of a 2.98 M solution in heptane, 0.110 mol) in Et<sub>2</sub>O (100 mL) at 0 °C. The reaction mixture was then stirred for an additional 15 min at 0 °C. The resulting solution of 4-lithioanisole was then added dropwise to (Me<sub>2</sub>N)<sub>2</sub>P-Cl (14.7 g, 0.085 mol) in Et<sub>2</sub>O (50 mL) at -78 °C. The mixture was then warmed slowly to 25 °C. After dilution with anhydrous Et<sub>2</sub>O (50 mL), the solution was filtered under argon through celite. Concentration of the solution followed by purification of the yellow liquid by fractional distillation (100-110 °C, 1.1 mm) gave 20.7 g (92%) of (38) as a viscous clear oil.

<sup>1</sup>H NMR (CDCl<sub>3</sub>) δ 7.29 (dd, *J* = 5.3 and 8.6 Hz, 2H, ArH), 6.89 (dd, *J* = 1.9 and 8.6 Hz, 2H, ArH), 3.80 (s, 3H, OCH<sub>3</sub>), 2.72 (d, *J* = 9.2 Hz, 12H, NCH<sub>3</sub>); <sup>13</sup>C NMR (CDCl<sub>3</sub>, <sup>1</sup>H decoupled) δ 140.6, 132.6, 132.4, 113.9 (Cs of the Ar), 55.2 (s, OCH<sub>3</sub>), 41.6 (d, *J* = 7.1 Hz, 4C, NCH<sub>3</sub>).

**Chloro-(dimethylamino)-4-methoxyphenyl phosphine (39a)**

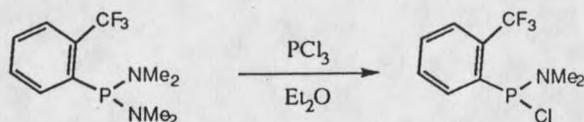


PCl<sub>3</sub> (12.6 g, 0.092 mol) was slowly added to (38) (20.7 g, 0.092 mol) at 0 °C. The reaction mixture was stirred for 2h at 0 °C, then warmed to 25 °C for

1h. Purification of the resulting product by fractional distillation (135-145 °C, 0.60 mm) gave 18.7 g (99%) of **(39a)** as a viscous oil.

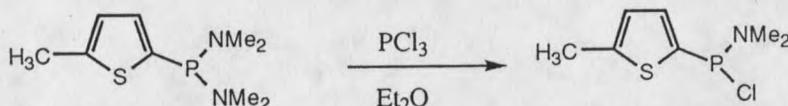
$^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  7.60 (dd,  $J = 6.1$  and  $8.7$  Hz, 2H, ArH), 6.96 (dd,  $J = 1.6$  and  $8.7$  Hz, 2H, ArH), 3.83 (s, 3H,  $\text{OCH}_3$ ), 2.65 (d,  $J = 13.0$  Hz, 6H,  $\text{NCH}_3$ );  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  141.3, 140.6, 132.5, 132.2, 113.9 (C s of the Ar), 55.3 (s,  $\text{OCH}_3$ ), 40.0 (d,  $J = 7.0$  Hz, 2C,  $\text{NCH}_3$ ).

### Chloro-(dimethylamino)-2-trifluoromethylphenyl phosphine (**39b**)



Fractional distillation (75 °C, 0.050 mm) gave 24.5 g (96%) of **(39b)**:  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  8.34 (dd,  $J = 3.1$  and  $8.0$  Hz, 1H, ArH), 7.72 (m, 1H, ArH), 7.64 (t,  $J = 7.1$  Hz, 1H, ArH), 7.52 (t,  $J = 7.5$  Hz, 1H, ArH), 2.60 (d,  $J = 12.9$  Hz, 6H,  $\text{NCH}_3$ );  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  133.3, 133.2, 131.5, 130.1 (C s of Ar), 126.7 (m,  $\text{CF}_3$ ), 126.1 (d,  $J = 2.3$  Hz), 122.5 (d,  $J = 2.2$  Hz, C s of the Ar), 40.0 (d,  $J = 7.0$ , 2C,  $\text{NCH}_3$ ).

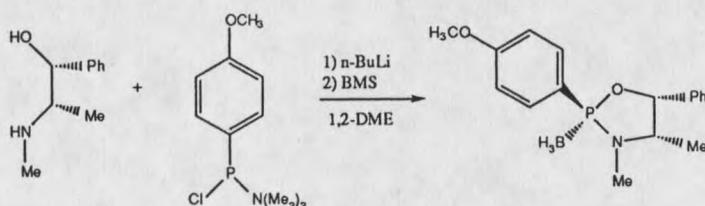
### Chloro-(dimethylamino)-[2-(5-methylthienyl)] phosphine (**39c**)



Fractional distillation (63 °C, 1.00 mm) gave 20.6 g (99%) of **(39c)**:  $^1\text{H}$

NMR ( $C_6H_6$ )  $\delta$  7.5-6.5 (m, 2H, *H* of the thienyl), 2.32 (d,  $J = 13.6$ Hz, 6H,  $NCH_3$ ), 2.05 (s, 3H,  $CH_3$ );  $^{31}P$  NMR ( $CDCl_3$ )  $\delta$  132.8.

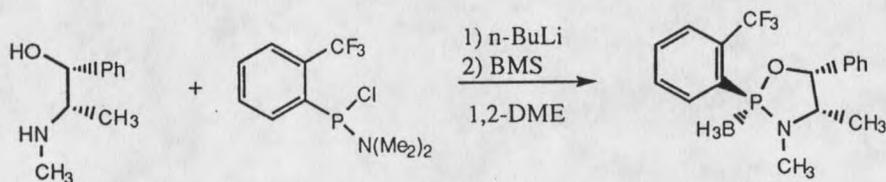
**(2*R*, 4*S*, 5*R*)-2-(4-Methoxyphenyl)-3,4-dimethyl-5-phenyl-1,3,2-oxazaphospholidine 2-borane (44)**



To a solution of (-)-ephedrine (14.1 g, 0.086 mol) in 1,2-DME (125 mL) at  $-50$  °C was added *exactly* 1eq. of *n*-BuLi (21.5 mL of a 4.00 M solution in heptane, 0.086 mol). To this solution was added (39a) (18.7 g, 0.0907 mol) in 1,2-DME (25 mL) at  $-50$  °C. The resulting reaction mixture was then stirred vigorously and slowly warmed to  $25$  °C ( $\sim 2$  h), during which time a precipitate formed. A catalytic amount of chlorotrimethylsilane (500  $\mu$ L, 5 mol%) was then added and the reaction mixture was refluxed for 10 h. After cooling to  $0$  °C,  $BH_3 \cdot S(CH_3)_2$  (8.5 mL of a 10.1M solution, 0.086 mol) was added. The reaction mixture was then stirred for an additional 2 h at  $25$  °C. The resulting mixture was concentrated *in vacuo* to yield a beige viscous residue which was diluted with anhydrous benzene (100 mL) and filtered through florisil. Concentration of the solution followed by trituration with anhydrous methanol gave the title compound as a white solid. Recrystallization with anhydrous methanol or methylcyclohexane afforded 22.2 g (82%) of the pure complex.

mp 82 °C;  $[\alpha]^{25}_D -6.5^\circ$  (c 2.0 in  $\text{CHCl}_3$ );  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )  $\delta$  7.78 (dd,  $J = 9.2$  and  $9.4$  Hz, 2H, ArH), 7.4-7.2 (m, 5H, PhH), 6.95 (dd,  $J = 1.7$  and  $8.8$  Hz, 2H, ArH), 5.55 (dd,  $J = 2.5$  and  $5.9$  Hz, 1H, OCH). 3.82 (s, 3H,  $\text{OCH}_3$ ), 3.65 (m, 1H, NCH), 2.61 (d,  $J = 10.9$  Hz, 3H,  $\text{NCH}_3$ ), 0.85 (d,  $J = 6.6$  Hz, 3H,  $\text{CH}_3$ ), 1.45-0.40 (broad envelope, 3H,  $\text{BH}_3$ );  $^{13}\text{C NMR}$  ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  136.6, 136.0, 133.4, 133.2, 128.3 (2C), 128.2, 126.7, 126.6 (2C), 114.2, 114.1 (C s of the phenyl and Ar), 83.7 (app s, NCH<sub>3</sub>), 59.4 (app s, NCH), 55.4 (s,  $\text{OCH}_3$ ), 29.4 (app s, OCH), 13.4 (s,  $\text{CH}_3$ );  $^{31}\text{P NMR}$  ( $\text{CDCl}_3$ )  $\delta$  131.9 (d,  $J = 93.1$  Hz); IR (film) 2974, 2934, 2902, 2839, 2380 (B-H), 2340, 1596, 1501, 1259, 1114, 966  $\text{cm}^{-1}$ ; high resolution mass spectrum calcd. for  $\text{C}_{17}\text{H}_{23}\text{BNO}_2\text{P}$  ( $\text{M}^+$ ) 315.1559. Found 315.1530; Rf = 0.22 (20% EtOAc/hexane); GC: t = 10.50 (70-2-15).

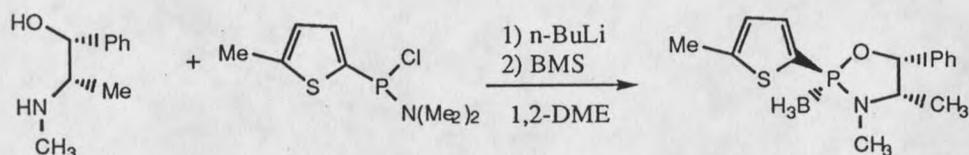
**(2*R*, 4*S*, 5*R*)-2-(2-Trifluoromethylphenyl)-3,4-dimethyl-5-phenyl-1,3,2-oxazaphospholidine 2-borane (42)**



Recrystallization with methylcyclohexane or methanol afforded 24.3 g (77%) of **(42)** as needle shaped white crystals: mp 106.6-108.0 °C;  $[\alpha]^{25}_D -10^\circ$  (c 2.0 in  $\text{CHCl}_3$ );  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )  $\delta$  7.83 (dd,  $J = 7.5$  and  $11.1$  Hz, 1H, ArH), 7.74 (m, 1H, ArH), 7.60 (m, 2H, ArH), 7.33 (m, 5H, PhH), 5.21 (d.d,  $J = 3.4$  and  $6.0$  Hz, 1H, OCH), 3.66 (m, 1H, NCH), 2.97 (d,  $J = 9.8$  Hz, 3H,  $\text{NCH}_3$ ), 0.81 (d,  $J = 6.6$  Hz, 3H,  $\text{CH}_3$ ), 1.75-0.40 (broad envelope, 3H,  $\text{BH}_3$ );  $^{13}\text{C NMR}$  ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  136.0 (d,  $J = 5.5$  Hz), 132.2, 132.1, 131.5 (d,  $J = 7.7$  Hz), 131.2,

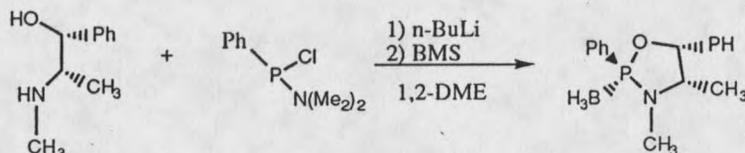
128.2 (2C), 128.1, 127.2 (m, CF<sub>3</sub>), 126.2, 125.4, 121.8 (C of the phenyl and Ar), 83.3 (d, *J* = 8.0 Hz, NCH<sub>3</sub>), 58.3 (app s, NCH), 30.8 (d, *J* = 8.9 Hz, OCH), 13.1 (s, CH<sub>3</sub>); <sup>31</sup>P NMR (CDCl<sub>3</sub>) δ 131.3 (d, *J* = 89.5 Hz); IR (film) 2995, 2937, 2869, 2425, 2383 (B-H), 1456, 1318, 1135, 973 cm<sup>-1</sup>; high resolution mass spectrum calcd. for C<sub>17</sub>H<sub>20</sub>BF<sub>3</sub>NOP (M<sup>+</sup>) 353.1328. Found 353.1315; R<sub>f</sub> = 0.25 (20% EtOAc/Hexane); GC: t = 10.50 (70-2-15).

**(2*R*, 4*S*, 5*R*)-2-[2-(5-Methylthienyl)]-3,4-dimethyl-5-phenyl-1,3,2-oxazaphospholidine 2-borane (46)**



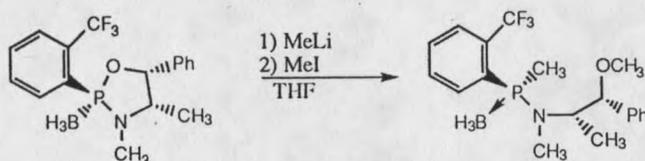
Recrystallization with anhydrous ethanol or methanol afforded 24.9 g (82%) of **(46)** as needle shaped white crystals: mp 76.3 °C; [ $\alpha$ ]<sub>D</sub><sup>25</sup> +8.0° (c 2.0 in CHCl<sub>3</sub>); <sup>1</sup>H NMR (CDCl<sub>3</sub>) δ 7.58 (dd, *J* = 6.2 and 3.0 Hz, 1H, *H* of thienyl), 7.36 (m, 6H, Ph*H* and *H* of thienyl), 5.58 (dd, *J* = 2.9 and 6.0 Hz, 1H, OCH), 3.64 (m, 1H, NCH<sub>3</sub>), 2.61 (d, *J* = 11.4 Hz, 3H, NCH<sub>3</sub>), 2.53 (s, 3H, CH<sub>3</sub> on the thienyl), 0.78 (d, *J* = 6.6 Hz, 3H, CH<sub>3</sub>), 1.7-0.2 (broad envelope, 3H, BH<sub>3</sub>); <sup>13</sup>C NMR (CDCl<sub>3</sub>, <sup>1</sup>H decoupled) δ 139.5, 139.4, 136.7, 129.0, 128.9 (2C), 128.1, 127.9, 127.3 (2C) (C of the phenyl and thienyl), 84.3 (d, *J* = 6.5 Hz, NCH<sub>3</sub>), 59.9 (app s, NCH), 30.1 (d, *J* = 8.1 Hz, OCH), 16.1 (s, CH<sub>3</sub>CS), 14.3 (s, CH<sub>3</sub>); <sup>31</sup>P NMR (CDCl<sub>3</sub>) δ 120.9 (d, *J* = 88.8 Hz); IR (film) 3066, 3031, 2975, 2959, 2844, 2399 (B-H), 2373, 2340, 1436, 1213, 1179, 960, 845, 628 cm<sup>-1</sup>; high resolution mass spectrum calcd. for C<sub>15</sub>H<sub>21</sub>BNOPS (M<sup>+</sup>) 305.1175. Found 305.1154; R<sub>f</sub> = 0.34 (20% EtOAc/Hexane); GC: t = 11.17 (70-2-15).

**(2*R*, 4*S*, 5*R*)-3,4-Dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidine  
2-borane (48)**



Recrystallization with methanol afforded 19.60 g (80%) of **(48)** as needle shaped white crystals: mp 103.3-104.6 °C,  $[\alpha]^{25}_D +4.0^\circ$  (c 1.0 in  $\text{CHCl}_3$ );  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  7.84 (m, 2H, PhH), 7.54 (m, 3H, PhH), 7.40 (m, 5H, PhH), 5.59 (dd,  $J = 6.0$  and  $3.0$  Hz, 1H, OCH), 3.67 (d.d.q.,  $J = 6.0, 8.7$  and  $6.5$  Hz, 1H, NCH), 2.67 (d,  $J = 11.0$  Hz, 3H, NCH<sub>3</sub>), 0.81 (d,  $J = 6.5$  Hz, 3H, CH<sub>3</sub>), 1.7-0.2 (broad envelope, 3H, BH<sub>3</sub>);  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  133.0, 131.7, 131.5, 129.3, 129.21 (2C<sub>o</sub>), 129.0 (C<sub>s</sub> of phenyls), 127.3 (2C<sub>c</sub> of the phenyl), 84.8 (d,  $J = 9.0$  Hz, NCH<sub>3</sub>), 59.8 (app s, NCH), 30.1 (d,  $J = 8.6$  Hz, OCH), 14.2 (s, CH<sub>3</sub>);  $^{31}\text{P}$  NMR ( $\text{CDCl}_3$ )  $\delta$  132.8 (d,  $J = 96.0$  Hz); IR (film) 3060, 2976, 2386 (B-H), 1436, 1207, 1177, 1113, 965, 748, 699  $\text{cm}^{-1}$ ; R<sub>f</sub> = 0.31 (20% EtOAc/hexane); GC: t = 11.00 (70-2-15).

**(*Rp*)-N-Methyl, N-[(1*R*, 2*S*)-(1-methoxy-1-phenyl-2-propyl)]-amino-  
methyl-(2-trifluoromethylphenyl)-phosphine borane (49)**

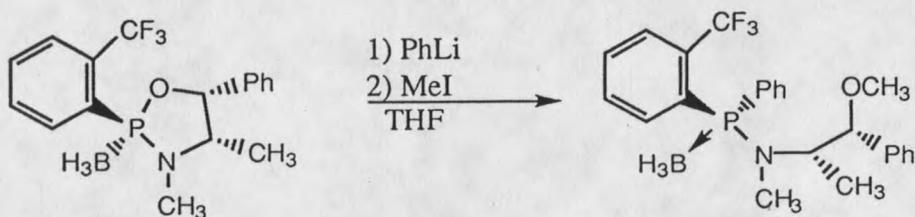


A 50 mL flask charged with MeLi (6.92 mL of a 1.46 M solution in Et<sub>2</sub>O,

0.0101 mol) and THF (11 mL) was cooled to  $-120\text{ }^{\circ}\text{C}$  (THF/ Et<sub>2</sub>O/ N<sub>2</sub>(liquid)). A 1 M solution of oxazaphospholidine borane complex (42) (3.54 g, 0.01 mol) in THF (10 mL) was then added slowly via a cold addition funnel so that the temperature did not exceed  $-70\text{ }^{\circ}\text{C}$ . Upon completion of the addition, the light yellow solution was then stirred vigorously and gradually warmed to  $-78\text{ }^{\circ}\text{C}$  for 4 h, and then warmed to  $0\text{ }^{\circ}\text{C}$  for 2 h. After cooling to  $-78\text{ }^{\circ}\text{C}$ , MeI (1.86 mL, newly filtered through florisil, 0.03 mol) was added. The reaction mixture was then stirred for additional 12 h at  $25\text{ }^{\circ}\text{C}$ . The resulting mixture was diluted with anhydrous benzene (20 mL). The organic phase was extracted with saturated aqueous NH<sub>4</sub>Cl (3 x 10 mL) and brine (3 x 10 mL). The organic phase was dried over Na<sub>2</sub>SO<sub>4</sub> and filtered through florisil. Concentration of the organic phase *in vacuo* for 12 h afforded a crude product as a white solid. Recrystallization with anhydrous methanol or methylcyclohexane provided 3.0 g (80%) of the pure complex as needle shaped white crystals.

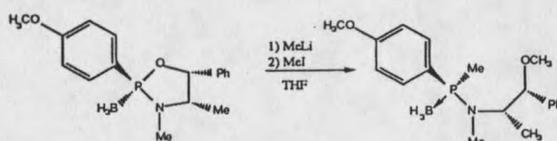
mp  $89.2\text{ }^{\circ}\text{C}$ ,  $[\alpha]_{\text{D}}^{25} +17.0^{\circ}$  (c 2.0 in CHCl<sub>3</sub>); <sup>1</sup>H NMR (CDCl<sub>3</sub>)  $\delta$  7.78 (m, 2H, ArH), 7.62 (m, 2H, ArH), 7.36 (m, 5H, PhH), 4.36 (d,  $J = 4.5\text{ Hz}$ , 1H, OCH), 4.01 (m, 1H, NCH), 3.25 (s, 3H, OCH<sub>3</sub>), 2.52 (d,  $J = 7.9\text{ Hz}$ , 3H, NCH<sub>3</sub>), 1.61 (d,  $J = 8.8\text{ Hz}$ , 3H, PCH<sub>3</sub>), 1.17 (d,  $J = 6.9\text{ Hz}$ , 3H, CH<sub>3</sub>), 1.70-0.30 (broad envelope, 3H, BH<sub>3</sub>); <sup>13</sup>C NMR (CDCl<sub>3</sub>, <sup>1</sup>H decoupled)  $\delta$  140.5, 134.4 (d,  $J = 10.2\text{ Hz}$ ), 132.3 (d,  $J = 9.0\text{ Hz}$ ), 131.3, 128.9 (2C), 128.5, 128.4, 128.3 (Cs of the Ar and phenyl), 128.2 (m, CF<sub>3</sub>), 127.8 (2C, C of the phenyl), 89.58 (app s, NCH<sub>3</sub>), 59.23 (d,  $J = 10.0\text{ Hz}$ , NCH), 57.8 (s, OCH<sub>3</sub>), 30.8 (s, OCH), 15.4 (d,  $J = 4.0\text{ Hz}$ , PCH<sub>3</sub>), 12.3 (s, CH<sub>3</sub>); <sup>31</sup>P NMR (CDCl<sub>3</sub>)  $\delta$  73.4; IR (film) 2985, 2939, 2370 (B-H), 1312, 1179, 1117, 1038, 967 cm<sup>-1</sup>; high resolution mass spectrum calcd. for C<sub>19</sub>H<sub>26</sub>BF<sub>3</sub>NOP (M<sup>+</sup>) 383.1767. Found 383.1782; R<sub>f</sub> = 0.305 (20% EtOAc/ Hexane); GC: t = 10.12 (70-2-15).

**(*Rp*)-N-Methyl, N-[(1*R*, 2*S*)-(1-methoxy-1-phenyl-2-propyl)] amino-phenyl-(2-trifluoromethylphenyl)-phosphine borane (50)**



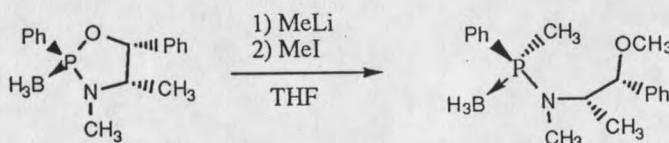
Recrystallization from anhydrous methanol afforded 3.65 g (78%) of pure (50). mp 140.0-141.2 °C;  $[\alpha]^{25}_D +10.0^\circ$  (c 1.8 in  $\text{CHCl}_3$ );  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )  $\delta$  7.74 (dd,  $J = 4.4$  and  $7.8$  Hz, 1H, ArH), 7.59-7.28 (m, 12H, PhH and ArH), 7.16 (dd,  $J = 7.9$  and  $12.0$  Hz, 1H, PhH), 4.93 (m, 2H, OCH and NCH), 3.25 (s, 3H,  $\text{OCH}_3$ ), 2.41 (d,  $J = 7.6$  Hz, 3H,  $\text{NCH}_3$ ), 1.08 (d,  $J = 6.39$  Hz, 3H,  $\text{CH}_3$ ), 1.70-0.70 (broad, envelope, 3H,  $\text{BH}_3$ );  $^{13}\text{C NMR}$  ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  140.4 (C of the Ar), 134.8 (d,  $J = 6.2$  Hz, C of the Ar), 132.6 (C of the Ar), 132.4 (C of the Ar), 132.1 (C of the Ar), 132.0 (C of the Ar), 131.7 (C of the phenyl), 131.4 (C of the phenyl), 129.5 (m,  $\text{CF}_3$ ), 129.5 (2C, C of the phenyl), 129.1 (C of the phenyl), 128.9 (C of the phenyl), 128.5 (C of the phenyl), 128.3 (2C, C of the phenyl), 89.0 (d,  $J = 6.0$  Hz,  $\text{NCH}_3$ ), 58.6 (d,  $J = 10.5$  Hz, NCH), 57.5 (s,  $\text{OCH}_3$ ), 32.0 (s, OCH), 13.6 (s,  $\text{CH}_3$ );  $^{31}\text{P NMR}$  ( $\text{CDCl}_3$ )  $\delta$  74.7 (d,  $J = 21.5$  Hz); IR (film) 2937, 2824, 2388 (B-H), 1437, 1311, 1178, 1117, 1008, 960  $\text{cm}^{-1}$ ; high resolution mass spectrum calcd. for  $\text{C}_{24}\text{H}_{28}\text{BF}_3\text{NOP}$  ( $\text{M}^+$ ) 445.1991. Found 445.1973;  $R_f = 0.26$  (20% EtOAc/hexane); GC: t = 12.95 (70-2-15).

**(Rp)-N-Methyl, N-[(1R, 2S)-(1-methoxy-1-phenyl-2-propyl)] amino-(4-methoxyphenyl)-methyl phosphine borane (52)**



The analytically pure product was isolated by column chromatography on silica gel (20% EtOAc/hexane for elution) in 70% yield as white solid.  $[\alpha]^{25}_D +36.3^\circ$  (c 14.1 in  $\text{CHCl}_3$ );  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )  $\delta$  7.34 (m, 5H, PhH), 7.04 (dd,  $J = 8.8$  and  $9.8$  Hz, 2H, ArH), 6.79 (dd,  $J = 1.9$  and  $8.7$  Hz, 2H, ArH), 4.12 (d,  $J = 7.2$  Hz, 1H, OCH), 3.91 (m, 1H, NCH), 3.78 (s, 3H, ArOCH<sub>3</sub>), 3.15 (s, 3H, OCH<sub>3</sub>), 2.48 (d,  $J = 8.7$  Hz, 3H, NCH<sub>3</sub>), 1.44 (d,  $J = 9.0$  Hz, 3H, PCH<sub>3</sub>), 1.14 (d,  $J = 6.7$  Hz, 3H, CH<sub>3</sub>);  $^{13}\text{C NMR}$  ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  140.7, 132.8, 132.6, 129.4, 129.0 (2C), 128.4, 128.2 (2C), 127.4, 114.7 (d,  $J = 11.8$  Hz) (C s of the phenyl), 88.1 (d,  $J = 5.6$  Hz, NCH<sub>3</sub>), 58.4 (d,  $J = 7.5$  Hz, NCH), 57.6 (s, PhOCH<sub>3</sub>), 55.9 (s, OCH<sub>3</sub>), 29.5 (s, OCH), 14.6 (s, CH<sub>3</sub>), 12.4 (d,  $J = 11.7$  Hz, PCH<sub>3</sub>);  $^{31}\text{P NMR}$  ( $\text{CDCl}_3$ )  $\delta$  63.7 (d,  $J = 96.6$  Hz); IR (film) 2935, 2836, 2370 (B-H), 1597, 1504, 1295, 1255, 1114, 1094, 1028  $\text{cm}^{-1}$ ; R<sub>f</sub> = 0.204 (20% EtOAc/hexane); GC: t = 13.41 (70-2-15).

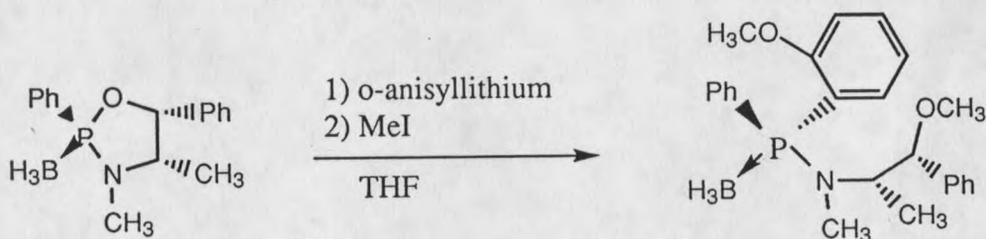
**(Rp)-N-Methyl, N-[(1R, 2S)-(1-methoxy-1-phenyl-2-propyl)] amino-methyl-phenyl-phosphine borane (53)**



Recrystallization with ethanol afforded 2.20 g (78%) of (53); mp 58.9 °C;

$[\alpha]^{25}_D -45.0^\circ$  (c 1.0 in  $\text{CHCl}_3$ );  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )  $\delta$  7.36-7.25 (m, 8H, PhH), 7.11-7.05 (m, 2H, PhH), 4.16 (d,  $J = 6.9$  Hz, 1H,  $\text{OCH}_3$ ), 3.91 (m, 1H, NCH), 3.17 (s, 3H,  $\text{OCH}_3$ ), 2.49 (d,  $J = 8.7$  Hz, 3H,  $\text{NCH}_3$ ), 1.48 (d,  $J = 9.0$  Hz, 3H,  $\text{PCH}_3$ ), 1.16 (d,  $J = 6.8$  Hz, 3H,  $\text{CH}_3$ ), 1.70-0.50 (broad envelope, 3H,  $\text{BH}_3$ );  $^{13}\text{C NMR}$  ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  140.7 (C of the phenyl), 131.1 (C of the phenyl), 131.0 (C of the phenyl), 130.9 (C of the phenyl), 129.2 (C of the phenyl), 129.1 (2C, C of phenyl), 128.5 (C of the phenyl), 128.3 (2C, C of the phenyl), 88.3 (d,  $J = 5.9$  Hz, NCH<sub>3</sub>), 58.5 (d,  $J = 7.8$  Hz, NCH), 57.6 (s,  $\text{OCH}_3$ ), 29.8 (s, OCH), 14.6 (s,  $\text{CH}_3$ ), 12.4 (d,  $J = 11.4$  Hz,  $\text{CH}_3$ );  $^{31}\text{P NMR}$  ( $\text{CDCl}_3$ )  $\delta$  65.23 (d,  $J = 81.4$  Hz); IR (film) 2982, 2934, 2821, 2370 (B-H), 1436, 1095, 1067, 1013, 968, 700  $\text{cm}^{-1}$ ; high resolution mass spectrum calcd. for  $\text{C}_{18}\text{H}_{27}\text{BNOP}$  ( $\text{M}^+$ ) 315.1931. Found 315.1928;  $R_f = 0.317$  (20% EtOAc/hexane); GC: t = 10.73 and 12.41 (70-2-15).

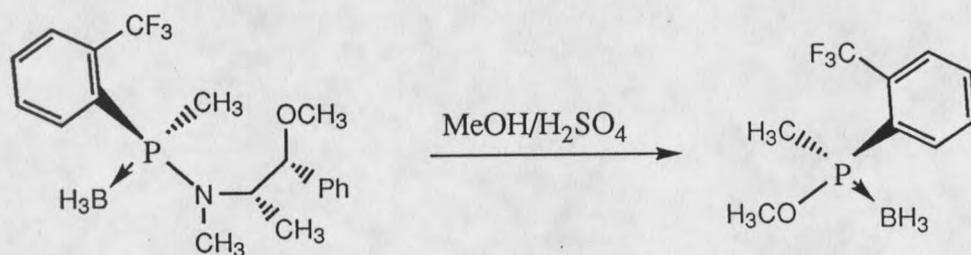
**(Sp)-N-Methyl, N-[(1R, 2S)-(1-methoxy-1-phenyl-2-propyl)] amino-(2-methoxyphenyl)-phenyl phosphine borane (54)**



This compound was prepared by the reaction of complex (48) with *o*-anisyl lithium. The *o*-anisyllithium was prepared from *o*-bromoanisole. An analytically pure sample was isolated by recrystallization with anhydrous methanol: mp 108.5-109.3 °C;  $[\alpha]^{25}_D +11.25^\circ$  (c 1.6 in  $\text{CHCl}_3$ );  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )

$\delta$  7.60-7.53 (m, 2H, ArH), 7.40-7.23 (m, 10H, ArH and PhH), 7.04 (m, 1H, ArH), 6.90 (m, 1H, PhH), 4.35 (d,  $J = 5.0$  Hz, 1H, OCH), 4.25 (m, 1H, NCH), 3.55 (s, 3H, ArOCH<sub>3</sub>), 3.18 (s, 3H, OCH<sub>3</sub>), 2.57 (d,  $J = 8.0$  Hz, 3H, NCH<sub>3</sub>), 1.15 (d,  $J = 6.8$  Hz, 3H, CH<sub>3</sub>), 1.68-0.50 (broad envelope, 3H, BH<sub>3</sub>); <sup>13</sup>C NMR (CDCl<sub>3</sub>, <sup>1</sup>H decoupled)  $\delta$  140.7, 135.7, 135.5, 133.8 (Cs of the phenyl), 131.8, 131.6, 130.6, 128.9 (2C, C of the phenyl and Ar), 128.7, 128.5 (C s of the phenyl), 128.1, 127.9 (2C, C of the phenyl), 121.6, 121.5 (C of the phenyl), 112.4, 112.3 (C of the phenyl), 89.6 (d,  $J = 4.4$  Hz, NCH<sub>3</sub>), 58.6 (d,  $J = 10.8$  Hz, NCH), 57.6 (s, ArOCH<sub>3</sub>), 55.8 (s, OCH<sub>3</sub>), 31.7 (s, OCH), 13.0 (s, CH<sub>3</sub>); <sup>31</sup>P NMR (CDCl<sub>3</sub>)  $\delta$  67.6 (m); IR (film) 2980, 2937, 2823, 2381 (B-H), 1589 (P-Ar), 1477, 1430 (P-N), 1276, 1251 (C-O), 1078, 1020, 965 cm<sup>-1</sup>; high resolution mass spectrum calcd. for C<sub>24</sub>H<sub>31</sub>BNO<sub>2</sub>P (M<sup>+</sup>-H) 406.2089. Found 406.2098; R<sub>f</sub> = 0.27 (20% EtOAc/hexane); GC: t = 15.23 (50-2-15).

**(S)-Methyl-(2-trifluoromethylphenyl)-methylphosphinite borane (58)**

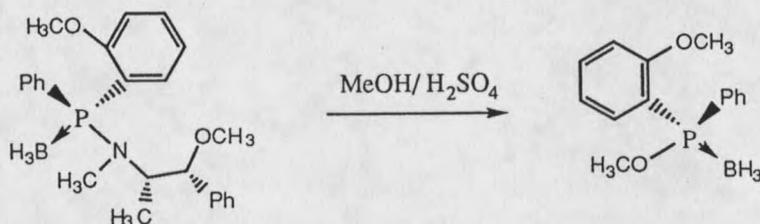


To a 0.125 M solution of pure (49) (3.84 g, 0.01 mol) in methanol (80 mL) was added a solution concentrated sulfuric acid (1.03 g, 0.01 mol) in methanol (5 mL) at 25 °C. The mixture was stirred for 12 h at 25 °C. The methanol was removed under reduced pressure and the resulting crude residue was diluted with anhydrous benzene (20 mL). The organic phase was extracted with 5%

H<sub>2</sub>SO<sub>4</sub> (3 x 5 mL) and 20% NaHCO<sub>3</sub> (3 x 5 mL). The organic phase was dried over Na<sub>2</sub>SO<sub>4</sub> and concentrated *in vacuo* to afford (58) (1.997 g, 85%) as viscous oil.

$[\alpha]^{25}_D +82.5^\circ$  (c 2.0 in CHCl<sub>3</sub>), <sup>1</sup>H NMR (CDCl<sub>3</sub>) δ 8.23-8.16 (m, 1H, ArH), 7.85-7.80 (m, 1H, ArH), 7.67-7.63 (m, 2H, ArH), 3.63 (d, *J* = 12.7 Hz, 3H, OCH<sub>3</sub>), 1.82 (d, *J* = 9.2 Hz, 3H, PCH<sub>3</sub>), 1.35-0.30 (broad envelope, 3H, BH<sub>3</sub>); <sup>13</sup>C NMR (CDCl<sub>3</sub>, <sup>1</sup>H decoupled) δ 136.96 (C of the Ar), 136.68 (C of the Ar), 132.89 (2C, C of the Ar), 132.63 (C of the Ar), 132.46 (C of the Ar), 128.40 (m, CF<sub>3</sub>), 54.94 (app s, OCH<sub>3</sub>), 18.04 (d, *J* = 47.4 Hz, PCH<sub>3</sub>); <sup>31</sup>P NMR (CDCl<sub>3</sub>) δ 117.73; IR (film) 2950, 2848, 2392, 1438, 1312, 1179, 1136, 1121, 1038, 900, 801 cm<sup>-1</sup>; Rf = 0.43 (20% EtOAc/hexane); GC: t = 2.53 and 4.79 (70-2-15).

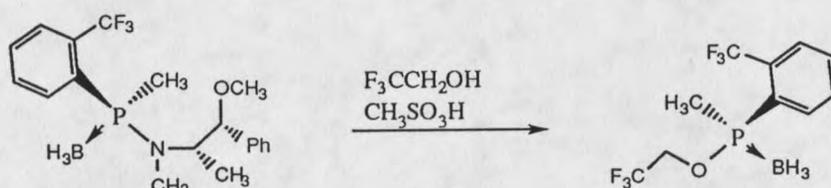
**(*R*)-(2-Methoxyphenyl)-phenyl-methylphosphinite borane (61)**



This compound was prepared by acid methanolysis of aminophosphine borane (54).  $[\alpha]^{25}_D -31.1^\circ$  (c 1.8 in CHCl<sub>3</sub>); e.e. = 100%; <sup>1</sup>H NMR (CDCl<sub>3</sub>) δ 7.82-7.68 (m, 3H, ArH); 7.51-7.37 (m, 4H, ArH and PhH), 7.08-7.03 (m, 1H, PhH), 6.87 (m, 1H, PhH), 3.74 (d, *J* = 12.0 Hz, 3H, PCH<sub>3</sub>), 3.60 (s, 3H, OCH<sub>3</sub>), 1.58-0.42 (broad envelope, 3H, BH<sub>3</sub>); <sup>13</sup>C NMR (CDCl<sub>3</sub>, <sup>1</sup>H decoupled) δ 134.70, 134.53, 131.93 (2C), 131.78 (2C), 128.86, 128.72, 121.63, 121.48, 112.40 (d, *J* = 5.5 Hz) (C of the phenyl and Ar), 56.21 (s ArOCH<sub>3</sub>), 54.90 (app s,

POCH<sub>3</sub>); <sup>31</sup>P NMR (CDCl<sub>3</sub>) δ 106.09 (d, *J* = 85.8 Hz); IR (film) 2942, 2839, 2380 (B-H), 1590, 1478, 1431, 1277, 1251, 1024, 753 cm<sup>-1</sup>; R<sub>f</sub> = 0.28 (20% EtOAc/hexane); GC: t = 9.47 (70-2-15).

**Methyl-(2-trifluoromethylphenyl)-trifluoroethylphosphinite  
borane (59)**

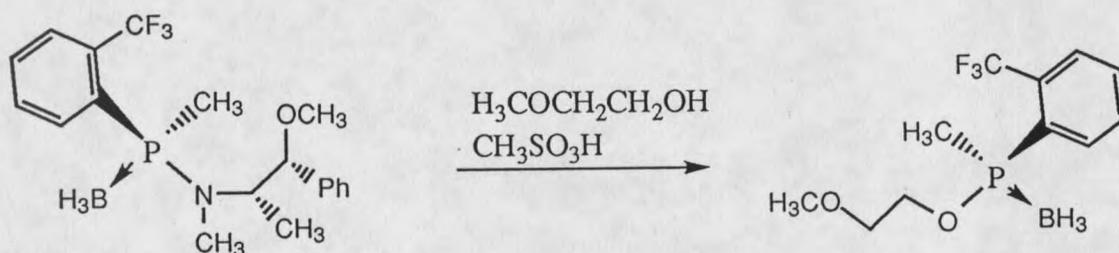


This compound was prepared by two methods. (1) To a 0.125 M solution of pure (49) (0.66 g, 1.72 mmol) in trifluoroethanol (30.25 mL) was added dropwise a solution of methanesulfonic acid (0.24 mL, 3.78 mmol) in trifluoroethanol (5 mL) at 25 °C. Then the resultant solution was stirred for 12 h at 25 °C and then diluted with anhydrous benzene (10 mL). The organic phase was extracted with 5% H<sub>2</sub>SO<sub>4</sub> (3 X 5 mL) and 20% NaHCO<sub>3</sub> (3 x 5 mL). The organic phase was dried over Na<sub>2</sub>SO<sub>4</sub> and concentrated *in vacuo* to furnish a clear liquid. Chromatography on silica gel (15% EtOAc/hexane for elution) afford (59) (0.300g, 40%). (2) To the trifluoroethanol (49 μl, 0.67 mmol) at -78 °C was added *exactly* 1eq. of n-BuLi (134.6 μl of a 5.00 M solution in heptane, 0.67 mmol), then a solution of (49) (0.158 g, 0.71 mmol) in THF (0.2 mL) was added to this mixture at -78 °C. The resulting reaction mixture was then stirred vigorously and slowly warmed to 0 °C for 4 h. The resulting mixture was concentrated *in vacuo* to yield liquid residue which was then diluted with anhydrous benzene (3 mL) and filtered through florisil. Concentration of the

solution followed by chromatography on silica gel (15% EtOAc/hexane for elution) afforded (59) (0.122 g, 60%).

$[\alpha]^{25}_D +20.0^\circ$  (c 2.0 in  $\text{CHCl}_3$ ), (from method 1);  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )  $\delta$  8.23-8.15 (m, 1H, ArH), 7.86-7.83 (m, 1H, ArH), 7.70-7.65 (m, 2H, ArH), 4.49-4.34 (m, 1H,  $\text{OCH}_2$ ), 4.17-4.03 (m, 1H,  $\text{OCH}_2$ ), 1.93 (d,  $J = 9.0$  Hz, 3H,  $\text{PCH}_3$ ), 1.50-0.40 (broad envelope, 3H,  $\text{BH}_3$ );  $^{13}\text{C NMR}$  ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  136.37, 136.10, 133.44 (2C), 132.72, 132.55 (C s of the Ar), 128.64 (m,  $\text{ArCF}_3$ ), 64.3 (m,  $\text{CF}_3$ ), 25.0 (app s, CH2), 19.7 (d,  $J = 44.0$  Hz,  $\text{PCH}_3$ );  $^{31}\text{P NMR}$  ( $\text{CDCl}_3$ )  $\delta$  124.43 (app. d,  $J = 66.2$ Hz); IR (film) 2927, 2855, 2396 (B-H), 1313, 1174, 1141, 1122, 1094, 909, 738  $\text{cm}^{-1}$ ; Rf = 0.32 (20% EtOAc/hexane), GC: t = 2.74 and 4.74 (70-2-15).

**Methyl-(2-trifluoromethylphenyl)-2-methoxyethylphosphinite  
borane (60)**

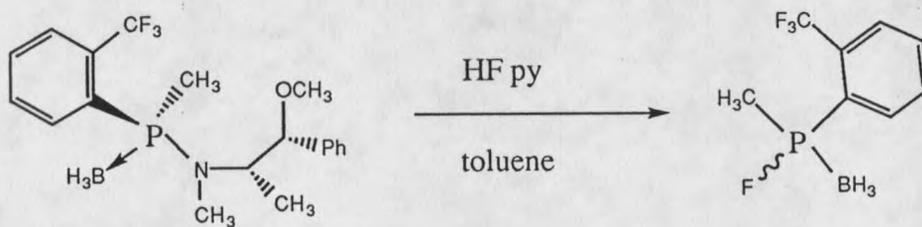


To a solution of 0.125 M of (49) (0.618 g, 1.61 mmol) in 2-methoxyethanol (32 mL) was added a solution of  $\text{CH}_3\text{SO}_3\text{H}$  (261.1  $\mu\text{L}$ , 4.03 mmol) in 2 methoxyethanol (4 mL) at 25  $^\circ\text{C}$ . The resultant mixture was stirred at 25  $^\circ\text{C}$  for 12 h and then concentrated *in vacuo* to yield liquid residue which was diluted with anhydrous benzene (10 mL). The organic phase was extracted with 5%  $\text{H}_2\text{SO}_4$  (3 x 5 mL) and 20%  $\text{NaHCO}_3$  (3 x 5 mL). Concentration of the

organic phase followed by chromatography on silica gel (20% EtOAc/hexane for elution) afforded (**60**) (0.251 g, 60%).

$[\alpha]^{25}_D +17.0^\circ$  (c 2.0 in  $\text{CHCl}_3$ );  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )  $\delta$  8.26-8.18 (m, 1H, ArH), 7.84-7.80 (m, 1H, ArH), 7.66-7.62 (m, 2H, ArH), 4.21-4.11 (m, 1H,  $\text{POCH}_2$ ), 3.94-3.85 (m, 1H,  $\text{POCH}_2$ ), 3.56 (t,  $J = 9.5$  Hz, 2H,  $\text{CH}_3\text{OCH}_2$ ), 3.31 (s, 3H,  $\text{OCH}_3$ ), 1.86 (d,  $J = 9.2$  Hz, 3H,  $\text{CH}_3$ ), 1.48-0.32 (broad envelope, 3H,  $\text{BH}_3$ );  $^{13}\text{C NMR}$  ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  136.54 (C of the Ar), 136.29 (C of the Ar), 132.78 (2C, C of the Ar), 132.56 (C of the Ar), 132.40 (C of the Ar), 128.47 (m,  $\text{CF}_3$ ), 72.35 (d,  $J = 6.8$  Hz,  $\text{POCH}_2$ ), 67.33 (app s,  $\text{OCH}_3\text{CH}_2$ ), 59.51 (s,  $\text{OCH}_3$ ), 18.7 (d,  $J = 44.2$  Hz,  $\text{PCH}_3$ ),  $^{31}\text{P NMR}$  ( $\text{CDCl}_3$ )  $\delta$  116.35 (app. d,  $J = 76.7$  Hz); IR (film) 2929, 2888, 2387 (B-H), 1312, 1173, 1120, 1037, 956, 908, 772  $\text{cm}^{-1}$ ; Rf = 0.315 (20% EtOAc/hexane); GC: t = 6.04 (70-2-15).

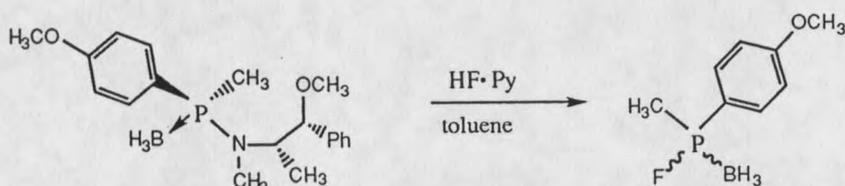
### Fluoromethyl-(2-trifluoromethylphenyl)-phosphine borane (**62**)



A solution of (**49**) (1.0 g, 2.6 mmol) in toluene (5 mL) was added over 10 min to a HF·py (1.0g, 2eq weight) in toluene (5 mL) at  $-78^\circ\text{C}$  (HF·py was transferred by plastic pipette under the Ar gas). After 15 min at  $-78^\circ\text{C}$ , the mixture was warmed to  $-25^\circ\text{C}$  and stirred vigorously for 5 h. After the reaction was quenched with 25% KF (10 mL), the mixture was diluted with ether. The organic phase was separated and combined with two 5 mL ether extractions of

the aqueous phase. The organic phases were dried over  $\text{MgSO}_4$  and concentrated *in vacuo* to afford (62) (0.460 g, 86.2%) as a clear liquid. An analytically pure sample was prepared by bulb-to-bulb distillation (50 °C, 1.0 mm):  $[\alpha]^{25}_{\text{D}} +2.0^\circ$  (c 2.0 in  $\text{CHCl}_3$ );  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  8.26-8.10 (m, 1H, ArH), 7.86-7.85 (m, 1H, ArH), 7.75-7.72 (m, 2H, ArH), 2.07-2.00 (dd,  $J = 8.7$  and 12.37 Hz, 3H,  $\text{PCH}_3$ ), 1.52-0.40 (broad envelope, 3H,  $\text{BH}_3$ );  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  134.50 (C of the Ar), 134.41 (C of the Ar), 134.24 (C of the Ar), 134.15 (C of the Ar), 133.13 (C of the Ar), 132.2 (d,  $J = 12.8$  Hz, C of the Ar), 127.91 (m,  $\text{CF}_3$ ), 18.44 (dd,  $J = 11.9$  and 33.7 Hz,  $\text{CH}_3$ );  $^{31}\text{P}$  NMR ( $\text{CDCl}_3$ )  $\delta$  162.85 (app. d,  $J = 59.0$  Hz), 158.28 (app. d,  $J = 64.4$  Hz); IR (film) 3227, 2392 (B-H), 1313, 1181, 1125, 899, 771  $\text{cm}^{-1}$ ; Rf = 0.31 (20% EtOAc/hexane); GC: t = 2.94, 4.58 (70-2-15).

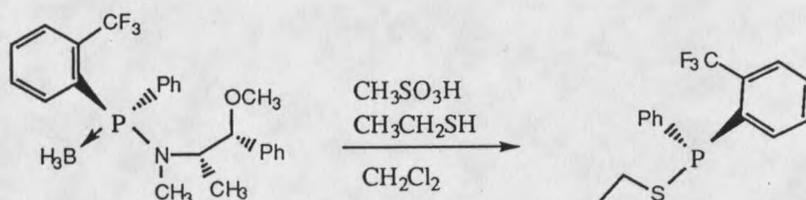
### Fluoromethyl-(4-methoxyphenyl)-phosphine borane (64)



This fluorophosphine compound was prepared by the reaction of (52) with HF·py. Bulb-to-bulb distillation (58 °C, 1.0 mm) gave 0.425 g (88%) of (64) as clear liquid.  $[\alpha]^{25}_{\text{D}} +2.3^\circ$  (c 2.1 in  $\text{CHCl}_3$ );  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  7.80-7.76 (app. q, 2H, ArH), 7.03-7.00 (app. q, 2H, ArH), 3.86 (s, 3H,  $\text{OCH}_3$ ), 1.94 (dd,  $J = 8.7$  and 12.2 Hz, 3H,  $\text{CH}_3$ ), 1.50-0.40 (broad envelope, 3H,  $\text{BH}_3$ );  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  133.67 (C of the Ar), 133.48 (C of the Ar), 115.38 (C of the Ar), 115.23 (C of the Ar), 56.18 (s,  $\text{OCH}_3$ ), 17.20 (dd,  $J = 16.0$  and 38.2 Hz,  $\text{PCH}_3$ );

$^{31}\text{P}$  NMR ( $\text{CDCl}_3$ )  $\delta$  156.74 (app d,  $J = 71.4$  Hz), 152.24 (app d,  $J = 62.1$  Hz), IR (film) 2937, 2385 (B-H), 1597, 1506, 1296, 1262, 1124, 894, 814  $\text{cm}^{-1}$ ;  $R_f = 0.23$  (20% EtOAc/hexane); GC:  $t = 6.44$  (70-2-15).

### Phenyl-(2-trifluoromethylphenyl)-ethylthiophosphinite (68b)

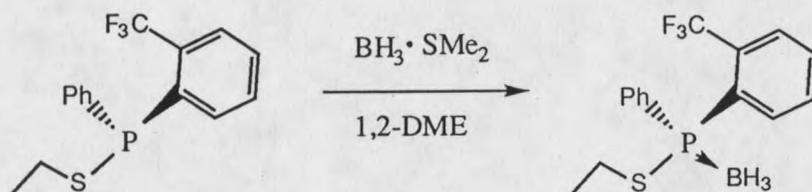


To a solution of pure (49) (0.445 g, 1 mmol) in  $\text{CH}_2\text{Cl}_2$  (2.5 mL) was added  $\text{CH}_3\text{CH}_2\text{SH}$  (1.48 mL, 20 mmol) followed by  $\text{CH}_3\text{SO}_3\text{H}$  (0.13 mL, 2 mmol) at  $-5$  °C. The resultant mixture was stirred for 12 h at  $-5$  °C and then diluted with  $\text{Et}_2\text{O}$ . The organic phases were extracted with saturated  $\text{NaHCO}_3$  (3 x 8 mL) and brine (3 x 5 mL). The organic phases were dried over  $\text{Na}_2\text{SO}_4$  and filtered through florisil. Concentration of the solution followed by chromatography on silica gel (15% EtOAc/hexane for elution) afforded (68b) (0.377 g, 85%) as a clear liquid.

$[\alpha]^{25}_{\text{D}} -8.4^\circ$  (c 1.9 in  $\text{CHCl}_3$ ),  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  7.83-7.80 (m, 1H, ArH), 7.73-7.69 (m, 1H, ArH), 7.53-7.42 (m, 4H, ArH and PhH), 7.34-7.28 (m, 3H, PhH), 2.83 (m, 2H,  $\text{SCH}_2$ ), 1.36 (t,  $J = 14.8$  Hz, 3H,  $\text{CH}_3$ );  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  136.65 (C of the Ar), 132.57 (2C, C of the Ar), 132.31 (C of the phenyl), 129.98 (m, C of the Ar and phenyl), 129.31 (C of the phenyl), 129.10 (C of the phenyl), 129.02 (2C, C of the phenyl), 126.55 (m,  $\text{CF}_3$ ), 29.18 (d,  $J = 27.2$  Hz,  $\text{SCH}_2$ ), 17.68 (d,  $J = 7.2$  Hz,  $\text{CH}_3$ );  $^{31}\text{P}$  NMR ( $\text{CDCl}_3$ )  $\delta$  22.14 (q,

$J = 177.1\text{ Hz}$ ; IR (film) 3058, 2974, 2926, 1434, 1310, 1260, 1172, 1115, 968, 768  $\text{cm}^{-1}$ ;  $R_f = 0.51$  (20% EtOAc/hexane); GC:  $t = 9.40$  (70-2-15).

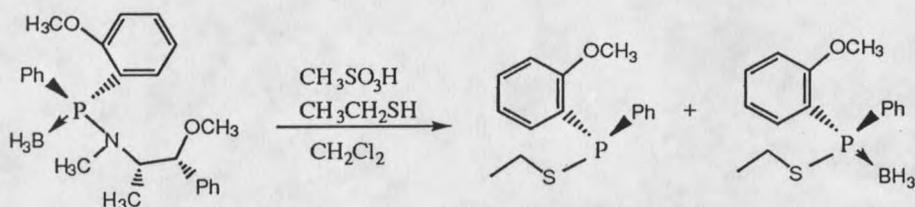
### Phenyl-(2-trifluoromethylphenyl)-ethylthiophosphinite borane (68a)



To a solution of (68b) (0.053 g, 0.17 mmol) in 1,2-DME (1.5 mL) was added  $\text{BH}_3\cdot\text{SMe}_2$  (18.5  $\mu\text{L}$  of a 10.0 M solution, 0.185 mmol) at 0  $^\circ\text{C}$ . The reaction mixture was then stirred for additional 6 h at 25  $^\circ\text{C}$ . The resulting mixture was concentrated *in vacuo* to yield (68a) (0.049 g, 90%) as a clear liquid. An analytically pure sample was prepared by column chromatography on silica gel (15% EtOAc/hexane for elution).

$[\alpha]_D^{25} +3.3^\circ$  (c 2.4 in  $\text{CHCl}_3$ );  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )  $\delta$  8.52-8.45 (m, 1H, ArH), 7.78-7.56 (m, 5H, ArH and PhH), 7.45-7.35 (m, 3H, PhH), 3.10-2.95 (m, 2H,  $\text{SCH}_2$ ), 1.33 (t,  $J = 14.9$  Hz, 3H,  $\text{CH}_3$ ), 1.80-0.70 (broad envelope, 3H,  $\text{BH}_3$ );  $^{13}\text{C NMR}$  ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  137.26 (C of the Ar), 137.04 (C of the Ar), 132.73 (C of the Ar), 132.51 (m, C of the Ar and phenyl), 132.35 (C of the phenyl), 131.88 (C of the phenyl), 131.75 (2C, C of the phenyl), 129.50 (m,  $\text{CF}_3$ ), 129.18 (m, C of the phenyl), 129.04 (C of the phenyl), 26.73 (app s,  $\text{SCH}_2$ ), 17.07 (s,  $\text{CH}_3$ );  $^{31}\text{P NMR}$  ( $\text{CDCl}_3$ )  $\delta$  55.07 (app. s); IR (film) 2928, 2399 (B-H), 1437, 1311, 1172, 1117, 1035, 770  $\text{cm}^{-1}$ ;  $R_f = 0.33$  (20% EtOAc/hexane); GC:  $t = 9.40$  (70-2-15).

### Phenyl-(2-methoxyphenyl)-ethylthiophosphinite (69b)



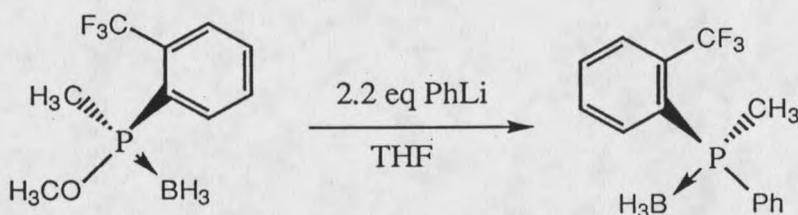
This compound was prepared by the reaction of (54) with  $\text{CH}_3\text{CH}_2\text{SH}$  /  $\text{CH}_3\text{SO}_3\text{H}$ . The analytically pure product was isolated by column chromatography on silica gel (15% EtOAc/hexane) in 46% yield (1st fraction):  $[\alpha]^{25}_{\text{D}} +2.0^\circ$  (c 5.1 in  $\text{CHCl}_3$ );  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )  $\delta$  7.62-7.57 (m, 1H, ArH), 7.48-7.43 (m, 2H, ArH), 7.34-7.26 (m, 4H, ArH and PhH), 7.01-6.98 (t,  $J = 16.0$  Hz, PhH), 6.87-6.82 (app. q,  $J = 12.7$  Hz, 1H, PhH), 3.73 (s, 3H,  $\text{OCH}_3$ ), 2.77-2.70 (m, 2H,  $\text{SCH}_2$ ), 1.35 (t,  $J = 14.8$  Hz, 3H,  $\text{CH}_3$ );  $^{13}\text{C NMR}$  ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  134.03 (C of the Ar), 133.94 (C of the Ar), 133.04 (C of the Ar), 132.76 (m, C of the Ar and phenyl), 131.55 (C of the Ar), 129.21 (C of the phenyl), 128.89 (C of the phenyl), 128.80 (C of the phenyl), 121.78 (C of the phenyl), 111.43 (C of the phenyl), 56.40 (s,  $\text{OCH}_3$ ), 28.98 (d,  $J = 26.2$  Hz,  $\text{SCH}_2$ ), 17.75 (d,  $J = 7.0$  Hz,  $\text{CH}_3$ );  $^{31}\text{P NMR}$  ( $\text{CDCl}_3$ )  $\delta$  17.07; IR (film) 3100, 3020, 1470, 1431, 1240, 1023, 754  $\text{cm}^{-1}$ ;  $R_f = 0.446$  (20% EtOAc/hexane); GC:  $t = 12.04$  (50-2-15).

### Phenyl-(2-methoxyphenyl)-ethylthiophosphinite borane (69a)

The analytically pure product was isolated by column chromatography on silica gel (15% EtOAc/hexane) in 30 % yield (2nd fraction):  $[\alpha]^{25}_{\text{D}} +8.3^\circ$  (C 0.6 in  $\text{CHCl}_3$ );  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )  $\delta$  8.01 (m, 1H ArH), 7.74-7.67 (m, 2H, ArH), 7.52-7.33 (m, 4H, ArH and PhH), 7.10-7.04 (m, 1H, PhH), 6.87 (app. q,  $J = 12.1$  Hz, 1H, PhH), 3.61 (s, 3H,  $\text{OCH}_3$ ), 3.01-2.90 (m, 2H,  $\text{SCH}_2$ ), 1.32 (t,  $J = 14.8$  Hz, 3H,  $\text{CH}_3$ );  $^{13}\text{C NMR}$  ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  135.32 (C of the Ar), 135.14 (C of the

Ar), 134.60, 131.97, 131.83, 131.16, 128.91, 128.76, 121.75, 121.59, 112.51 (C of the Ar and phenyl), 112.46 (C of the phenyl), 56.18 (s, OCH<sub>3</sub>), 26.03 (app s, SCH<sub>2</sub>), 17.28 (d, *J* = 4.9 Hz, CH<sub>3</sub>); <sup>31</sup>P NMR (CDCl<sub>3</sub>) δ 45.42; IR (flim) 2970, 2890, 2391 (B-H), 1588, 1477, 1435, 1277, 1251, 1053, 1020, 756 cm<sup>-1</sup>; R<sub>f</sub> = 0.35 (20% EtOAc/hexane); GC: t = 12.04 (50-2-15).

**(S)-Methyl-phenyl-(2-trifluoromethylphenyl)-phosphine borane (71)**

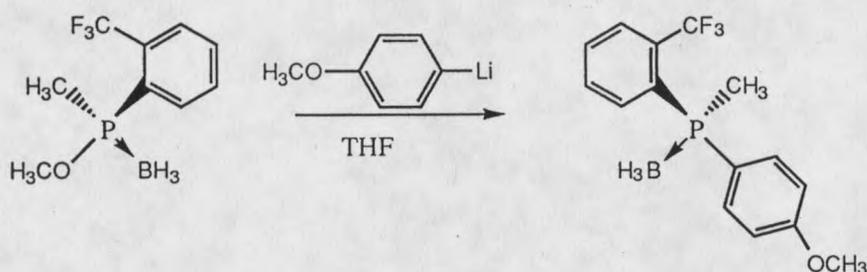


A solution of pure (62) (0.708 g, 3.0 mmol) in THF (3.0 mL) at -78 °C was treated with Ph-Li (1.14 M in Et<sub>2</sub>O, 5.79 mL, 6.6 mmol). After 15 minutes, the mixture was warmed to 0 °C and stirred for 27 h at 0 °C. After the reaction was quenched with saturated NH<sub>4</sub>Cl (10 mL), the mixture was diluted with anhydrous benzene. The organic phase was decanted and extracted with brine (3 x 5 mL). The organic phase was dried over Na<sub>2</sub>SO<sub>4</sub> and concentrated *in vacuo* to afford a crude product as a clear liquid. An analytically pure product was isolated by column chromatography on silica gel (15% EtOAc/hexane for elution) in 78% (0.658 g) yield.

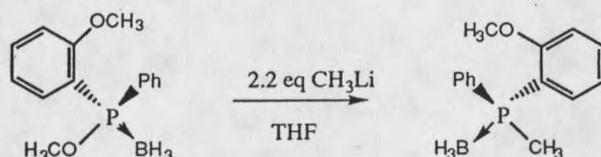
[α]<sub>D</sub><sup>25</sup> +2.8° (c 11.1 in CHCl<sub>3</sub>); <sup>1</sup>H NMR (CDCl<sub>3</sub>) δ 8.29-8.23 (m, 1H, ArH), 7.79-7.76 (m, 1H, ArH), 7.67-7.64 (m, 2H, ArH), 7.50-7.35 (m, 5H, PhH), 2.02 (d, *J* = 10.0 Hz, 3H, PCH<sub>3</sub>), 1.60-0.45 (broad envelope, 3H, BH<sub>3</sub>); <sup>13</sup>C NMR (CDCl<sub>3</sub>, <sup>1</sup>H decoupled) δ 138.10 (C of the Ar), 137.89, 132.65, 132.50, 132.38, 131.69, 131.56 (2C), 131.50, 129.35 (all Cs of the Ar and phenyl), 129.21 (C of

the phenyl), 128.70 (m,  $\text{CF}_3$ ), 13.17 (d,  $J = 42.7$  Hz,  $\text{PCH}_3$ ),  $^{31}\text{P}$  NMR ( $\text{CDCl}_3$ )  $\delta$  17.83 (d,  $J = 61.1$  Hz); IR (film) 3060, 2372(B-H), 2342, 1438, 1313, 1264, 1179, 1119, 1065, 1037, 897, 771  $\text{cm}^{-1}$ ;  $R_f = 0.36$  (20% EtOAc/hexane); GC:  $t = 7.70$  (70-2-15).

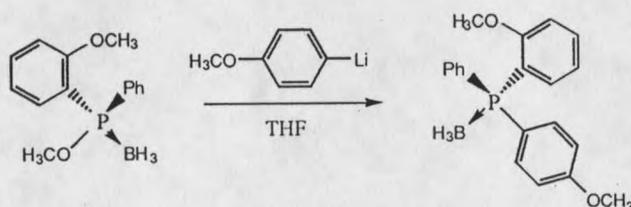
**(S)-(4-Methoxyphenyl)-methyl-(2-trifluoromethylphenyl)-phosphine borane (72)**



Chromatography on silica gel (20% EtOAc/hexane for elution) afforded **(72)** (0.562 g, 60%) as a viscous oil:  $[\alpha]^{25}_{\text{D}} +10.4^\circ$  (c 2.5 in  $\text{CHCl}_3$ );  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  8.25-8.15 (m, 1H, ArH), 7.76-7.70 (m, 1H, ArH), 7.64-7.60 (m, 2H, ArH), 7.46-7.40 (m, 2H, ArH), 6.93-6.89 (m, 2H, ArH), 3.80 (s, 3H,  $\text{OCH}_3$ ), 1.98 (d,  $J = 10.0$  Hz, 3H,  $\text{PCH}_3$ );  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  137.02 (C of the Ar), 136.82 (C of the Ar), 133.04 (2C, C of the Ar), 132.89 (2C, C of the Ar), 131.97 (C of the Ar), 131.82 (C of the Ar), 131.5 (C of the Ar), 127.96 (m,  $\text{CF}_3$ ), 114.45 (C of the Ar), 114.30 (C of the Ar), 55.33 (s,  $\text{OCH}_3$ ), 13.59 (d,  $J = 12.0$  Hz,  $\text{PCH}_3$ );  $^{31}\text{P}$  NMR ( $\text{CDCl}_3$ )  $\delta$  16.55 (d,  $J = 30.0$  Hz); IR (film) 2964, 2840, 2376, 1596, 1503, 1311, 1256, 1179, 1114, 1036, 769  $\text{cm}^{-1}$ ;  $R_f = 0.30$  (20% EtOAc/hexane); GC:  $t = 9.18$  (70-2-15).

**(S)-(2-Methoxyphenyl)-methyl-phenyl-phosphine borane (73)**

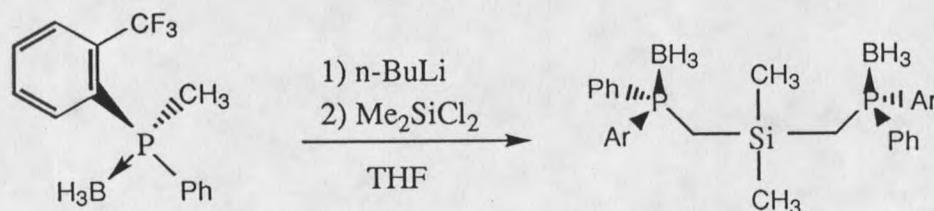
Concentration of the solution gave the title compound as a white solid. Recrystallization with anhydrous hexane afforded **(73)** 0.640 g (87%) of the pure complex: mp 68.0-68.9 °C;  $[\alpha]^{25}_D +8.3^\circ$  (c 0.6 in  $\text{CHCl}_3$ );  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )  $\delta$  7.91-7.84 (m, 1H, ArH), 7.65-7.58 (m, 2H, ArH), 7.50-7.45 (m, 1H, ArH), 7.40-7.34 (m, 2H, PhH), 7.06-7.03 (m, 1H, PhH), 6.89-6.85 (m, 1H, PhH), 3.66 (s, 3H, OCH<sub>3</sub>), 1.95 (d,  $J = 10.5$  Hz, 3H, PCH<sub>3</sub>); 1.60-0.48 (broad envelope, 3H, BH<sub>3</sub>);  $^{13}\text{C NMR}$  ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  136.19, 135.99, 134.29, 131.78 (2C), 131.65, 130.91, 128.93, 128.79, 121.70, 121.54, 111.90 (Cs of the phenyl and Ar), 55.95 (s, OCH<sub>3</sub>), 11.48 (d,  $J = 39.0$  Hz, PCH<sub>3</sub>),  $^{31}\text{P NMR}$  ( $\text{CDCl}_3$ )  $\delta$  8.17 (d,  $J = 73.4$  Hz); IR (film) 3059, 2940, 2374 (B-H), 1590, 1575, 1479, 1435, 1278, 1250, 1063, 1021, 895, 758  $\text{cm}^{-1}$ ; R<sub>f</sub> = 0.25 (20% EtOAc/hexane); GC: t = 9.00 (70-2-15).

**(R)-(2-Methoxyphenyl)-(4-methoxyphenyl)-phenyl-phosphine borane (74)**

Recrystallization with anhydrous hexane afforded **(74)** 0.902 g (89%): mp 123.7-124.7 °C;  $[\alpha]^{25}_D -23.6^\circ$  (c 1.1 in  $\text{CHCl}_3$ );  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )  $\delta$  7.59-

7.4(m, 11H, ArH and PhH), 7.01-6.88 (m, 2H, PhH), 3.81 (s, 3H, OCH<sub>3</sub>), 3.53 (s, 3H, OCH<sub>3</sub>), 1.65-0.50 (broad envelope, 3H, BH<sub>3</sub>), <sup>13</sup>C NMR (CDCl<sub>3</sub>, <sup>1</sup>H decoupled) δ 136.73 (C of the Ar), 136.58 (C of the Ar), 135.66 (2C, C of the Ar), 135.51 (2C, C of the Ar), 134.32 (C of the Ar), 133.34 (2C, C of the Ar), 133.21 (2C, C of the Ar), 131.08 (C of the Ar), 129.00(m, C of the Ar), 128.86 (C of the Ar), 121.93 (C of the Ar), 121.78 (C of the Ar), 114.85 (C of the Ar), 114.70 (C of the Ar), 112.53 (d, *J* = 4.3 Hz) (C of the Ar), 56.03 (s, OCH<sub>3</sub>), 55.9 (s, OCH<sub>3</sub>); <sup>31</sup>P NMR (CDCl<sub>3</sub>) δ 16.41; IR (film) 3067, 2939, 2838, 2379 (B-H), 1596, 1502, 1478, 1436, 1254, 1182, 1108, 1060, 1023, 802, 757 cm<sup>-1</sup>; R<sub>f</sub> = 0.19 (20% EtOAc/hexane); GC: t = 13.33 and 14.99 (70-2-15).

**(*S,S*)-Bis[(phenyl-(2-trifluoromethylphenyl)-phosphino-borane)-methylene] dimethylsilane (75)**

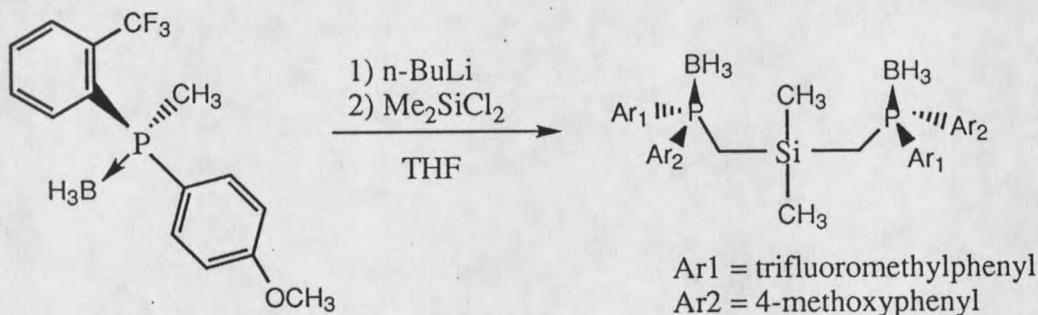


Ar = 2-trifluoromethylphenyl

A solution of (71) (0.325 g, 1.15 mmol) in THF (1.5 mL) was treated with *sec*-BuLi (1.37 M in cyclohexane, 0.92 mL, 1.26 mmol) at -78 °C. After 45 min, dichlorodimethylsilane (76.88 μL, 0.630 mmol) was added to the mixture. The resultant solution was stirred at -78 °C for 30 min and then warmed up to 25 °C for 40 min. After the reaction was quenched with saturated NH<sub>4</sub>Cl, the mixture was diluted with Et<sub>2</sub>O (5 mL). The organic phase was separated and filtered through florisil. Concentration of the solution gave the crude product as viscous

oil. Chromatography on silica gel (22% EtOAc/hexane for elution) afforded (**75**) (0.468 g, 69%) as a white solid: mp 86.0-87.8 °C;  $[\alpha]^{25}_D +58.5^\circ$  (c 1.0 in  $\text{CHCl}_3$ );  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )  $\delta$  8.52-8.44 (dd,  $J = 10.4$  and  $17.7$  Hz, 2H, ArH); 7.76-7.64 (m, 6H, ArH); 7.40-7.34 (m, 10H, ArH), 2.04-1.90 (m, 4H, SiCH<sub>2</sub>), 1.70-0.50 (broad envelope, 3H, BH<sub>3</sub>), -0.220 (s, 6H, SiCH<sub>3</sub>);  $^{13}\text{C NMR}$  ( $\text{CDCl}_3$ ,  $^1\text{H}$  decoupled)  $\delta$  138.93 (2C), 138.87 (2C), 133.64 (2C), 132.58 (2C), 131.27 (2C), 131.13 (2C), 131.13 (4C) (Cs of the phenyl and Ar), 128.97 (m, 2C, CF<sub>3</sub>), 12.61 (d,  $J = 12.6$  Hz, 2C, SiCH<sub>2</sub>), 0.641 (s, 2C, SiCH<sub>3</sub>);  $^{31}\text{P NMR}$  ( $\text{CDCl}_3$ )  $\delta$  21.41; IR (film) 3201, 3057, 2963, 2388 (B-H), 1438, 1311, 1265, 1181, 1116, 1036, 737  $\text{cm}^{-1}$ ; R<sub>f</sub> = 0.20 (20% EtOAc/hexane); GC: t = 14.13 (100-2-15).

**(S,S)-Bis[[(4-methoxyphenyl)-(2-trifluoromethylphenyl)-phosphino-borane)-methylene] dimethylsilane (**76**)**



Concentration of the solution gave the crude product as white solid. Recrystallization with anhydrous hexane afforded (**76**) (0.603 g, 81%): mp 162.0-167.4 °C;  $[\alpha]^{25}_D +30.0^\circ$  (c 0.6 in  $\text{CHCl}_3$ );  $^1\text{H NMR}$  ( $\text{CDCl}_3$ )  $\delta$  8.42-8.31 (dd,  $J = 11.5$  and  $23.0$  Hz, 2H, ArH); 7.76-7.58 (m, 6H, ArH); 7.38-7.30 (m, 4H, ArH), 6.95-6.82 (m, 4H, ArH), 3.79 (s, 6H, OCH<sub>3</sub>), 1.98-1.72 (m, 4H, SiCH<sub>2</sub>), 1.53-0.50 (broad envelope, 3H, BH<sub>3</sub>), -0.230 (s, 6H, SiCH<sub>3</sub>);  $^{13}\text{C NMR}$  ( $\text{CDCl}_3$ ,

$^1\text{H}$  decoupled)  $\delta$  138.32 (2C), 138.10 (2C), 139.92 (2C), 132.14 (2C), 132.13 (2C), 131.94 (4C), 130.73 (2C), 130.69 (4C), 130.49 (4C), 128.47 (m, 2C,  $\text{CF}_3$ ), 50.87 (2C) (Cs of Ar), 12.13 (dd,  $J = 11.5$  and  $24.1\text{Hz}$ , 2C,  $\text{SiCH}_2$ ), 0.125 (s, 2C,  $\text{SiCH}_3$ );  $^{31}\text{P}$  NMR ( $\text{CDCl}_3$ )  $\delta$  19.85; IR (film) 2894, 2843, 2377 (B-H), 1596, 1503, 1313, 1257, 1172, 1137, 1106, 1034, 825, 790  $\text{cm}^{-1}$ ;  $R_f = 0.09$  (20% EtOAc/hexane); GC:  $t = 16.38$  (100-2-15).

## CONCLUSION

(1) An efficient and operationally simple procedure for the synthesis of 2-substituted oxazaphospholidine derivative has been developed. This new method permits the large scale preparation of a range of electronically and sterically differentiated homochiral monophosphine precursors.

(2) Various homochiral phosphine borane derivatives have been synthesized and studied. This included the aminophosphine boranes, phosphinite boranes, fluorophosphine boranes and thiophosphine boranes.

(3) New homochiral monophosphine ligands have been synthesized with high enantiomeric purity.

(4) New homochiral biphosphine ligands have been synthesized. These biphosphine ligands should find numerous applications as enantioselective modifiers for many transformations catalyzed by transition metal complexes.

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**APPENDIX**

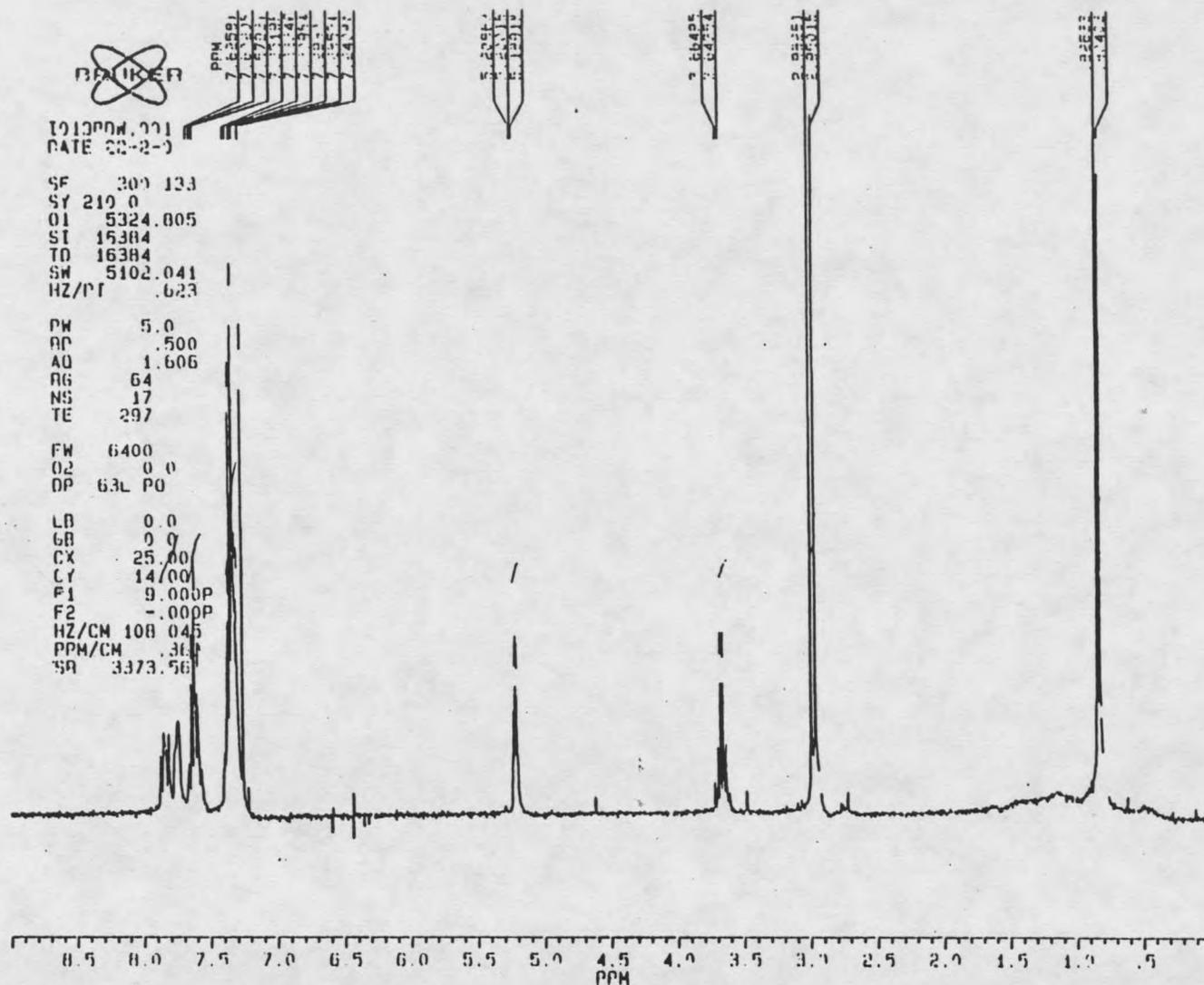


Figure 7.  $^1\text{H}$  NMR Spectrum of (2*R*, 4*S*, 5*R*)-2-(2-trifluoromethylphenyl)-3,4-dimethyl-5-phenyl-1,3,2-oxazaphospholidine 2-borane (42)

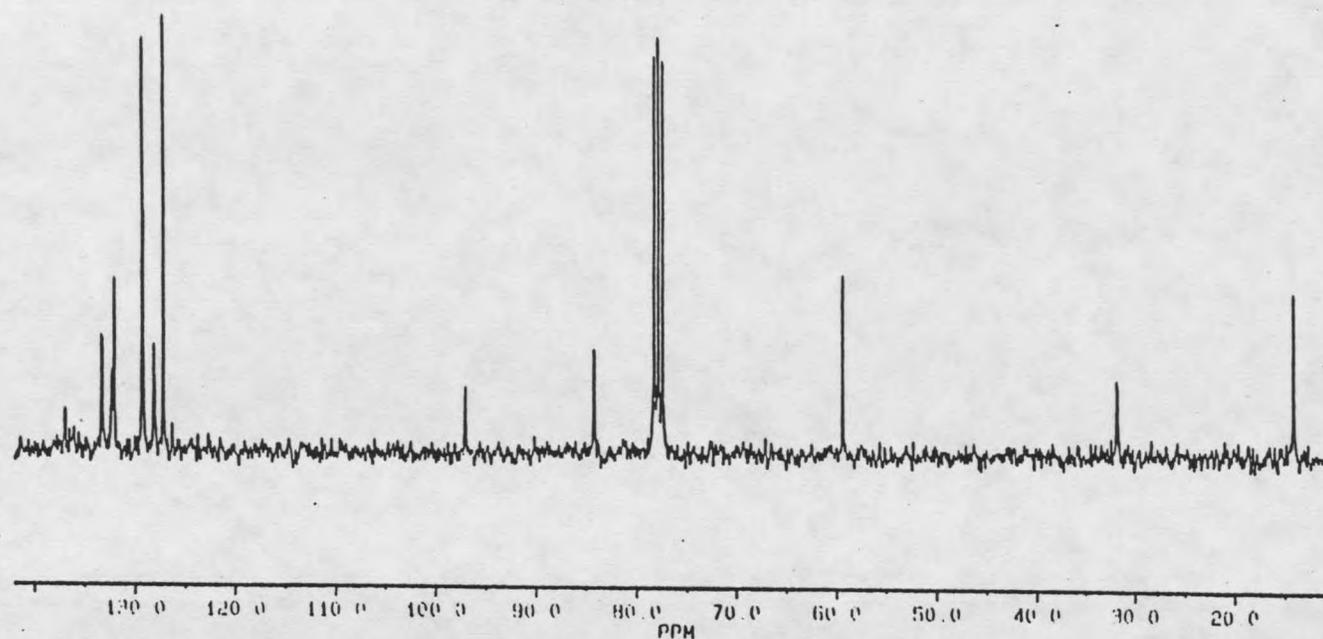
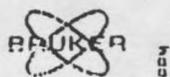


Figure 8.  $^{13}\text{C}$  NMR Spectrum of (2*R*, 4*S*, 5*R*)-2-(2-trifluoromethylphenyl)-3,4-dimethyl-5-phenyl-1,3,2-oxazaphospholidine 2-borane (42)



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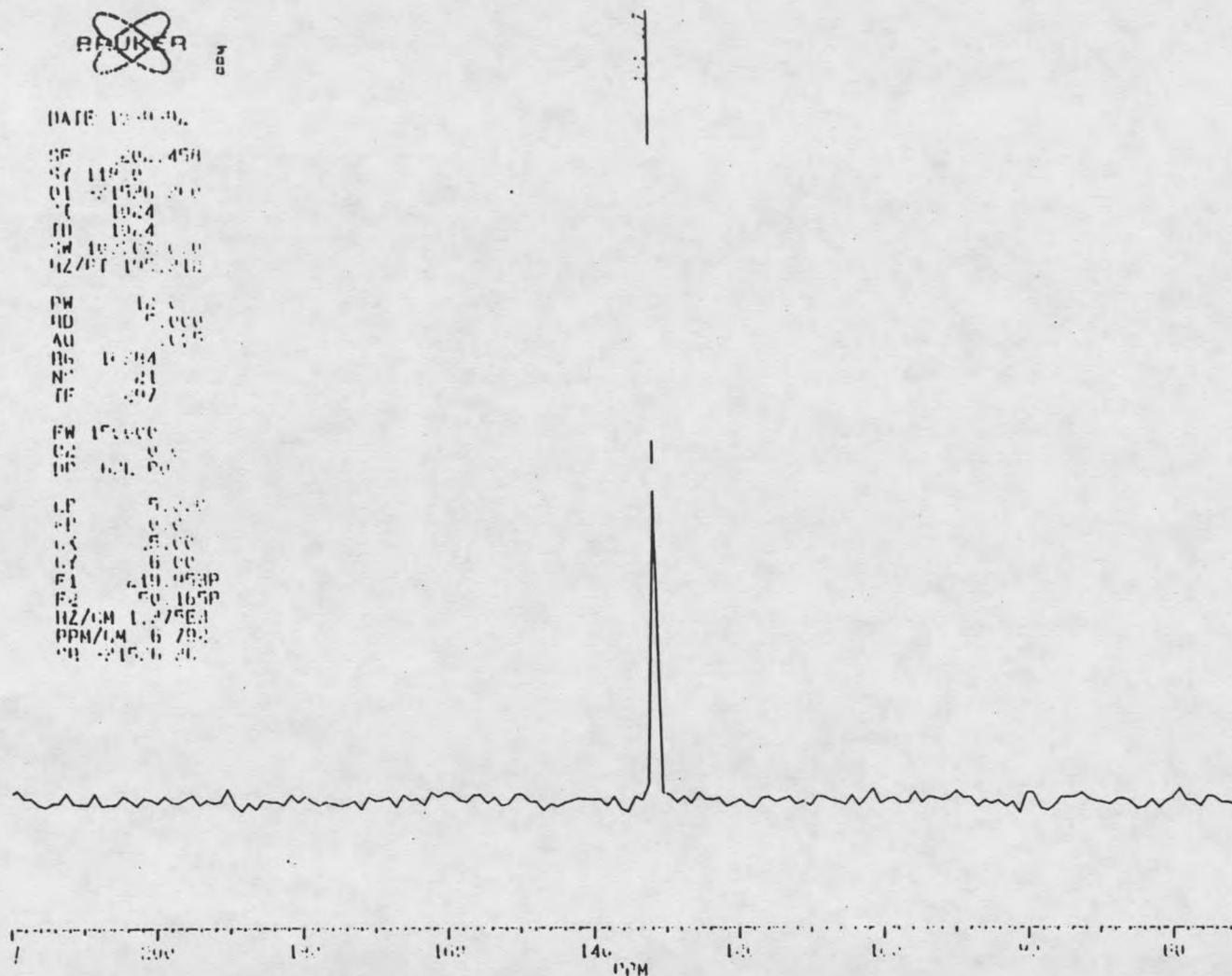


Figure 9.  $^{31}\text{P}$  NMR Spectrum of (2*R*, 4*S*, 5*R*)-2-(2-trifluoromethylphenyl)-3,4-dimethyl-5-phenyl-1,3,2-oxazaphospholidine 2-borane (42)

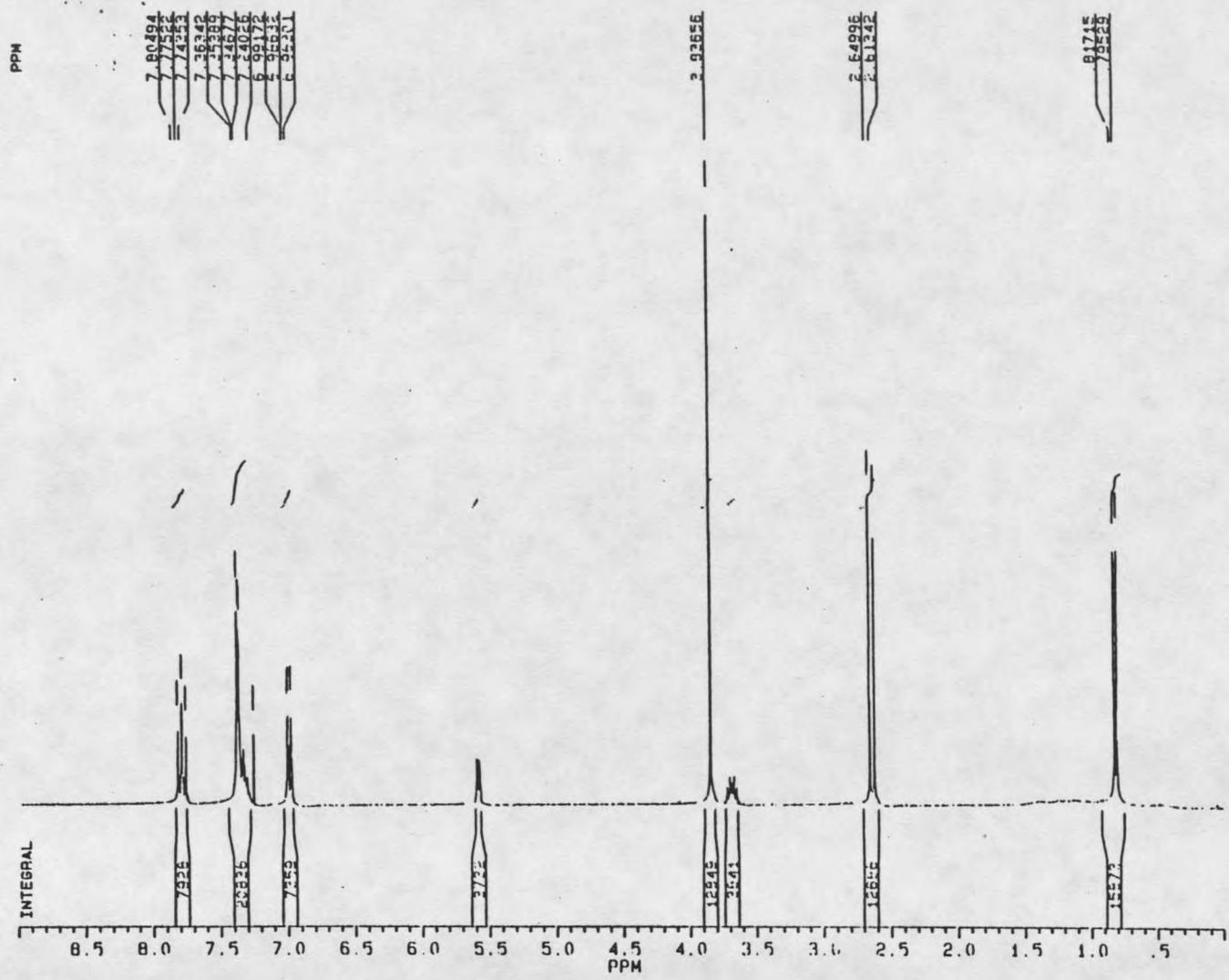


Figure 10. <sup>1</sup>H NMR Spectrum of (2*R*, 4*S*, 5*R*)-2-(4-methoxyphenyl)-3,4-dimethyl-5-phenyl-1,3,2-oxazaphospholidine 2-borane (44)

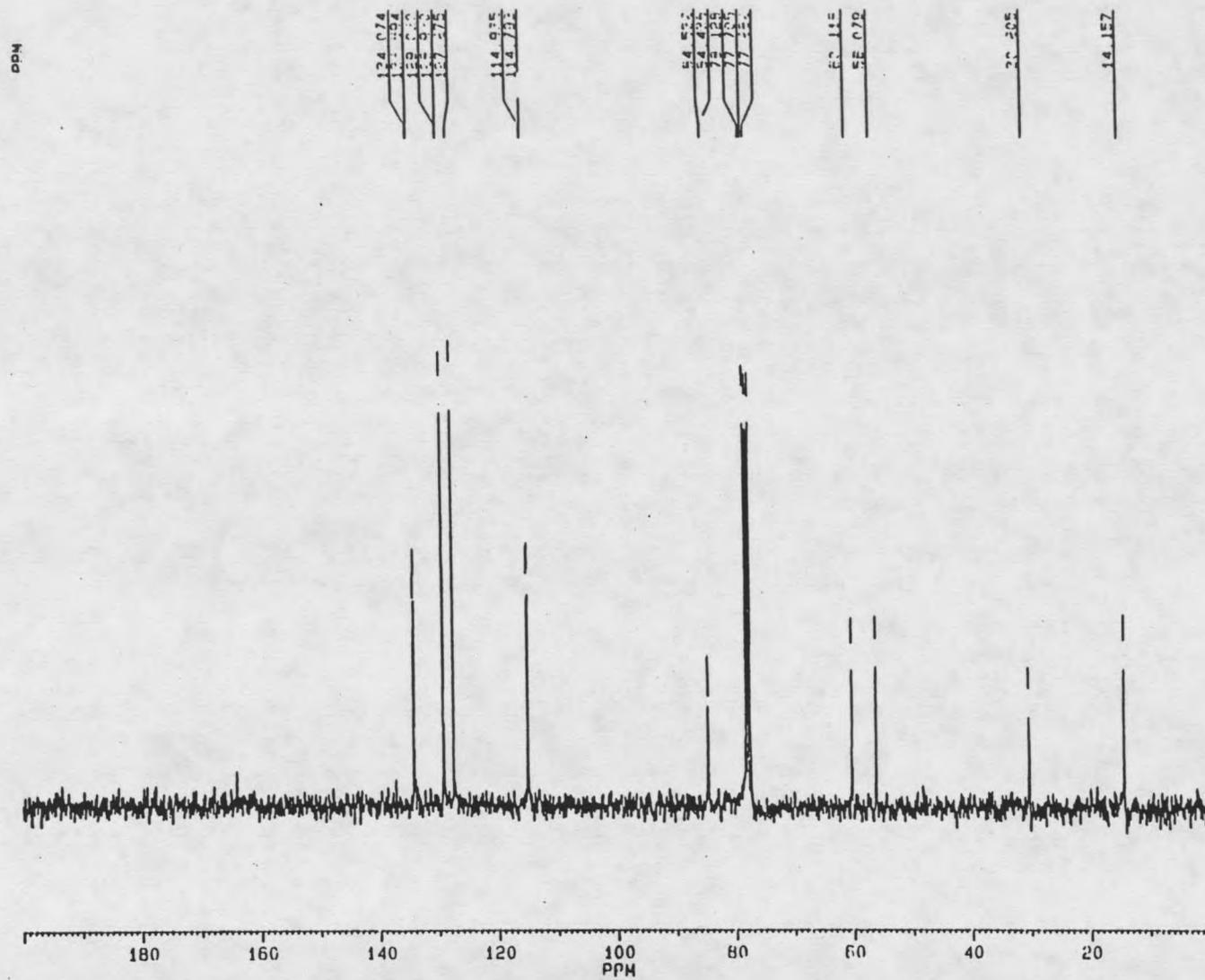
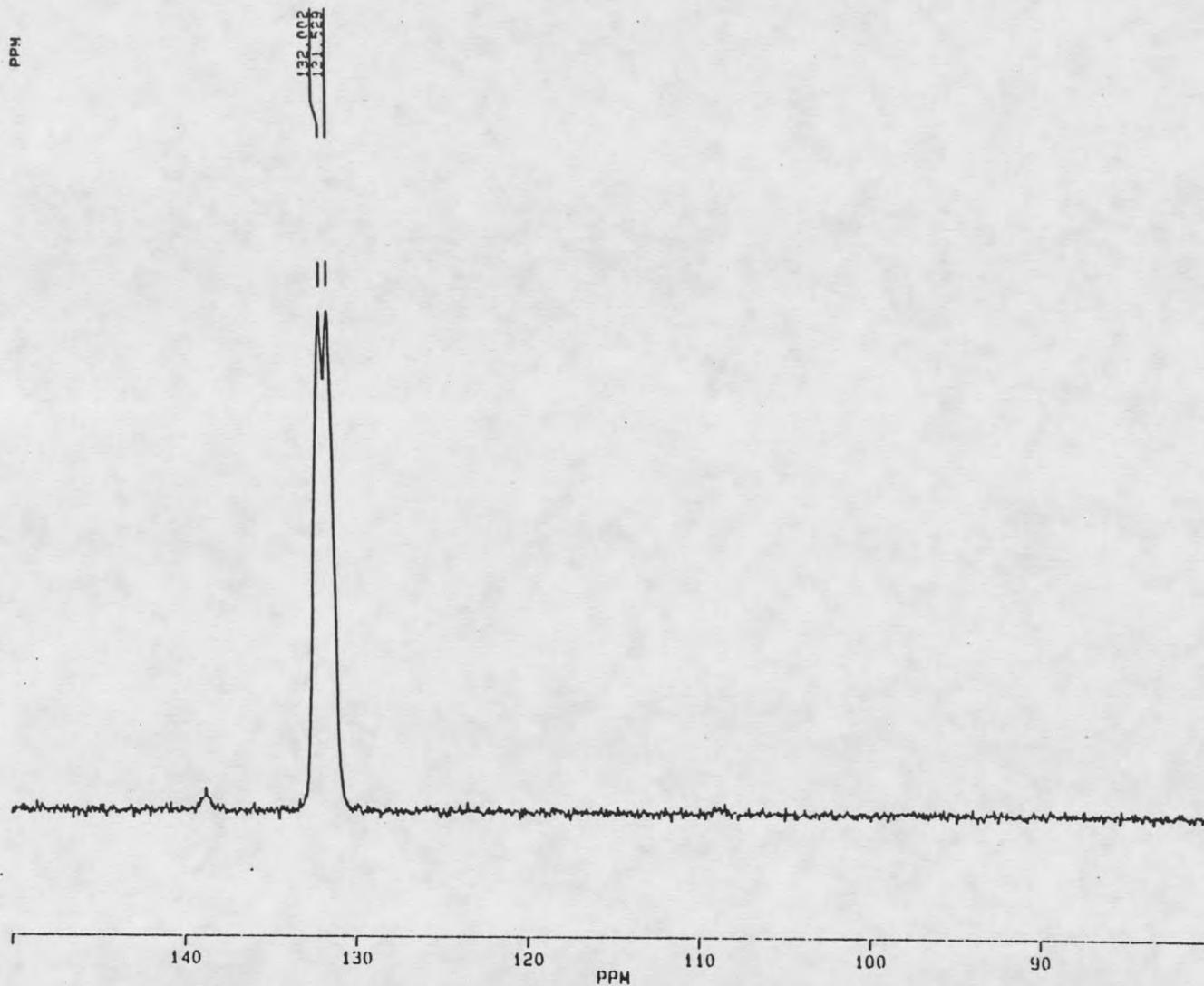


Figure 11. <sup>13</sup>C NMR Spectrum of (2R, 4S, 5R)-2-(4-methoxyphenyl)-3,4-dimethyl-5-phenyl-1,3,2-oxazaphospholidine 2-borane (44)



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Figure 12.  $^{31}\text{P}$  NMR Spectrum of  $(2R, 4S, 5R)$ -2-(4-methoxyphenyl)-3,4-dimethyl-5-phenyl-1,3,2-oxazaphospholidine 2-borane (**44**)

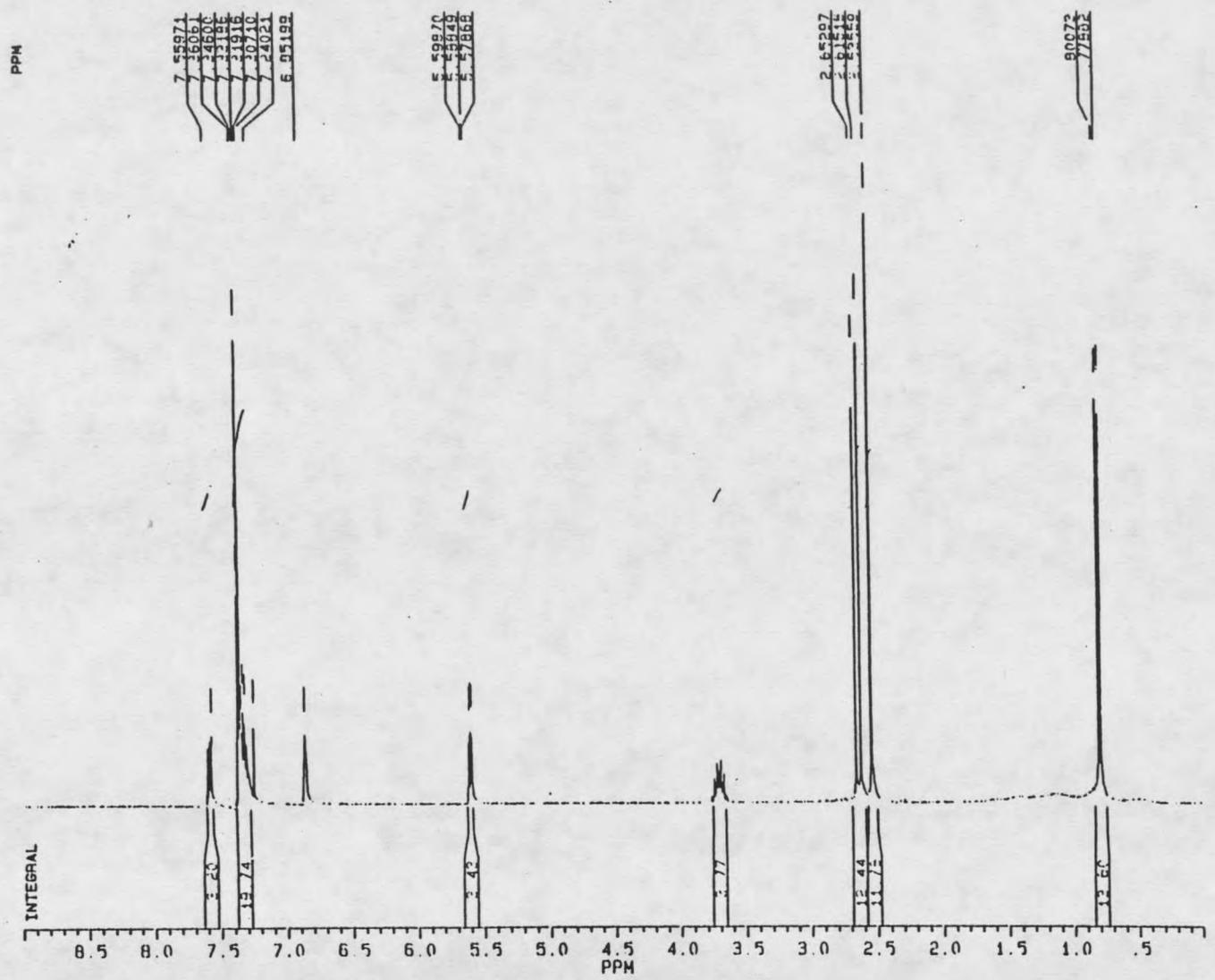


Figure 13. <sup>1</sup>H NMR Spectrum of (2*R*, 4*S*, 5*R*)-2-[2-(5-methylthienyl)]-3,4-dimethyl-5-phenyl-1,3,2-oxazaphospholidine 2-borane (46)

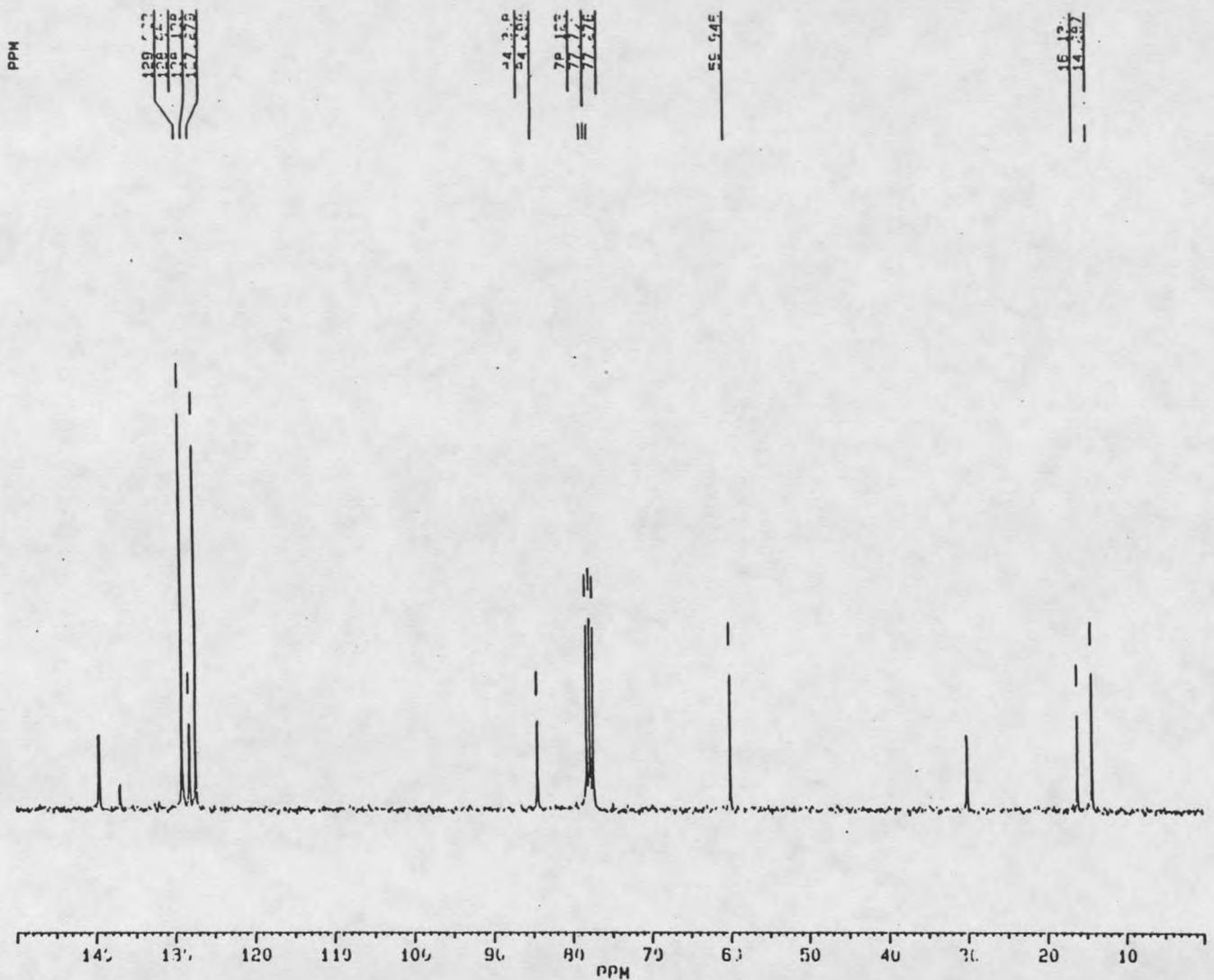


Figure 14. <sup>13</sup>C NMR Spectrum of (2R, 4S, 5R)-2-[2-(5-methylthienyl)]-3,4-dimethyl-5-phenyl-1,3,2-oxazaphospholidine 2-borane (46)

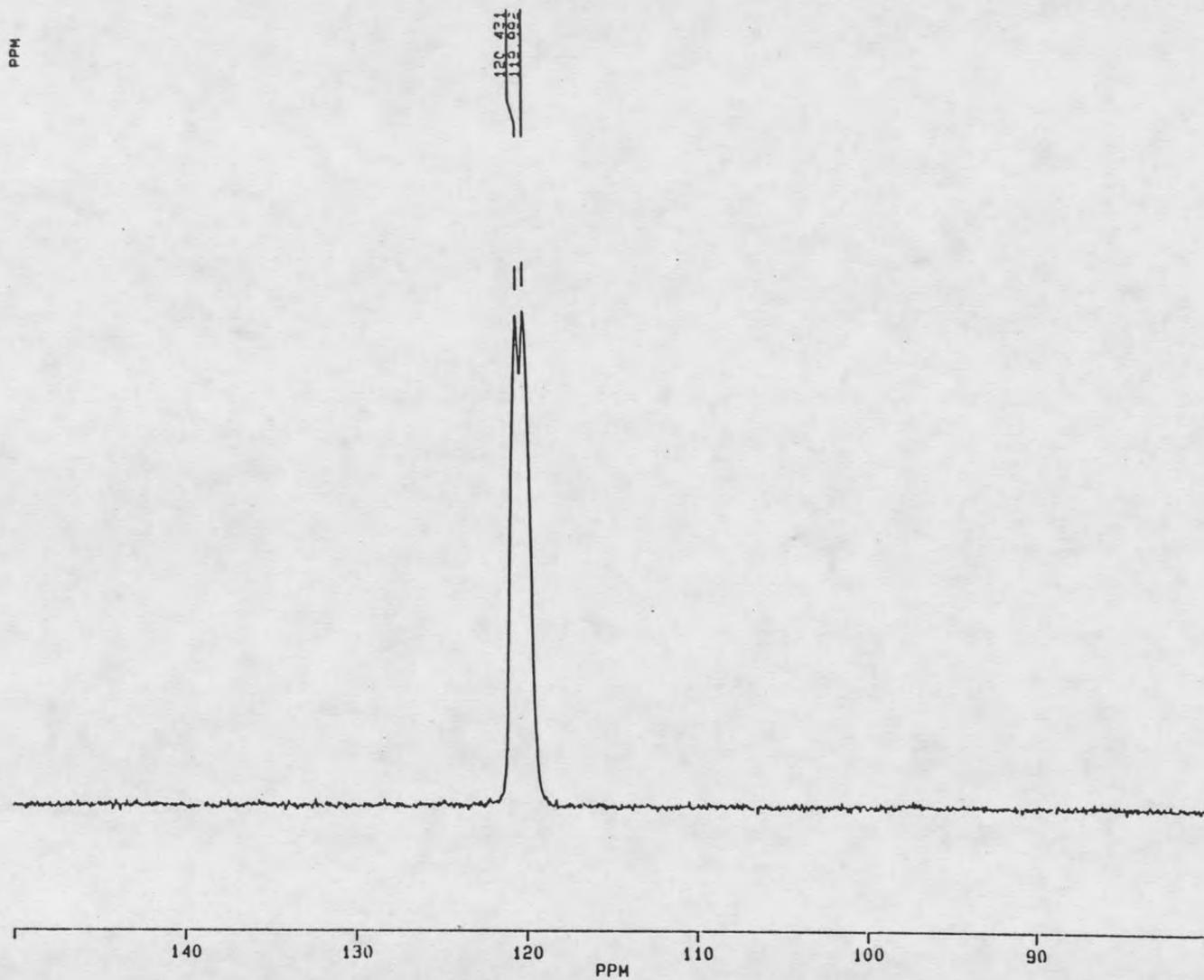


Figure 15.  $^{31}\text{P}$  NMR Spectrum of (2*R*, 4*S*, 5*R*)-2-[2-(5-methylthienyl)]-3,4-dimethyl-5-phenyl-1,3,2-oxazaphospholidine 2-borane (46)

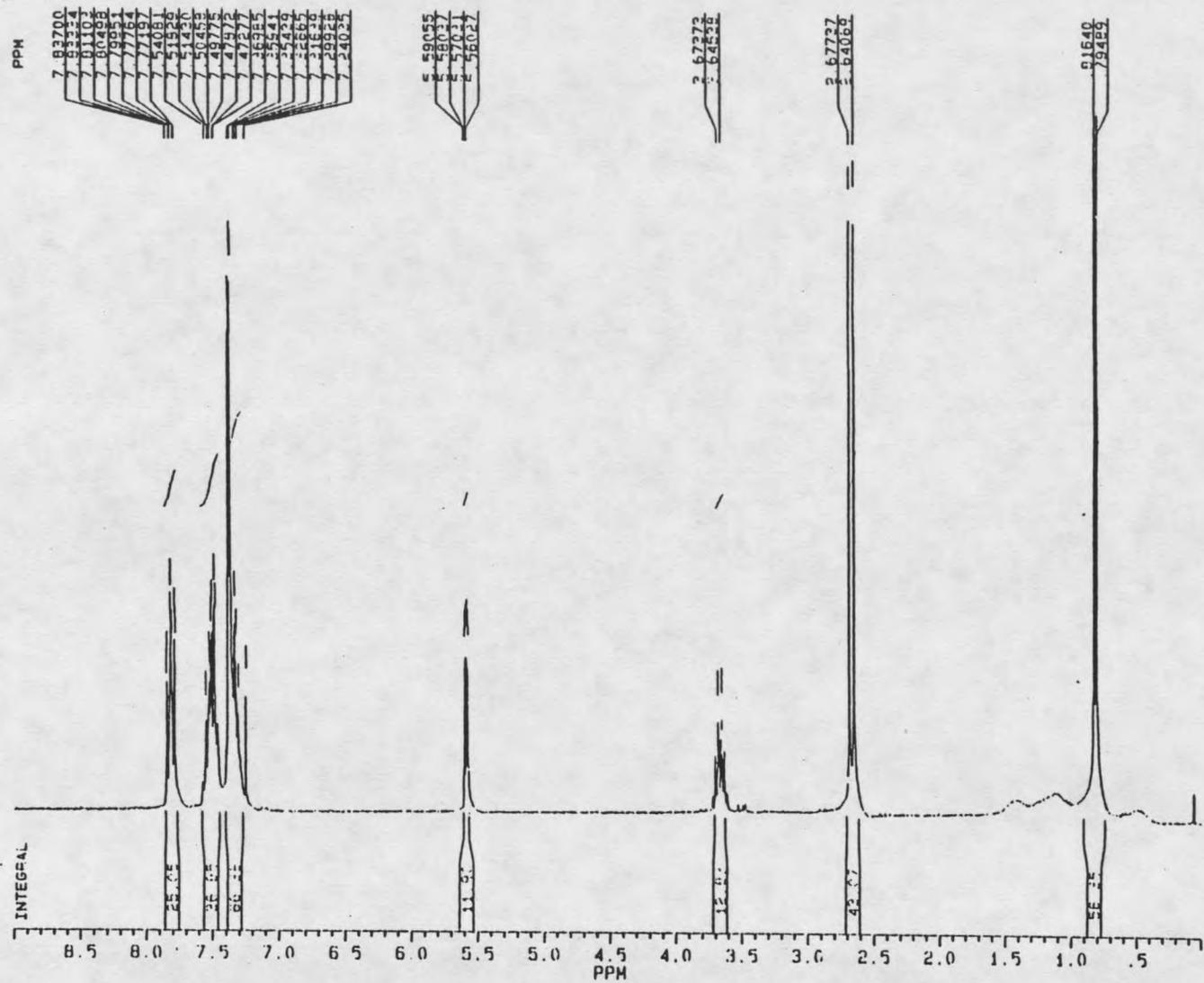


Figure 16.  $^1\text{H}$  NMR Spectrum of (2*R*, 4*S*, 5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidine 2-borane (**48**)

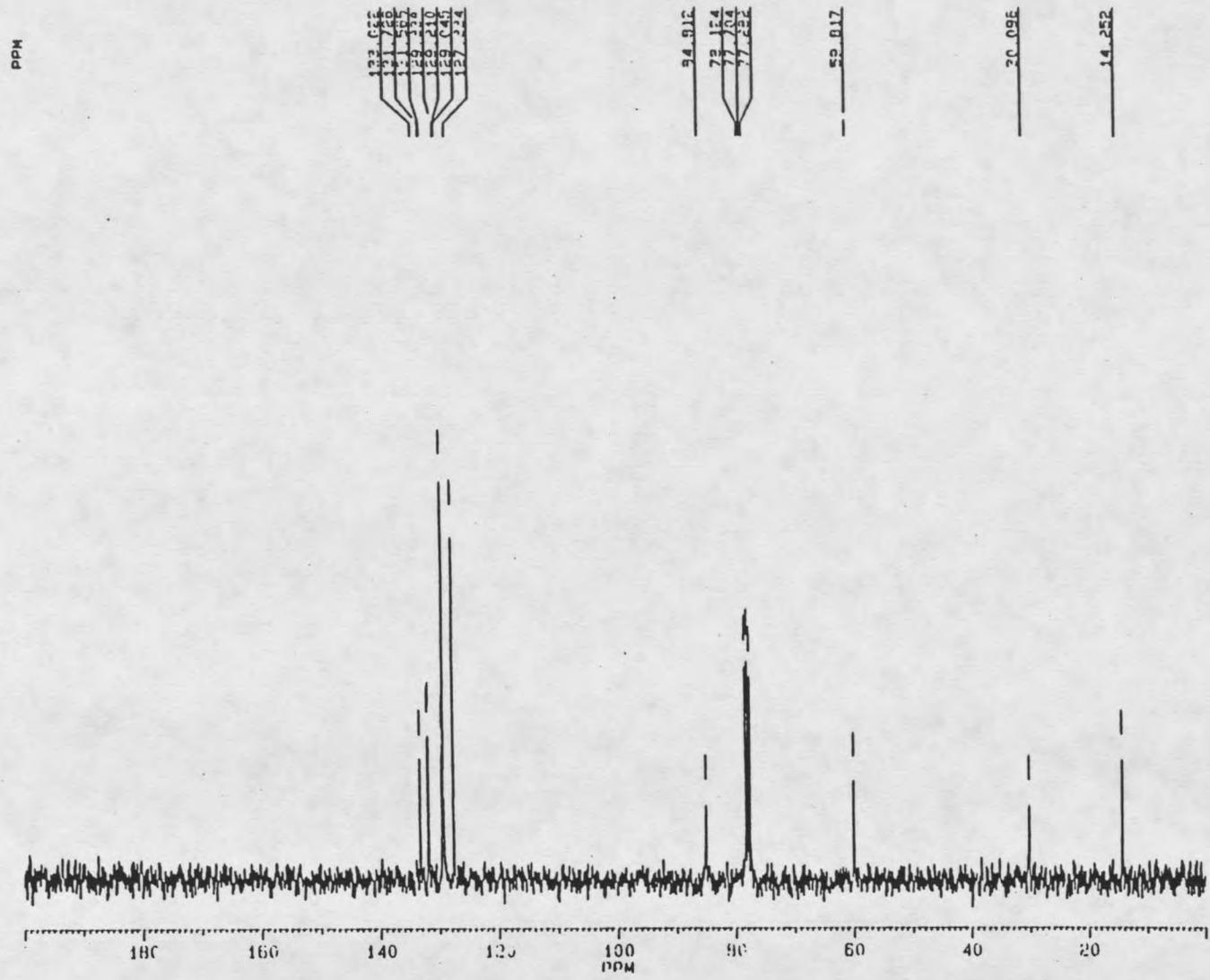
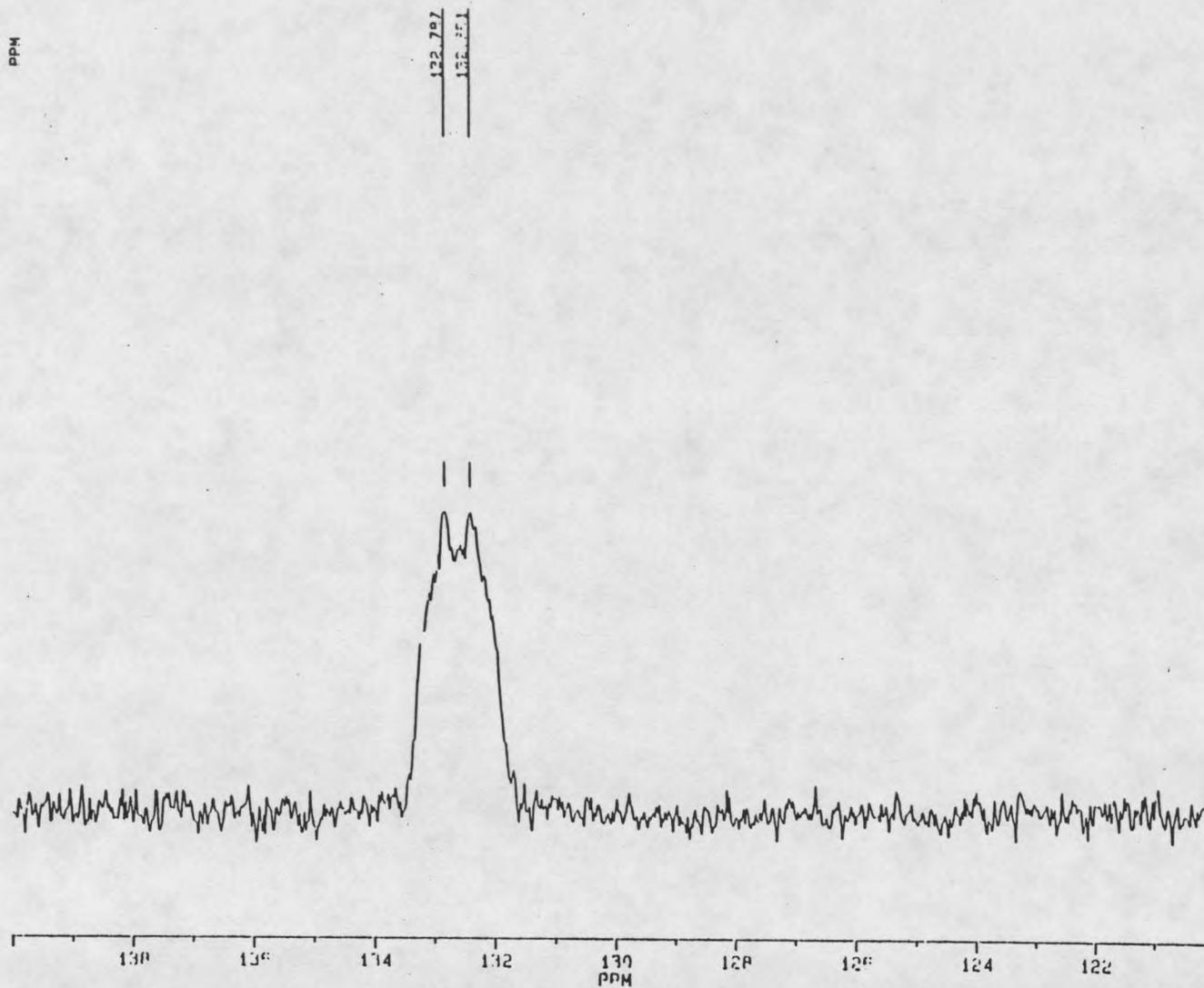


Figure 17. <sup>13</sup>C NMR Spectrum of (2*R*, 4*S*, 5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidine 2-borane (48)



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Figure 18.  $^{31}\text{P}$  NMR Spectrum of (2*R*, 4*S*, 5*R*)-3,4-dimethyl-2,5-diphenyl-1,3,2-oxazaphospholidine 2-borane (48)

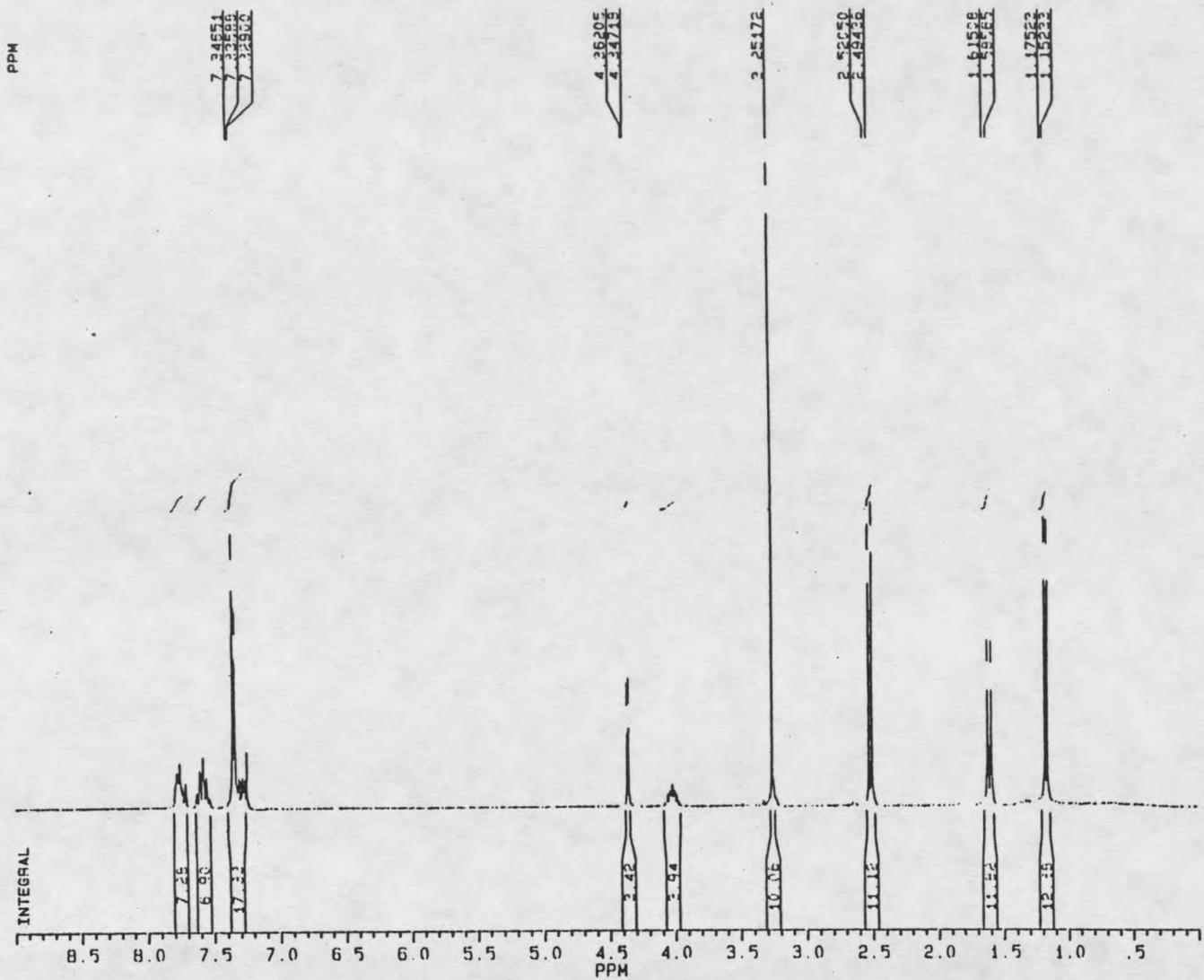


Figure 19. <sup>1</sup>H NMR Spectrum of (*R<sub>p</sub>*)-N-methyl, N-[(1*R*, 2*S*)-(1-methoxy-1-phenyl-2-propyl)] amino-methyl-(2-trifluoromethylphenyl)-phosphine borane (49)

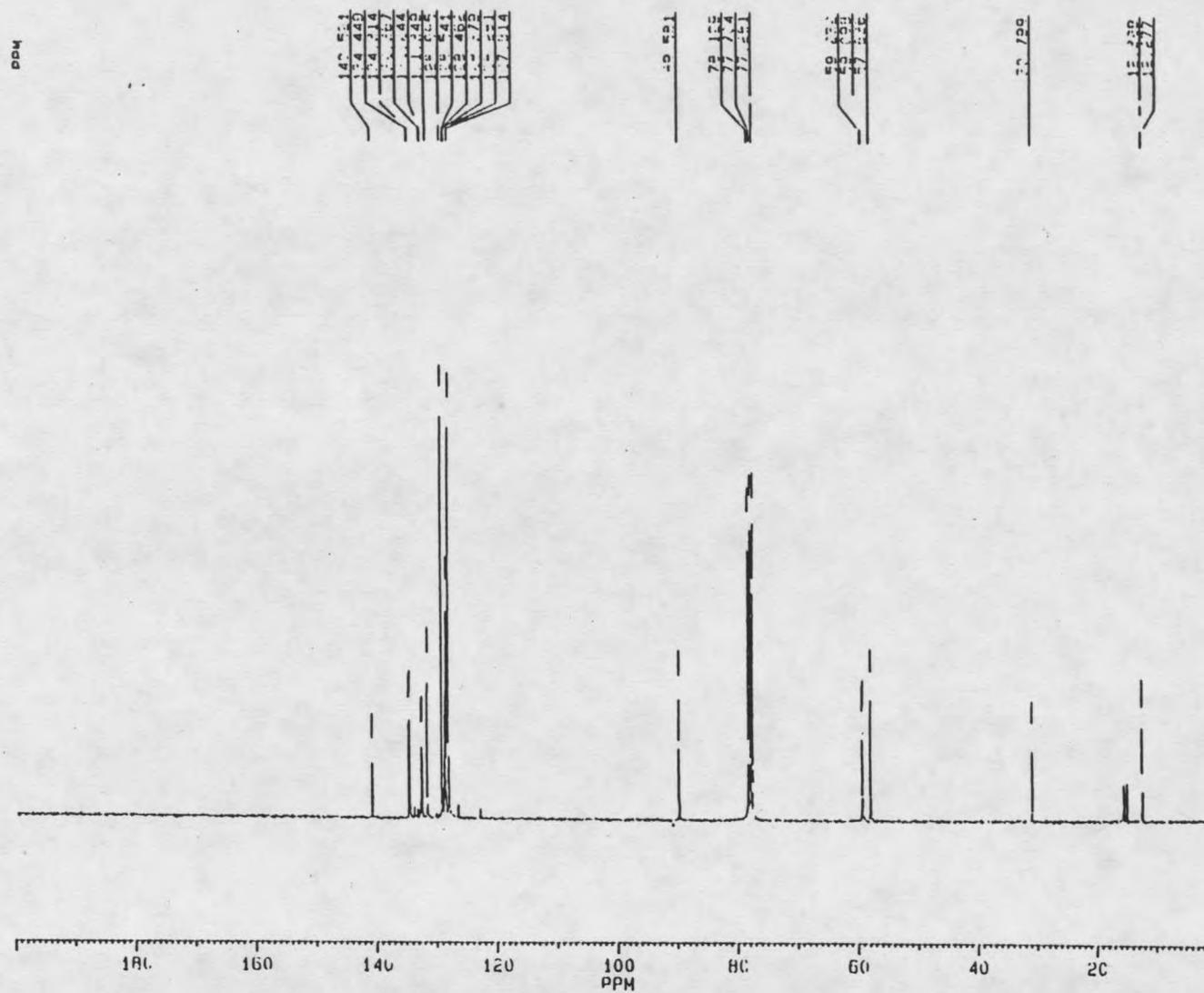
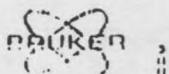


Figure 20.  $^{13}\text{C}$  NMR Spectrum of (*R<sub>p</sub>*)-*N*-methyl, *N*-[(*1R, 2S*)-(1-methoxy-1-phenyl-2-propyl)] amino-methyl-(2-trifluoromethylphenyl)-phosphine borane (**49**)



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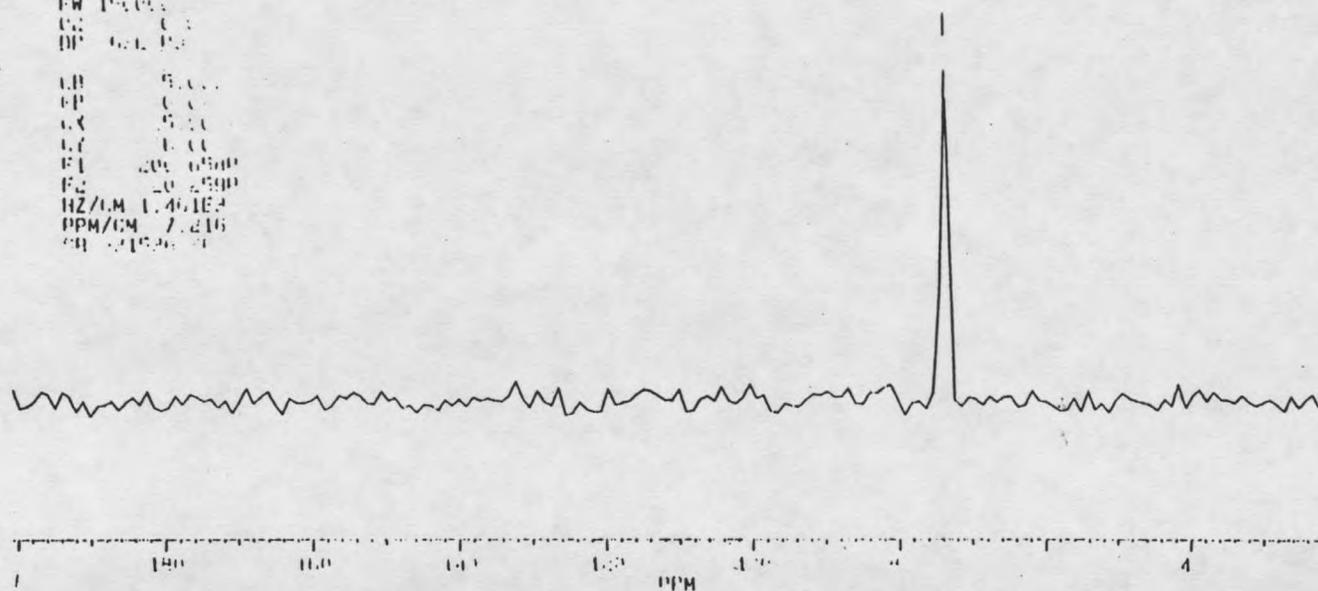


Figure 21.  $^{31}\text{P}$  NMR Spectrum of (*Rp*)-*N*-methyl, *N*-[(*1R*, *2S*)-(1-methoxy-1-phenyl-2-propyl)] amino-methyl-(2-trifluoromethylphenyl)-phosphine borane (49)

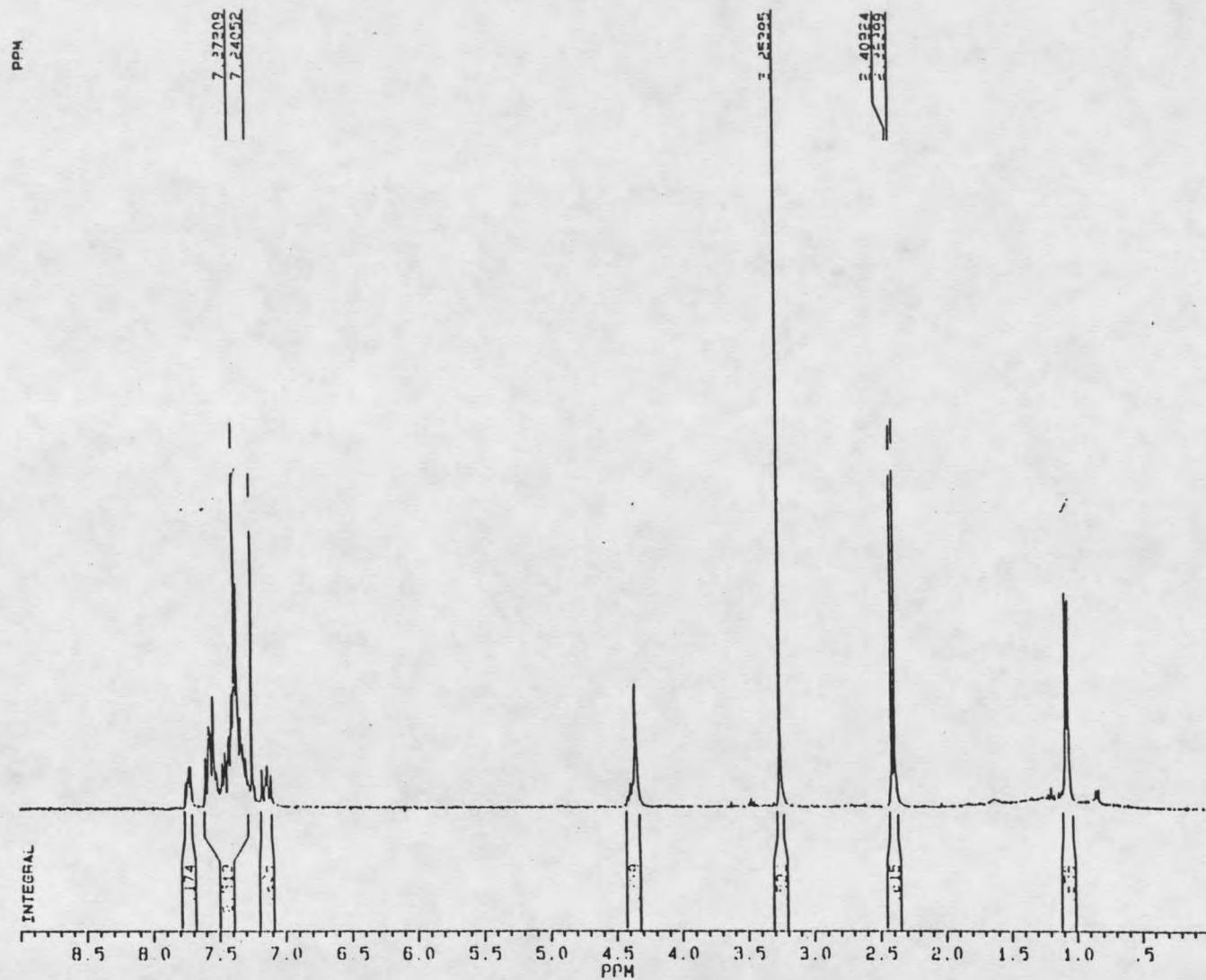


Figure 22.  $^1\text{H}$  NMR Spectrum of (Rp)-N-methyl, N-[(1R, 2S)-(1-methoxy-1-phenyl-2-propyl)]-amino-phenyl-(2-trifluoromethylphenyl)-phosphine borane(50)

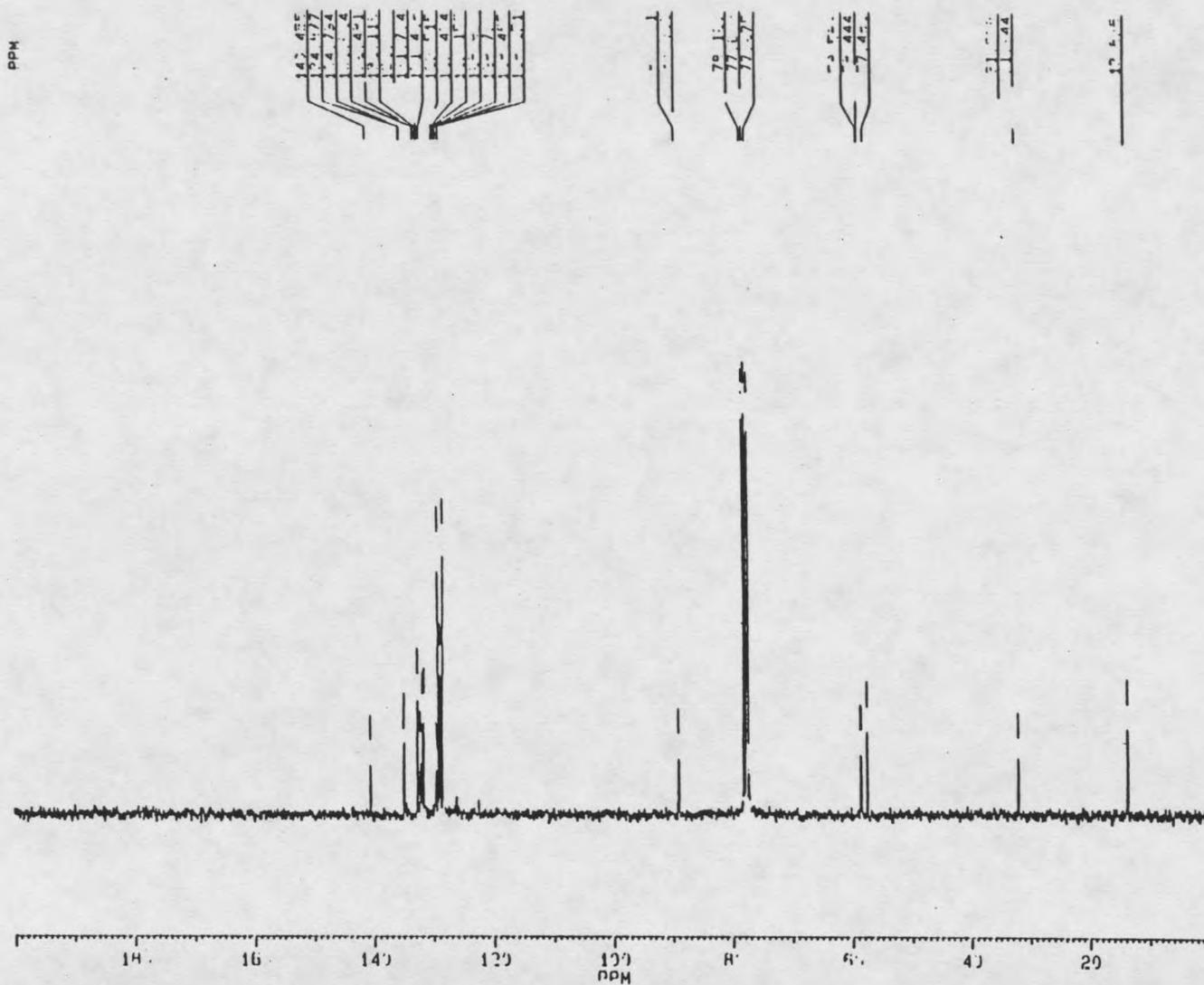
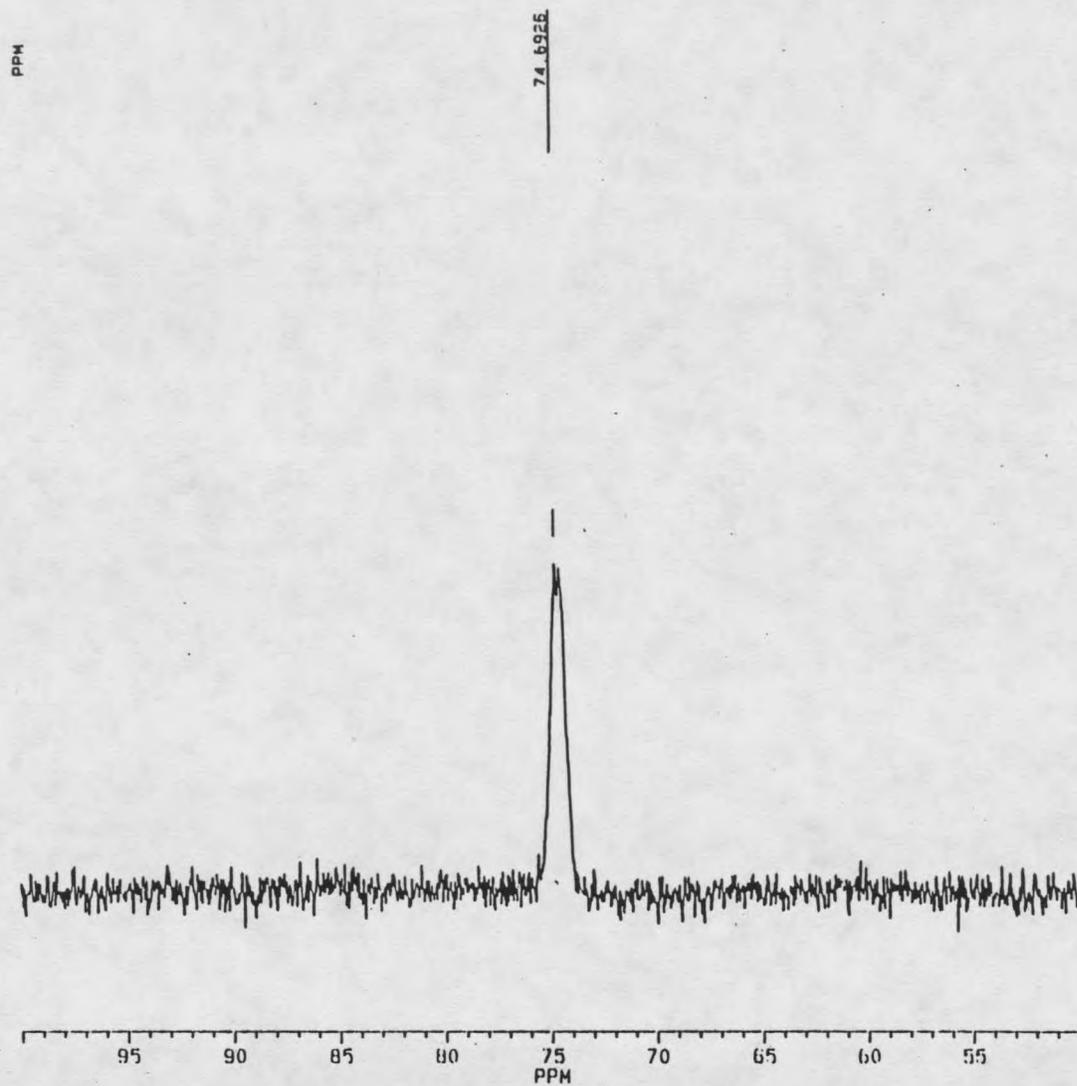


Figure 23.  $^{13}\text{C}$  NMR Spectrum of (*R<sub>p</sub>*)-*N*-methyl, *N*-[(*1R, 2S*)-(1-methoxy-1-phenyl-2-propyl)]-amino-phenyl-(2-trifluoromethylphenyl)-phosphine borane (50)



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Figure 24.  $^{31}\text{P}$  NMR Spectrum of (*R<sub>p</sub>*)-*N*-methyl, *N*-[(*1R*, *2S*)-(1-methoxy-1-phenyl-2-propyl)]-amino-phenyl-(2-trifluoromethylphenyl)-phosphine borane (50)

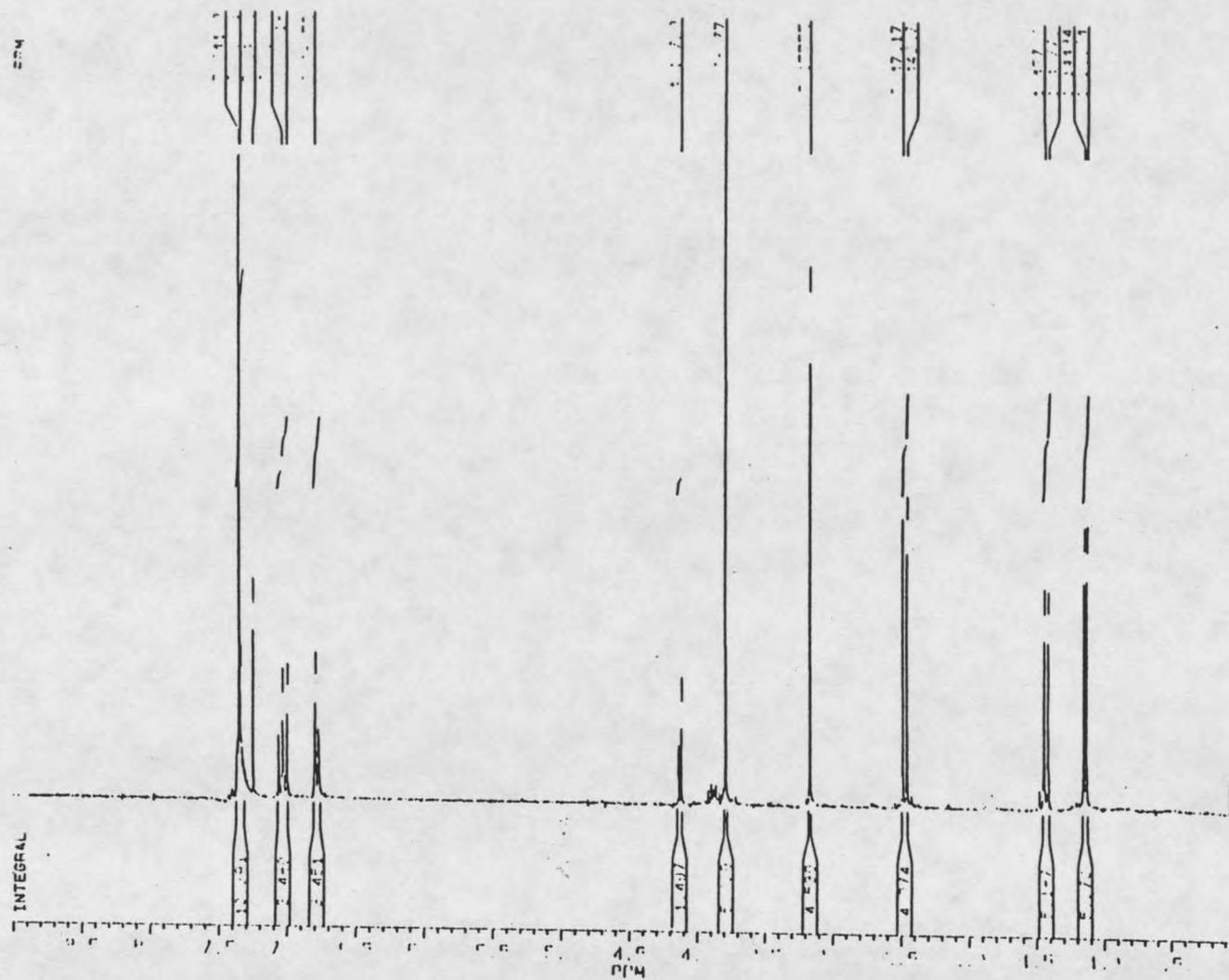
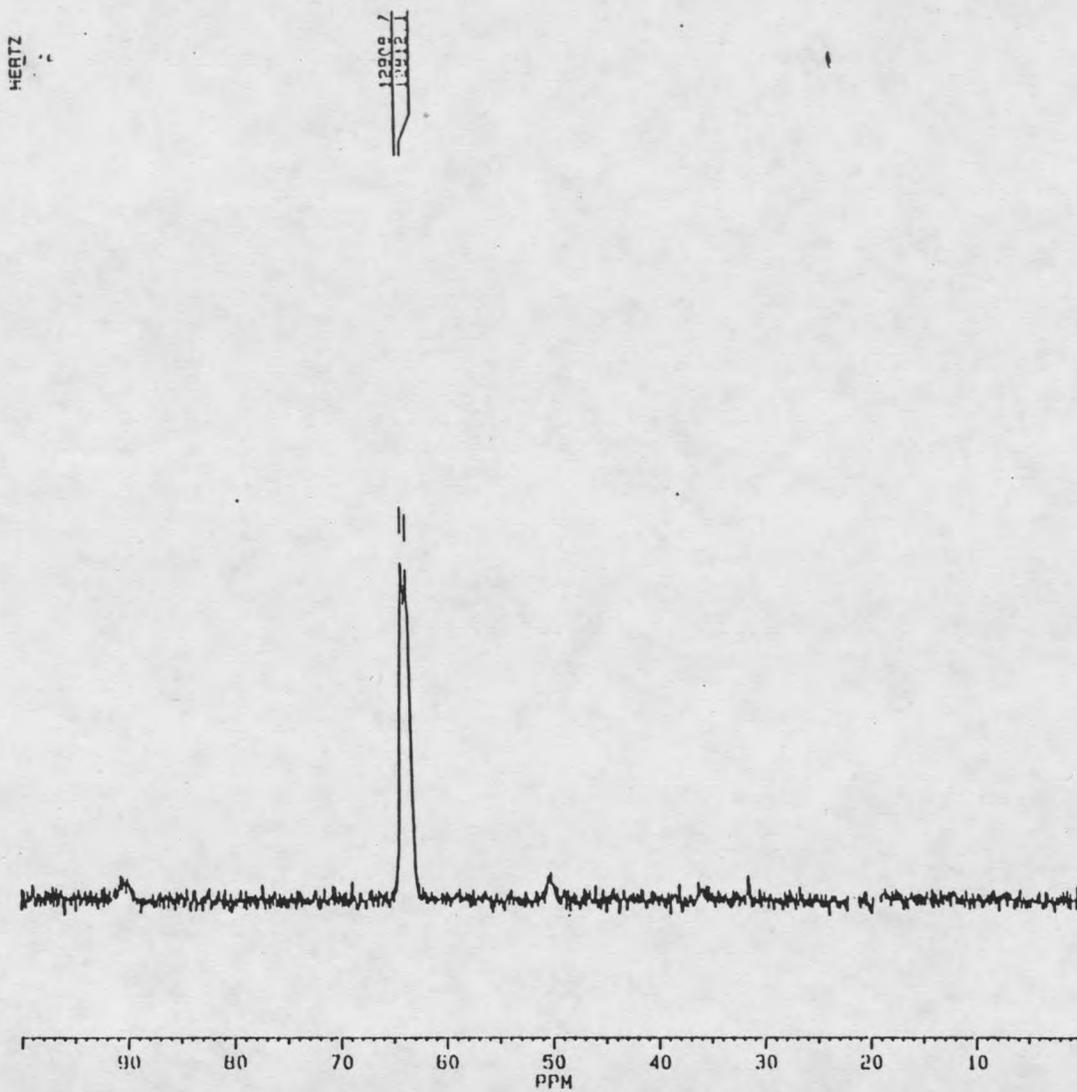


Figure 25. <sup>1</sup>H NMR Spectrum of (*R<sub>p</sub>*)-*N*-methyl, *N*-[(*1R, 2S*)-(1-methoxy-1-phenyl-2-propyl)]-amino-(4-methoxyphenyl)-methyl-phosphine borane (52)





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Figure 27.  $^{31}\text{P}$  NMR Spectrum of (*R<sub>p</sub>*)-*N*-methyl, *N*-[*(1R, 2S)*-(1-methoxy-1-phenyl-2-propyl)]-amino-(4-methoxyphenyl)-methyl-phosphine borane (52)

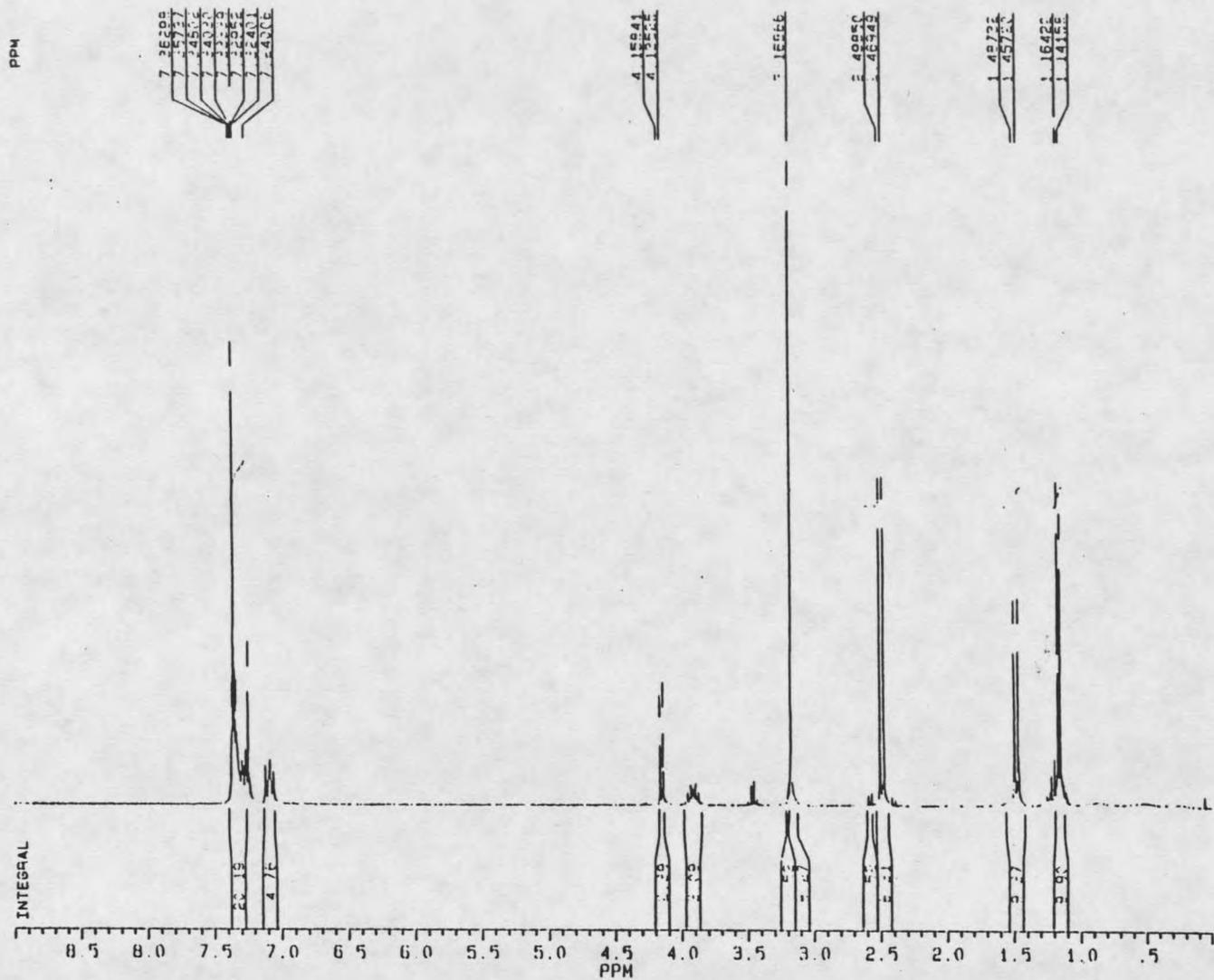


Figure 28. <sup>1</sup>H NMR Spectrum of (*R<sub>p</sub>*)-N-methyl, N-[(1*R*, 2*S*)-(1-methoxy-1-phenyl-2-propyl)]-amino-methyl-phenyl-phosphine borane (53)

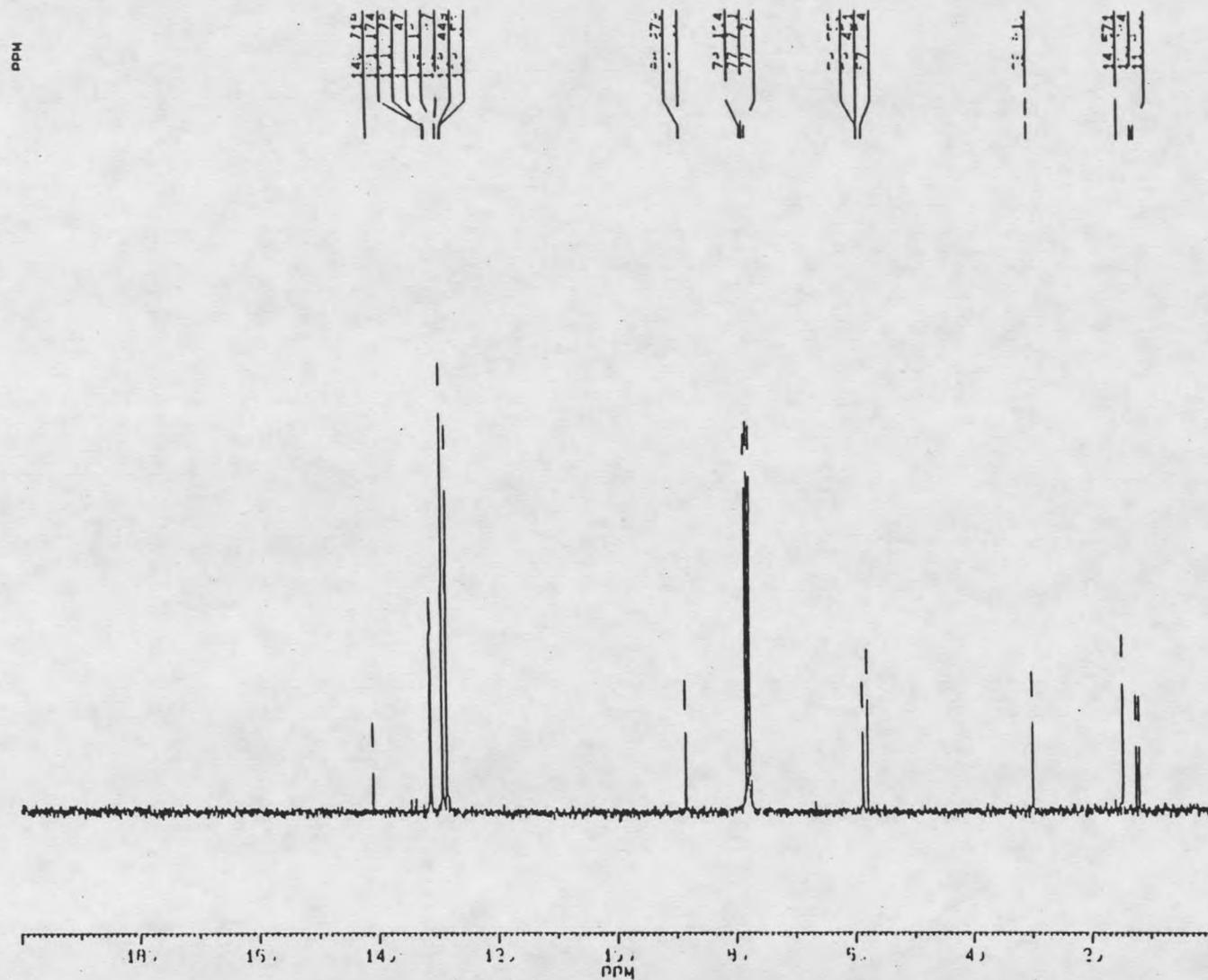


Figure 29.  $^{13}\text{C}$  NMR Spectrum of (*R<sub>p</sub>*)-*N*-methyl, *N*-[(1*R*, 2*S*)-(1-methoxy-1-phenyl-2-propyl)]-amino-methyl-phenyl-phosphine borane (53)



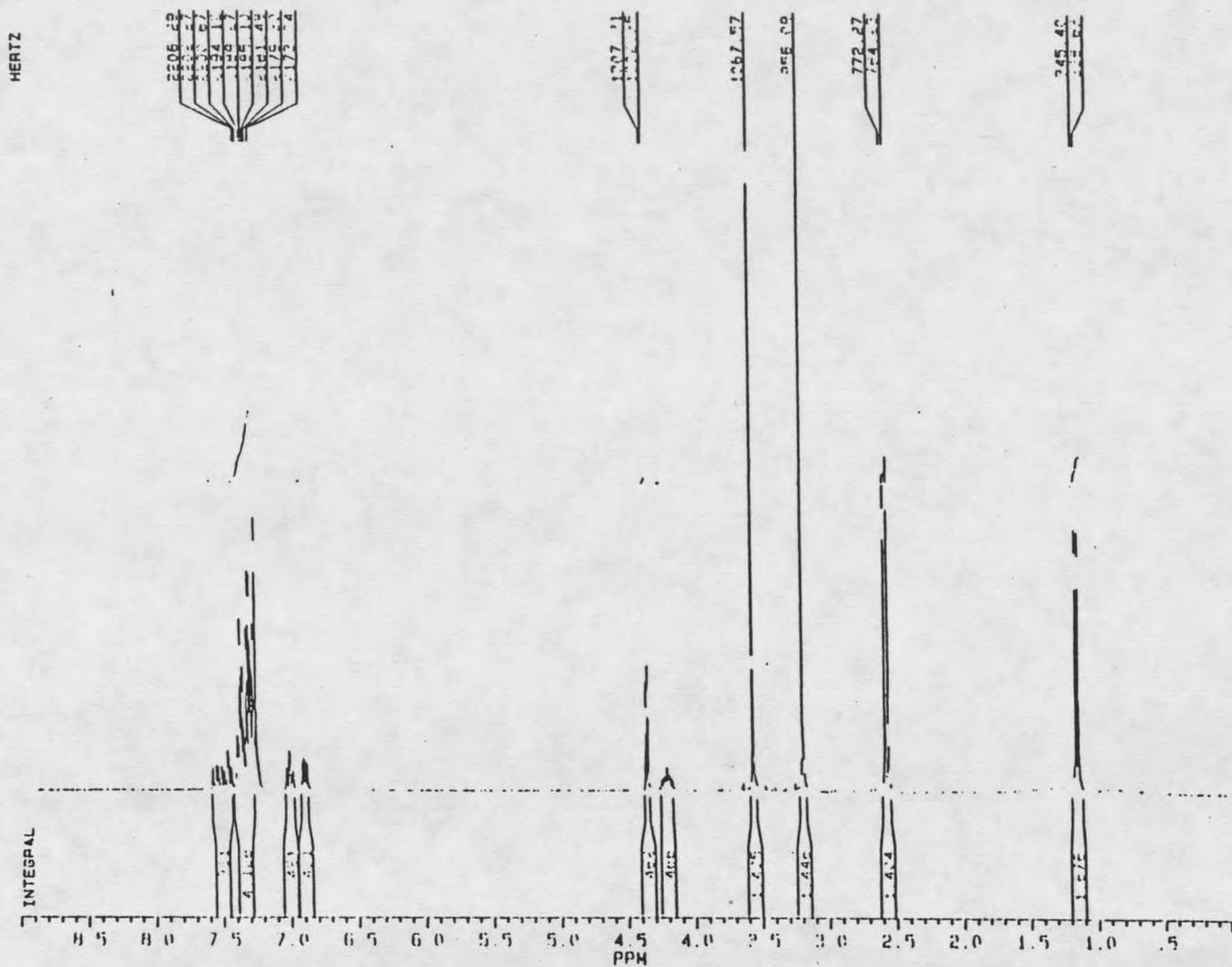


Figure 31.  $^1\text{H}$  NMR Spectrum of (*Sp*)-*N*-methyl, *N*-[(*1R*, *2S*)-(1-methoxy-1-phenyl-2-propyl)]-amino-(2-methoxyphenyl)-phenyl-phosphine borane (54)

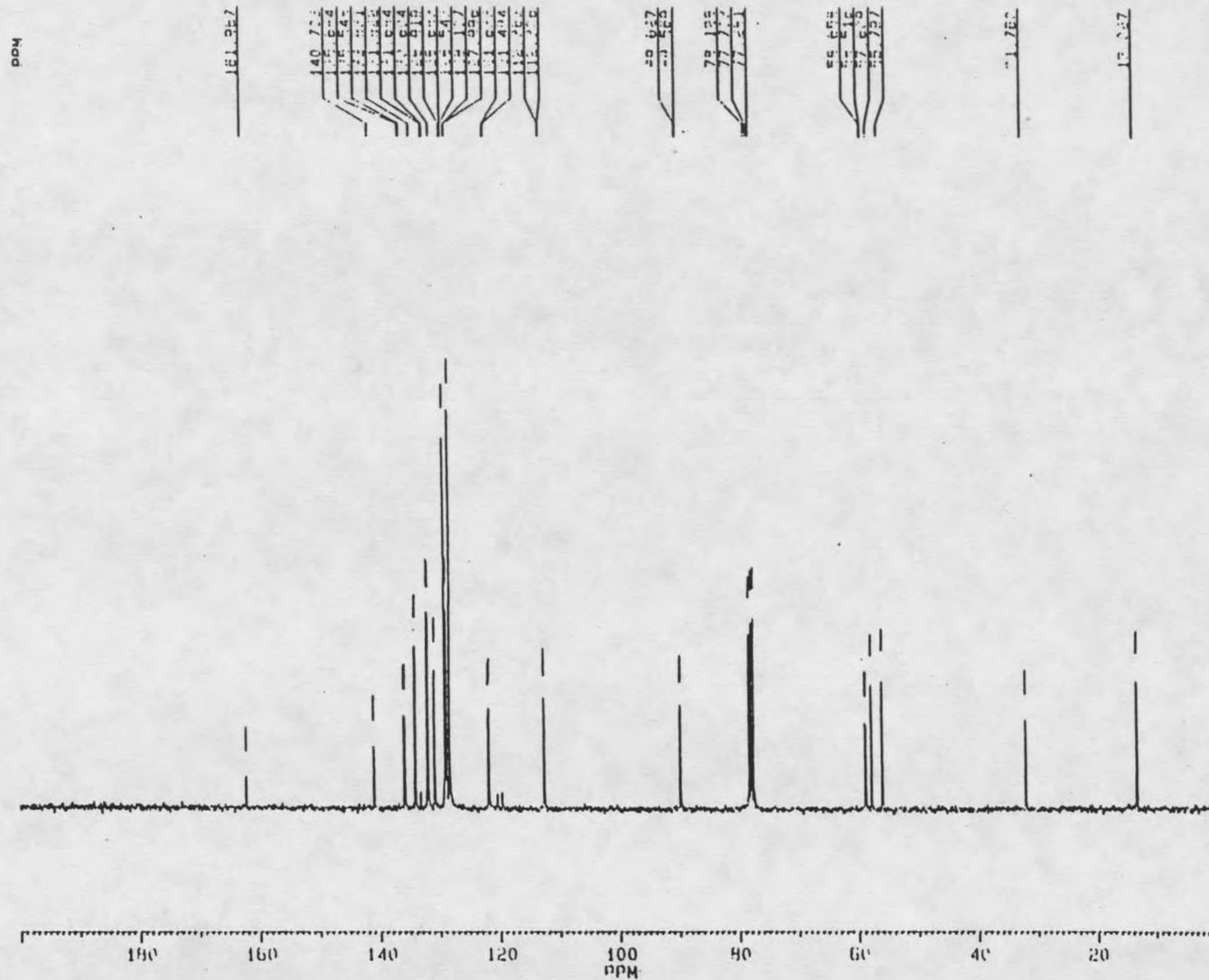
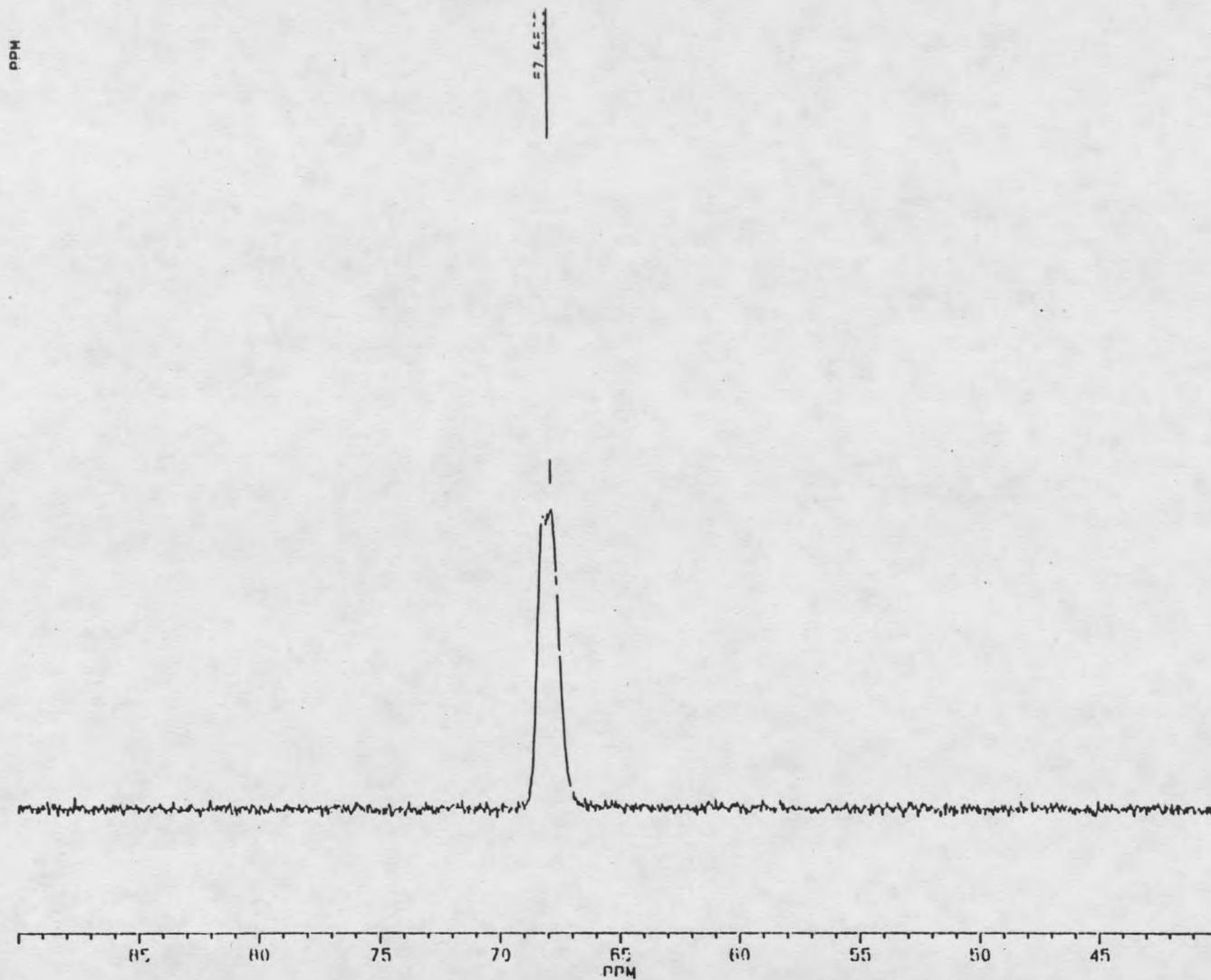


Figure 32.  $^{13}\text{C}$  NMR Spectrum of (*Sp*)-*N*-methyl, *N*-[(1*R*, 2*S*)-(1-methoxy-1-phenyl-2-propyl)]-amino-(2-methoxyphenyl)-phenyl-phosphine borane (**54**)



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Figure 33.  $^{31}\text{P}$  NMR Spectrum of (*Sp*)-*N*-methyl, *N*-[(1*R*, 2*S*)-(1-methoxy-1-phenyl-2-propyl)]-amino-(2-methoxyphenyl)-phenyl-phosphine borane (54)

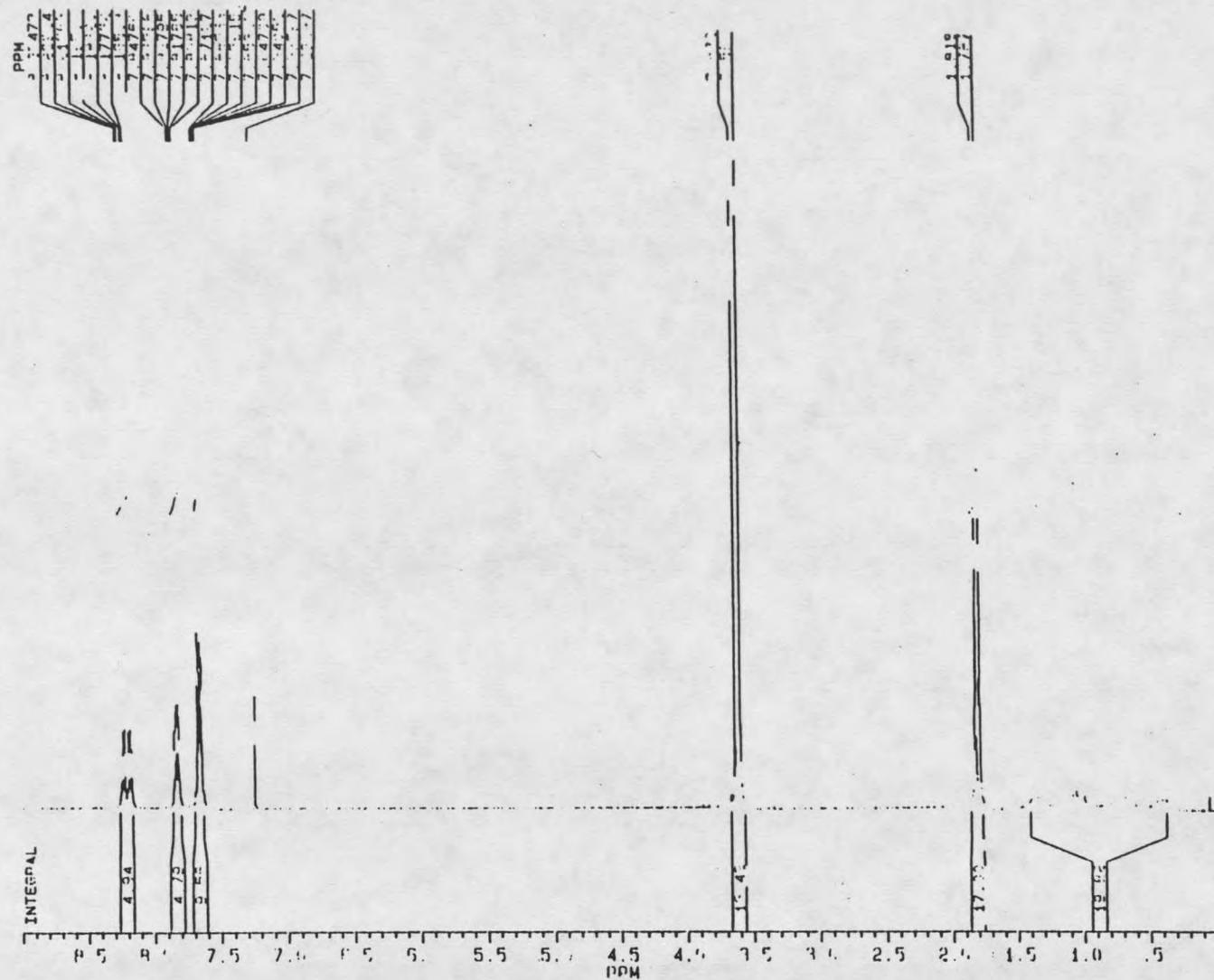


Figure 34.  $^1\text{H}$  NMR Spectrum of (*S*)-methyl-(2-trifluoromethylphenyl)-methylphosphinite borane (58)

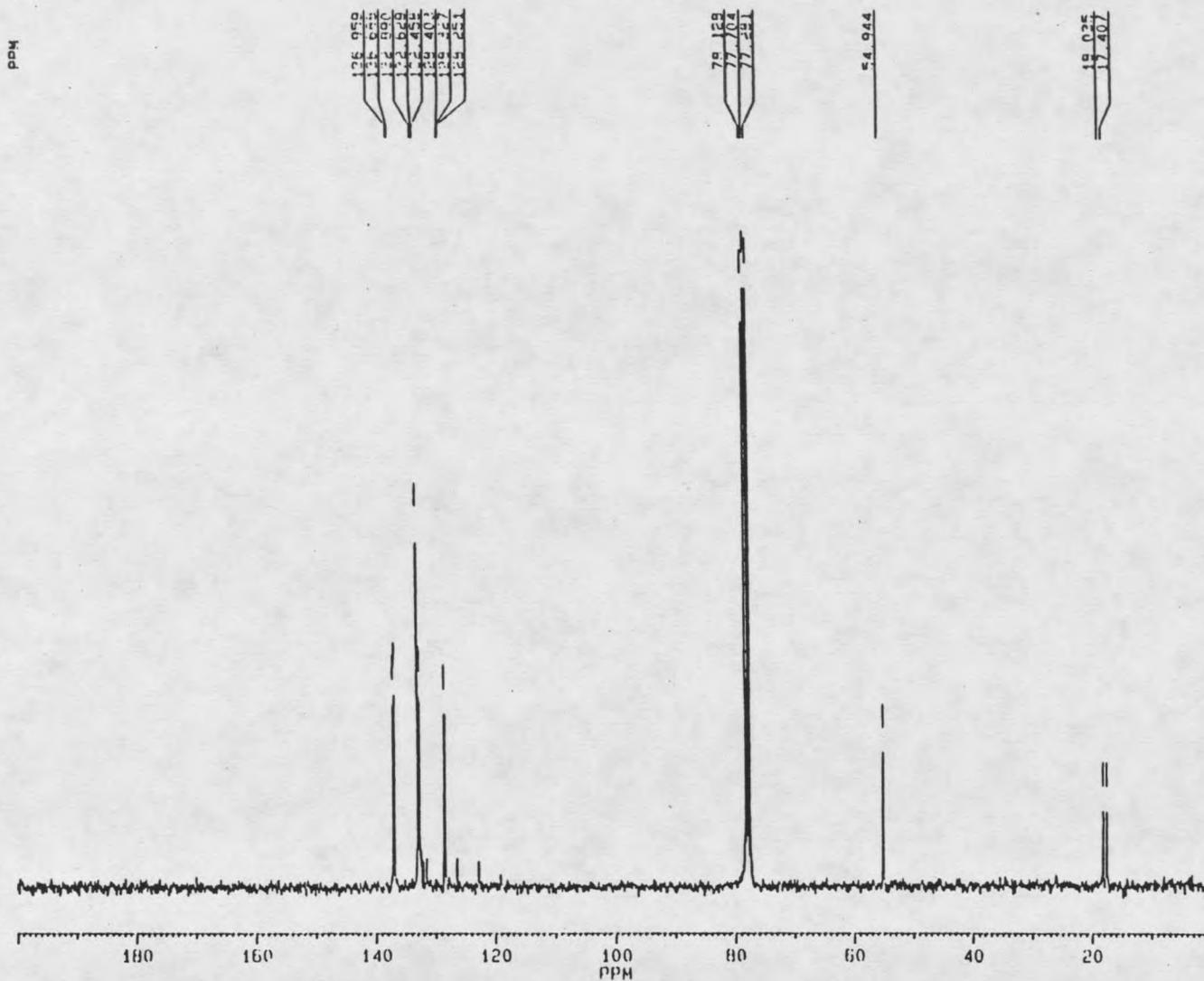


Figure 35. <sup>13</sup>C NMR Spectrum of (S)-methyl-(2-trifluoromethylphenyl)-methylphosphinite borane (58)



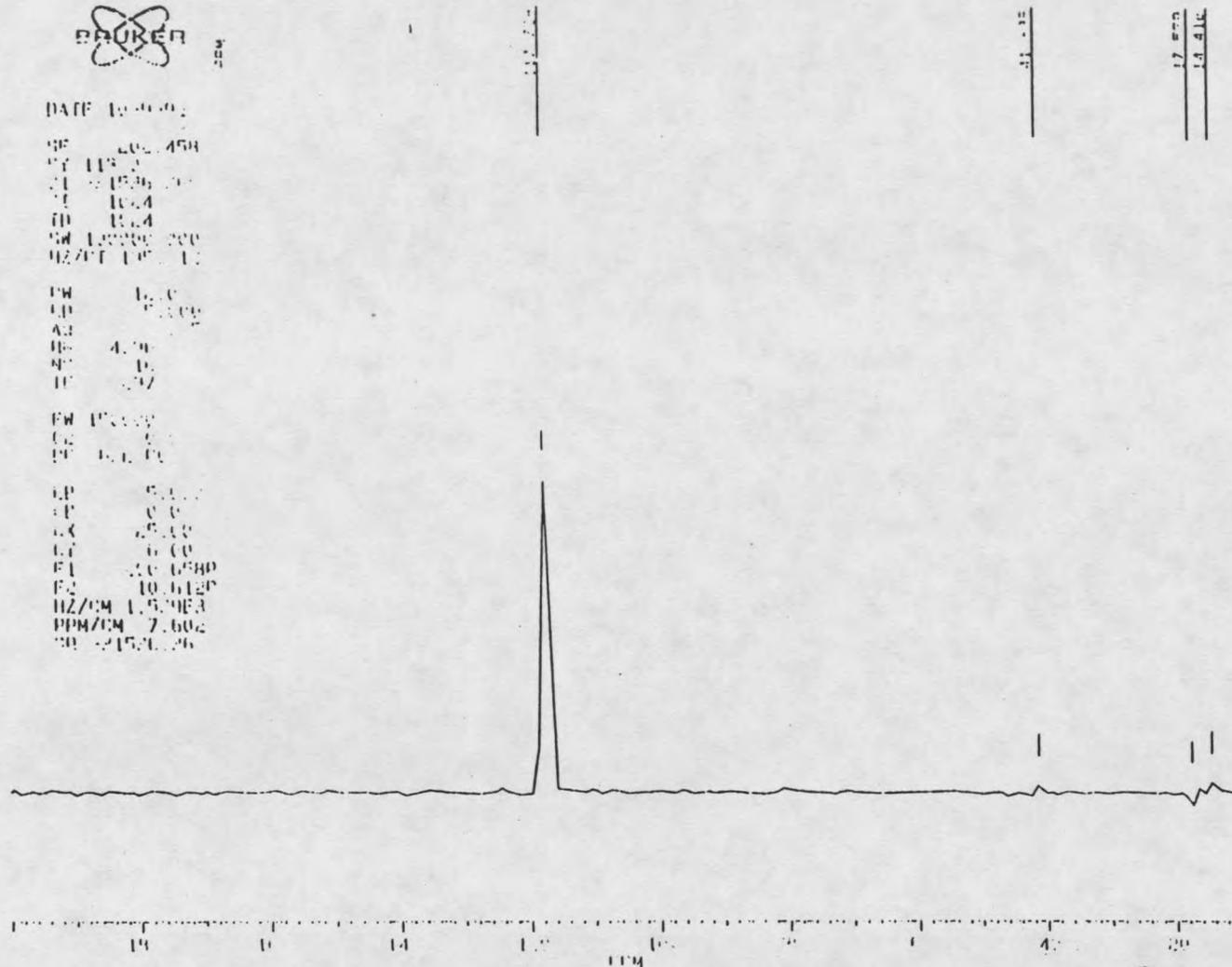
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115

Figure 36.  $^{31}\text{P}$  NMR Spectrum of (*S*)-methyl-(2-trifluoromethylphenyl)-methylphosphinite borane (58)

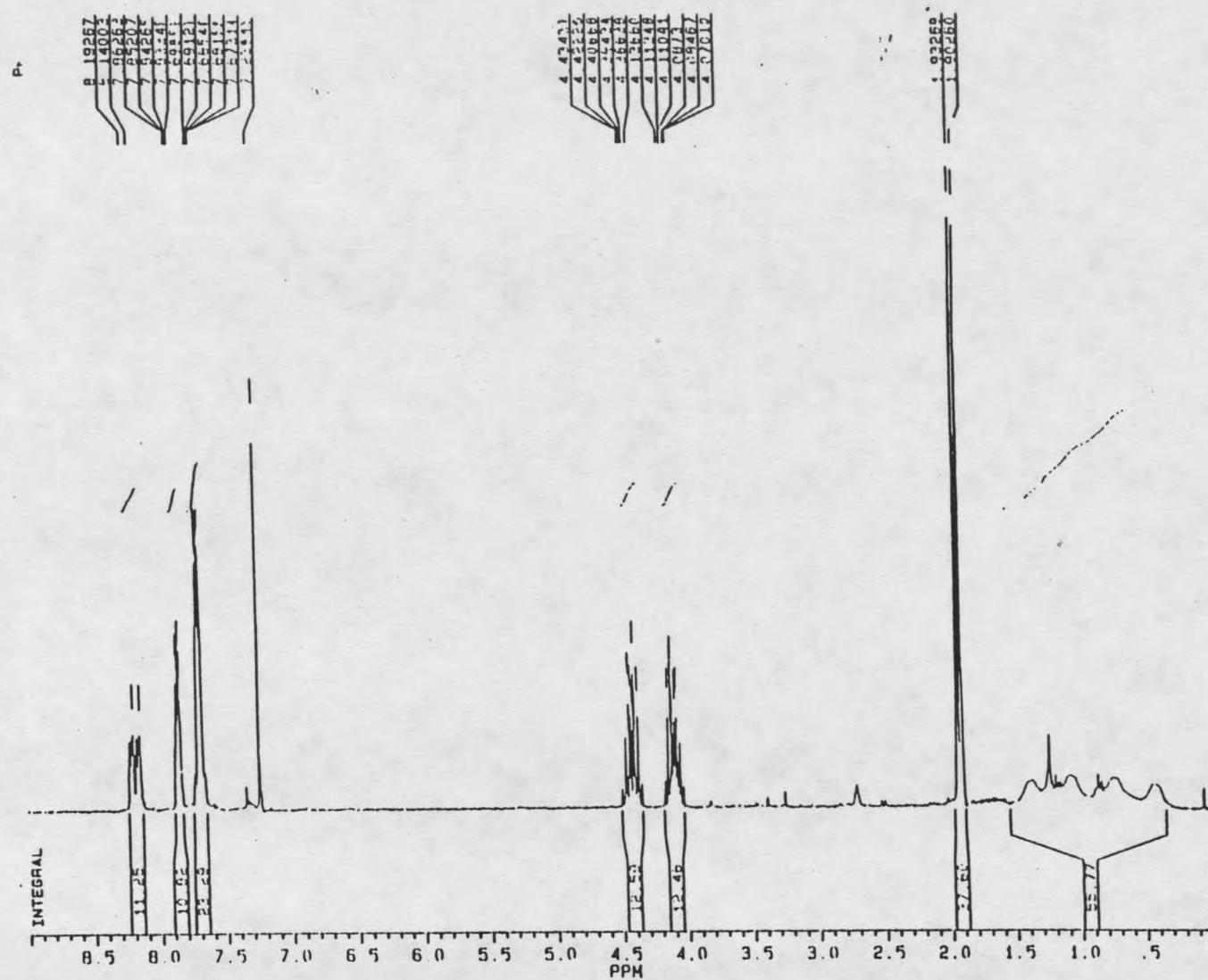


Figure 37.  $^1\text{H}$  NMR Spectrum of Methyl-(2-trifluoromethylphenyl)-trifluoroethylphosphinite borane (59)

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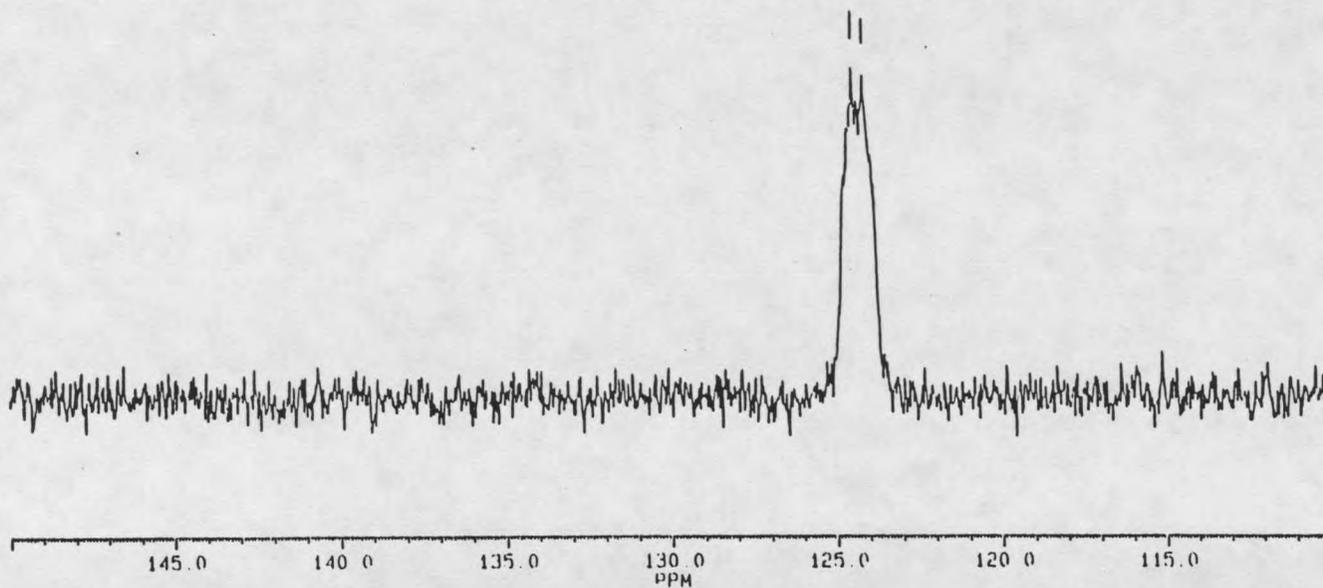


Figure 38.  $^{31}\text{P}$  NMR Spectrum of Methyl-(2-trifluoromethylphenyl)-trifluoroethylphosphinite borane (59)





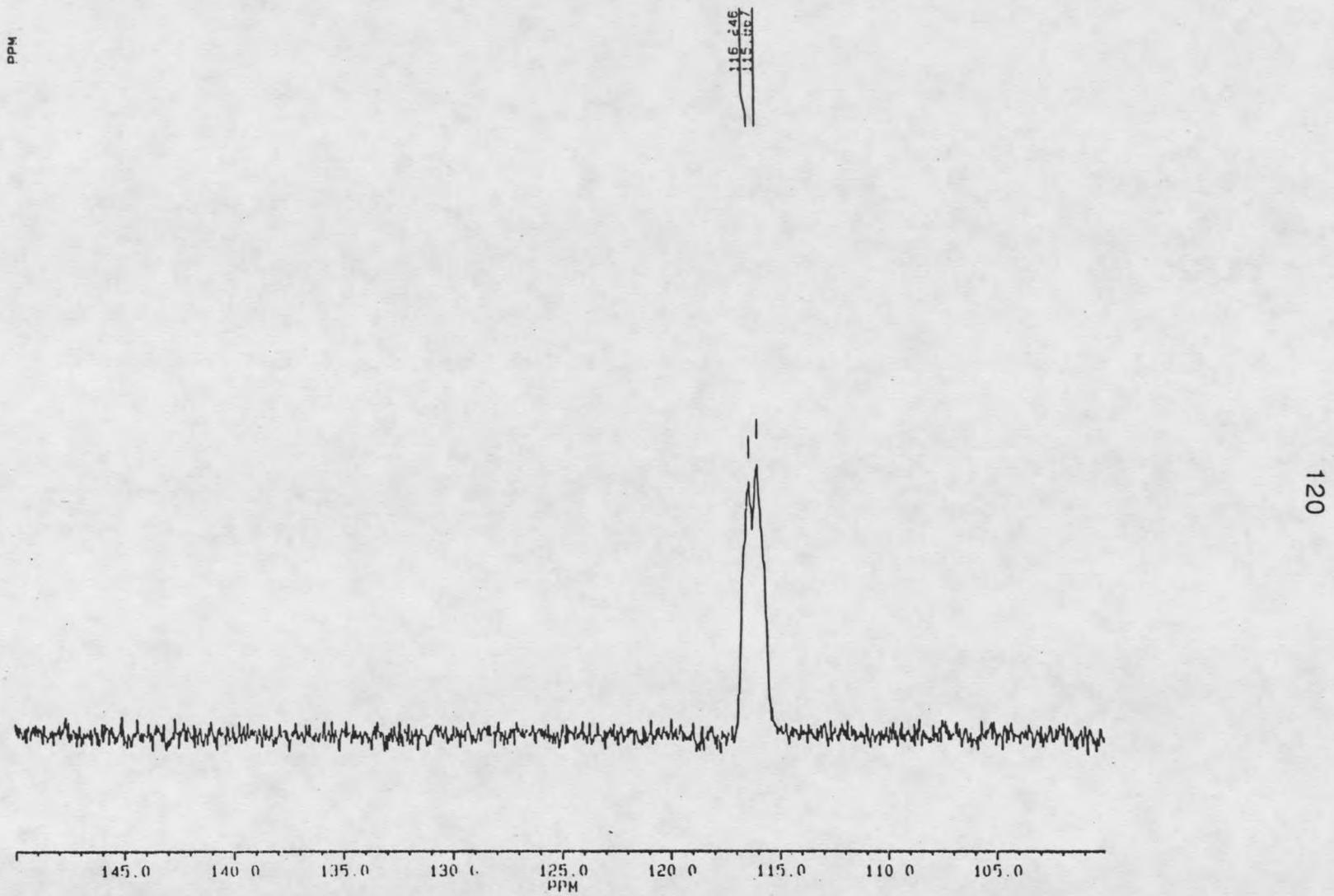
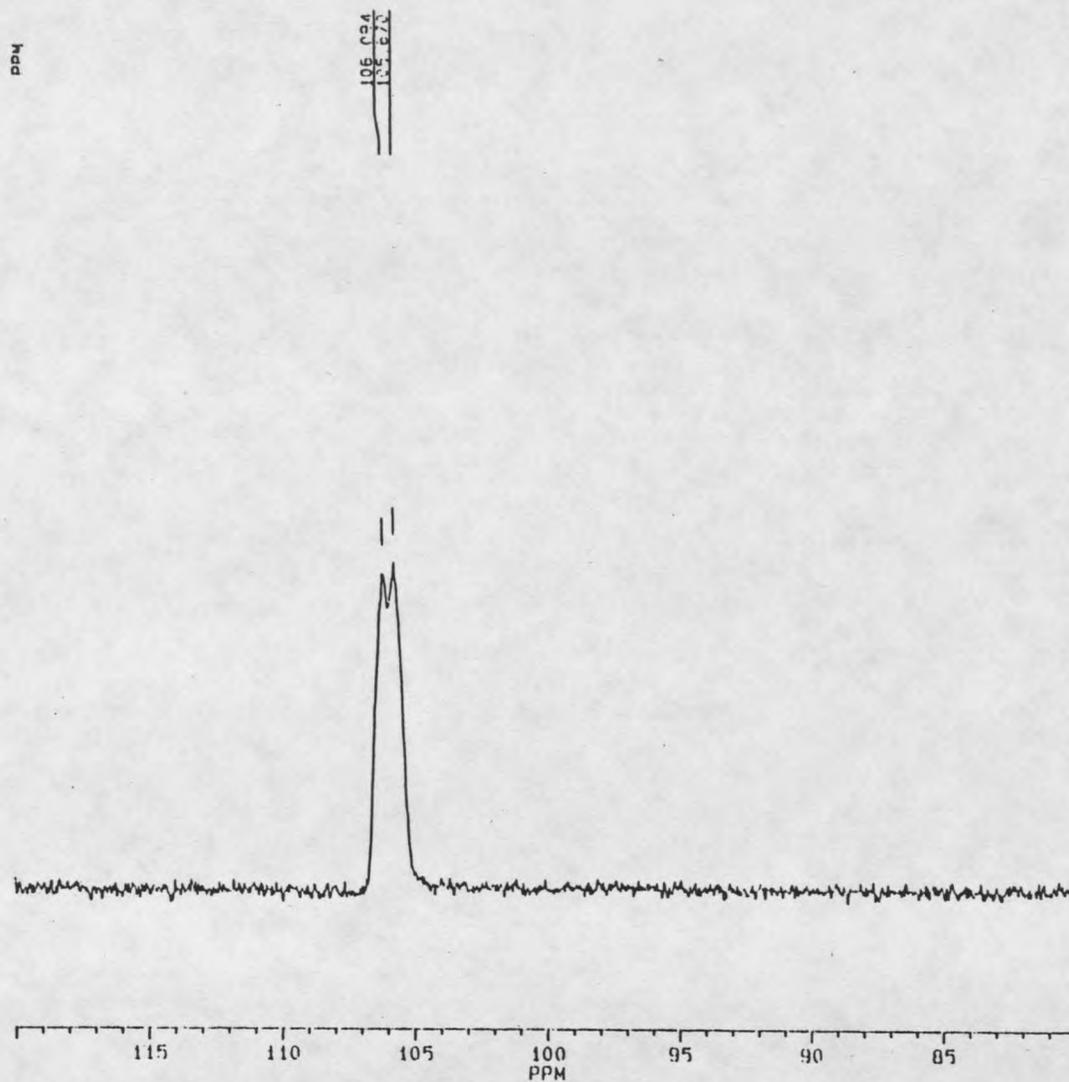


Figure 41.  $^{31}\text{P}$  NMR Spectrum of (*S*)-methyl-(2-trifluoromethylphenyl)-2-methoxyethylphosphinite borane (60)







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Figure 44.  $^{31}\text{P}$  NMR Spectrum of (*R*)-(2-methoxyphenyl)-phenyl-methylphosphinite borane (61)



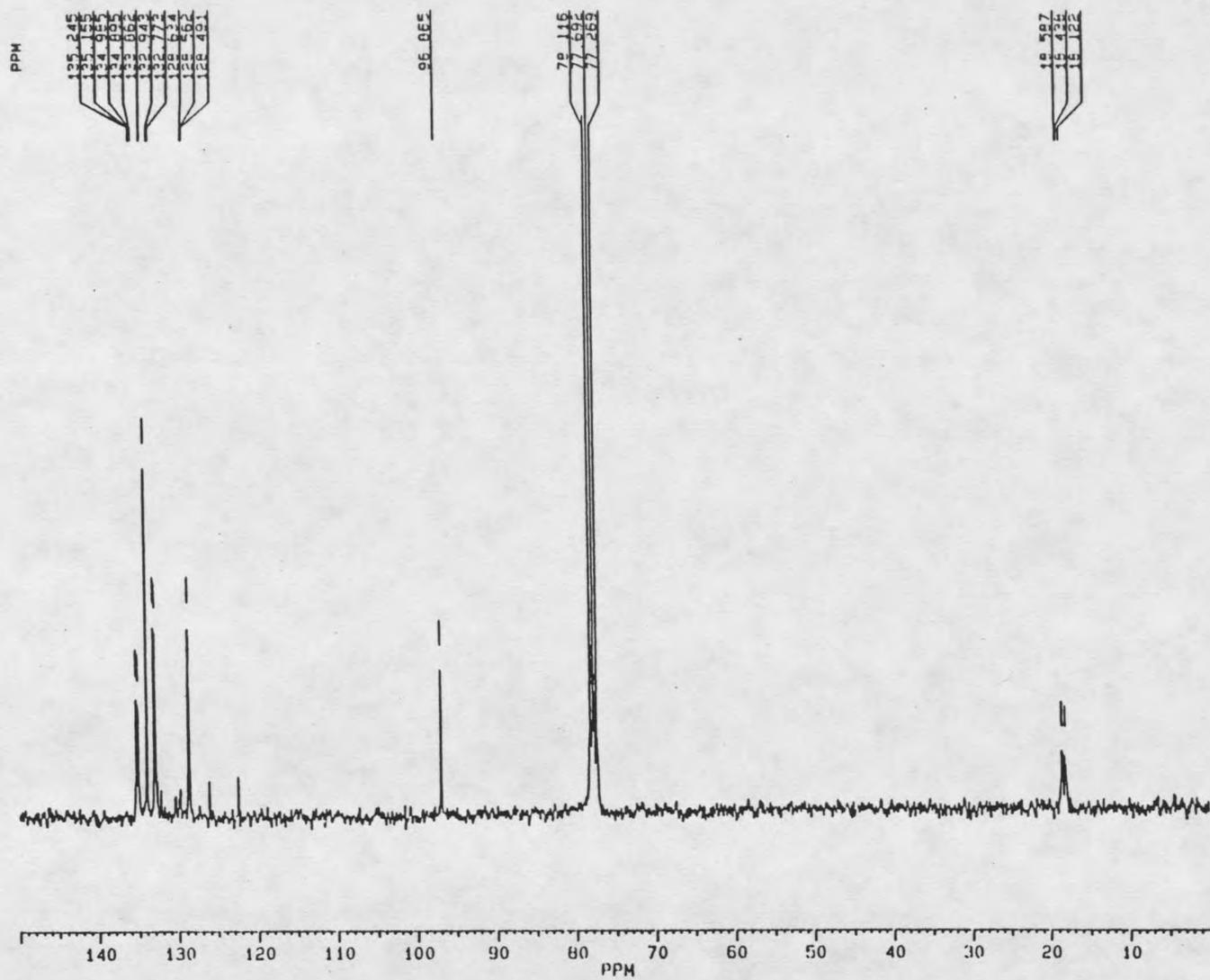


Figure 46.  $^{13}\text{C}$  NMR Spectrum of Fluoro methyl-(2-trifluoromethylphenyl)-phosphine borane (62)

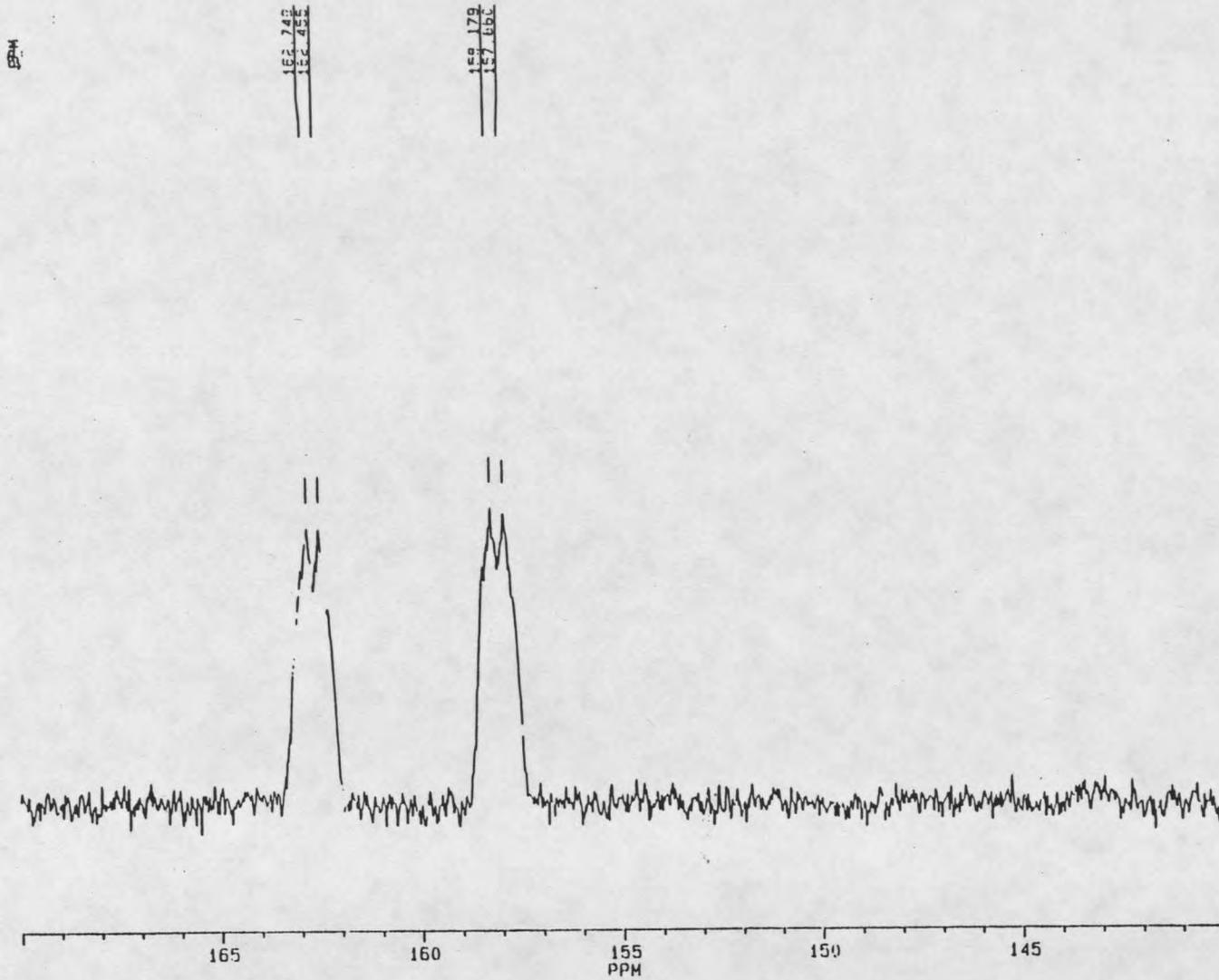


Figure 47.  $^{31}\text{P}$  NMR Spectrum of Fluoro methyl-(2-trifluoromethylphenyl)-phosphine borane (62)

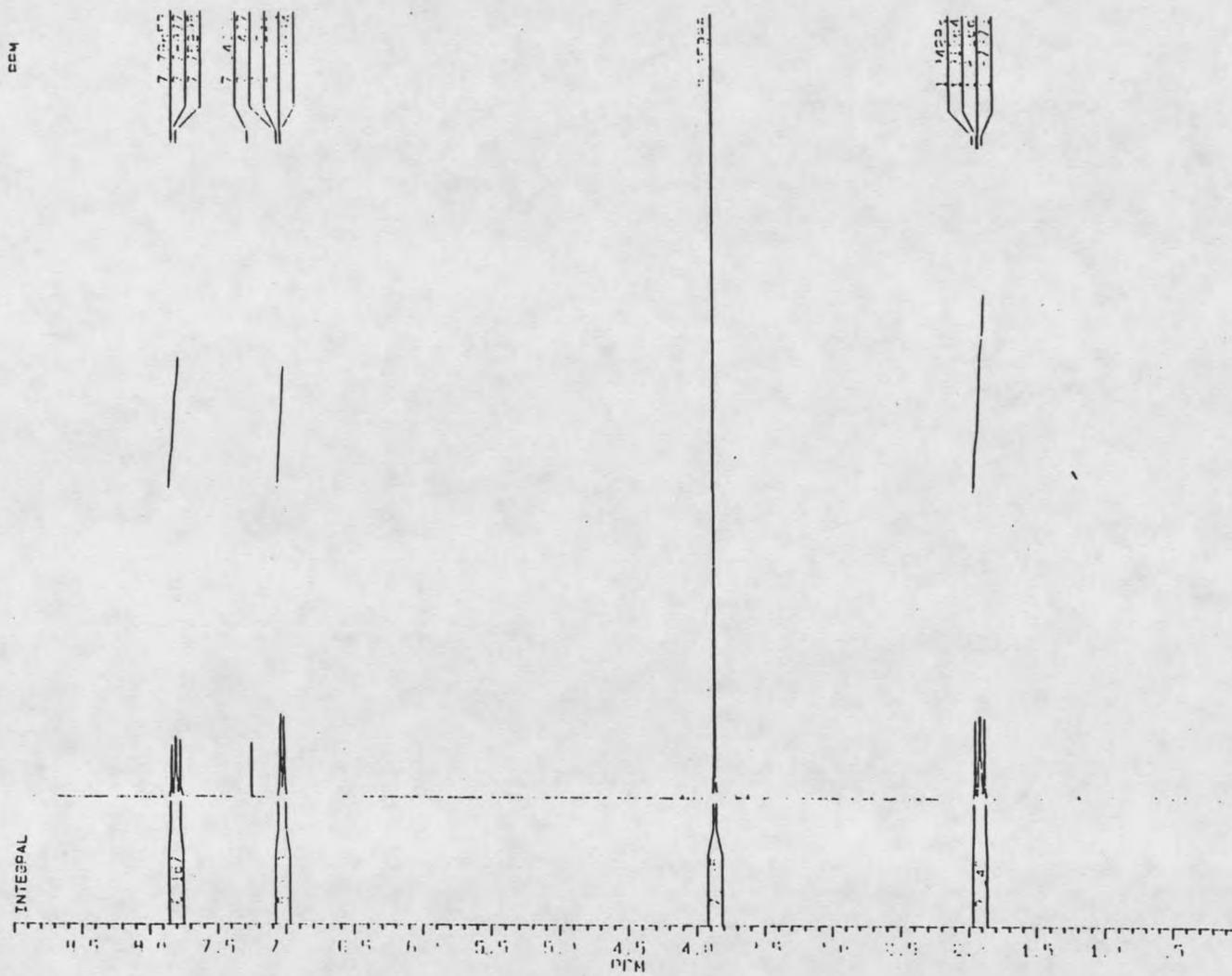


Figure 48.  $^1\text{H}$  NMR Spectrum of Fluoro methyl-(4-methoxyphenyl)-phosphine borane (64)

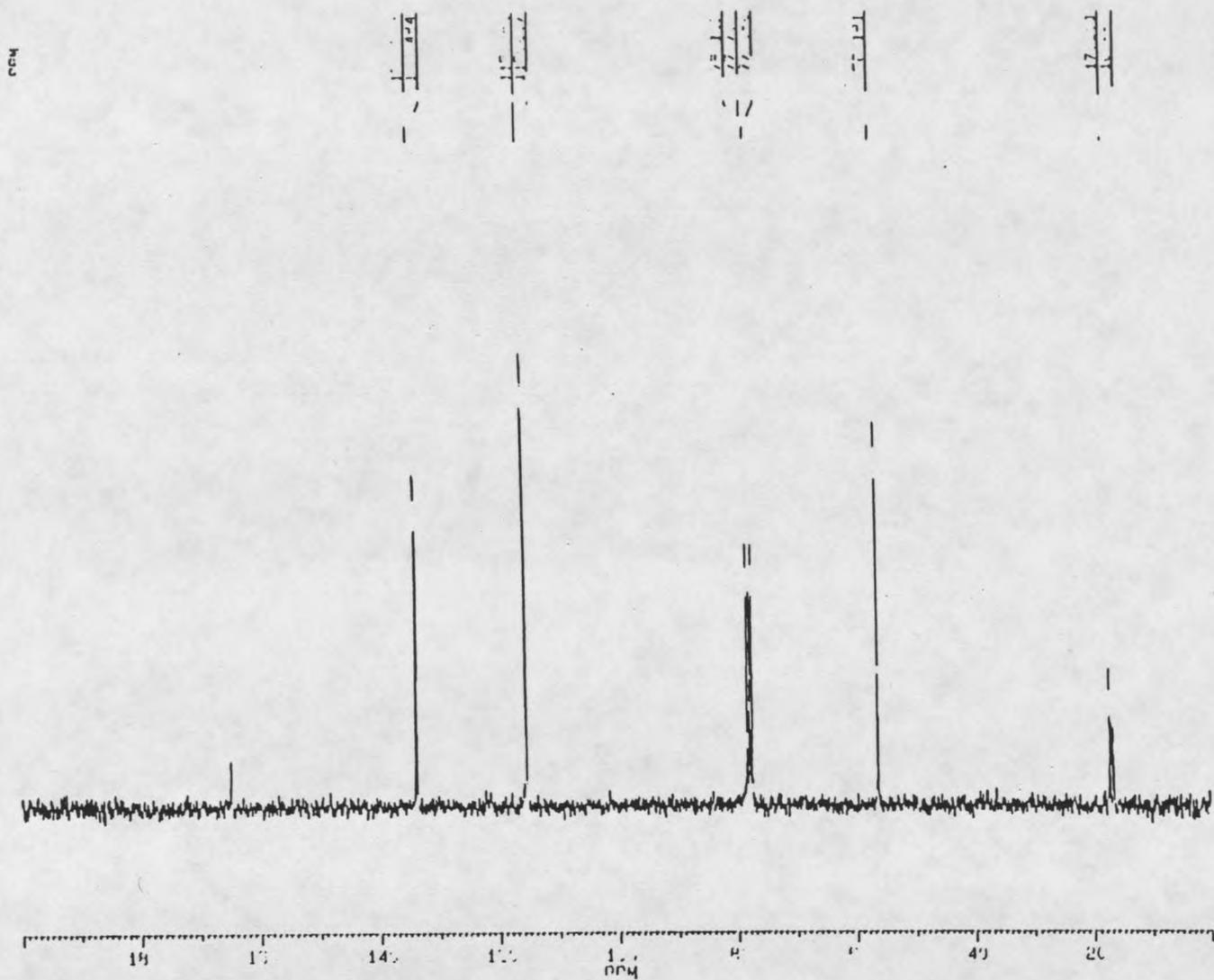


Figure 49.  $^{13}\text{C}$  NMR Spectrum of Fluoro methyl-(4-methoxyphenyl)-phosphine borane (64)

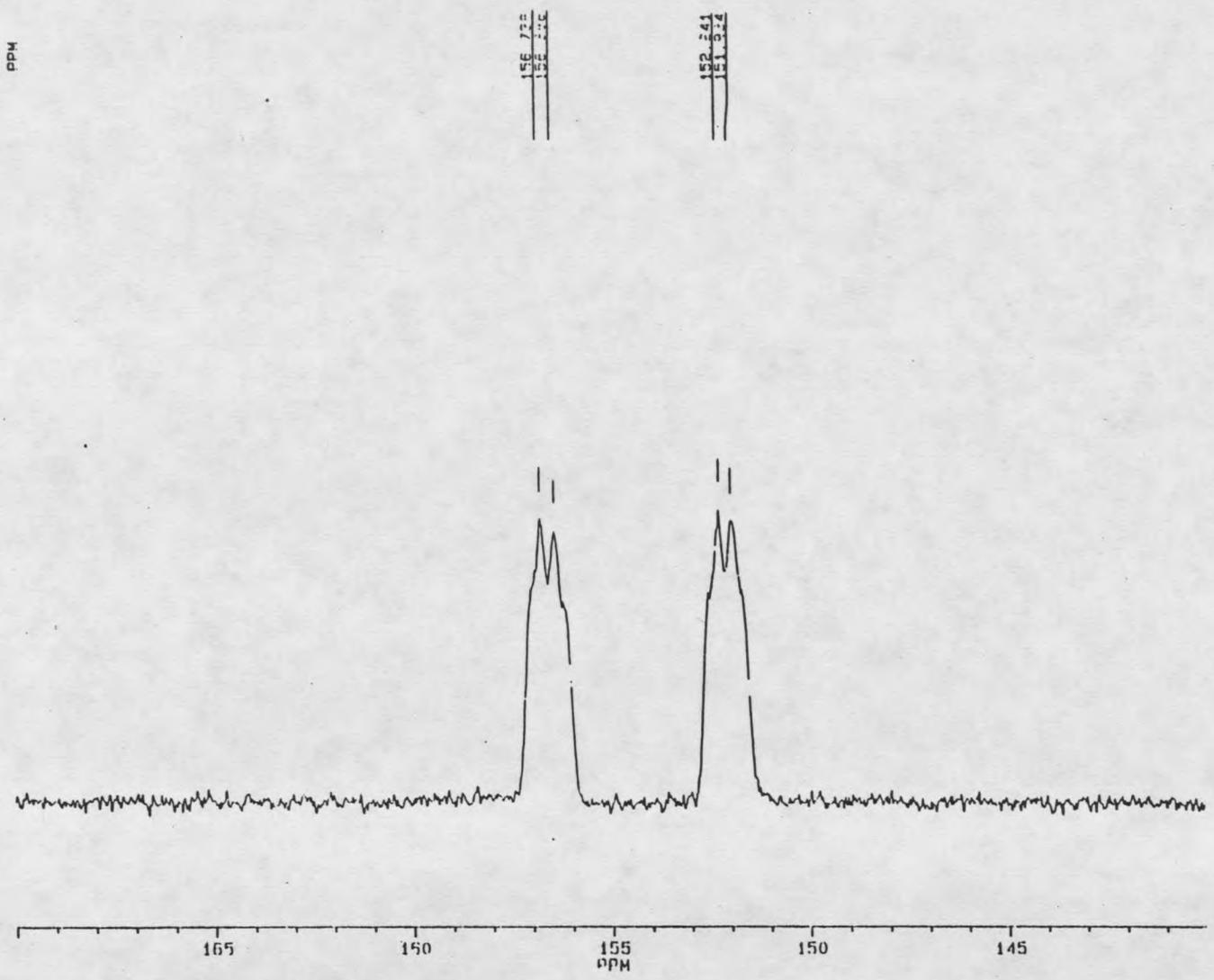
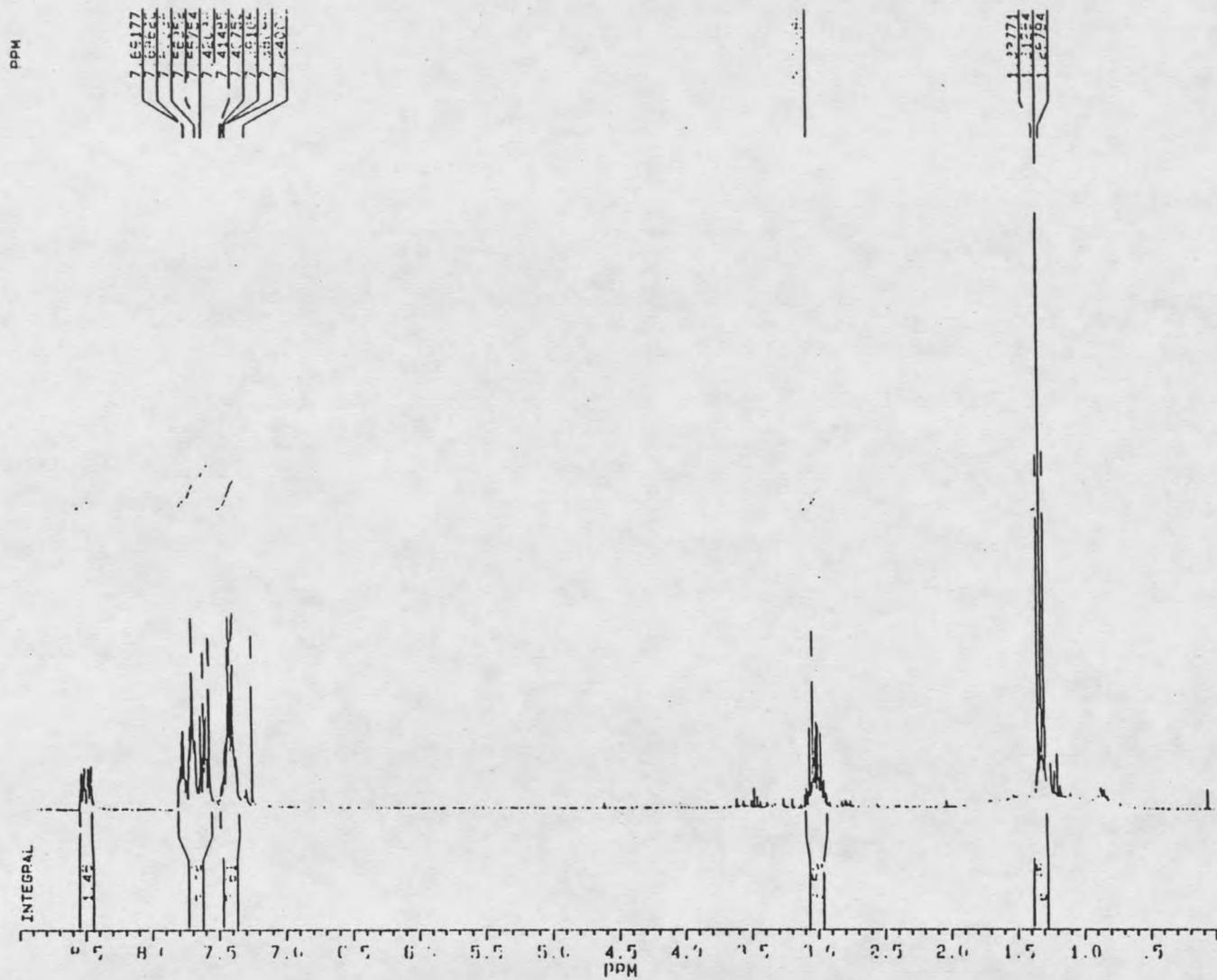


Figure 50.  $^{31}\text{P}$  NMR Spectrum of Fluoro methyl-(4-methoxyphenyl)-phosphine borane (64)



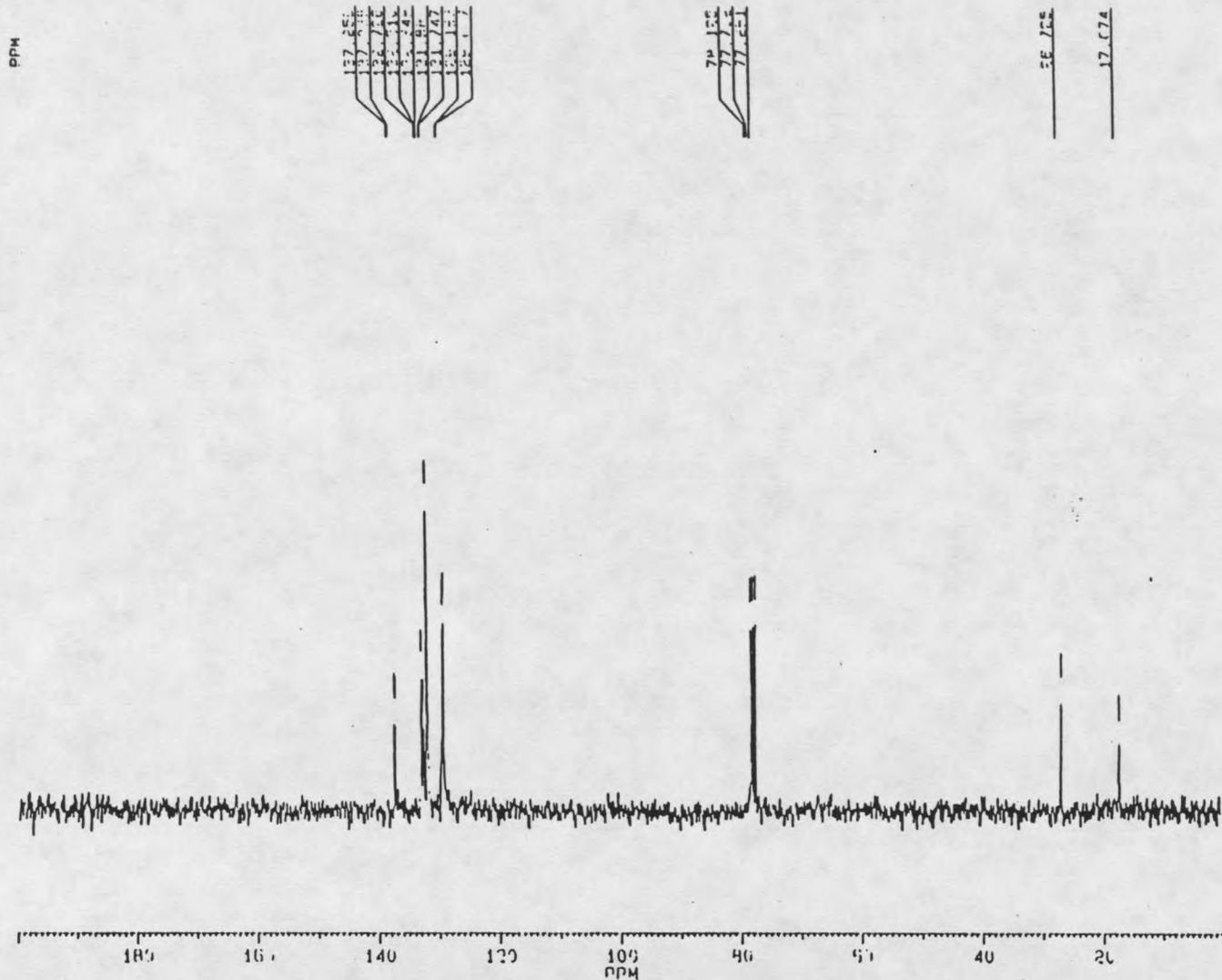
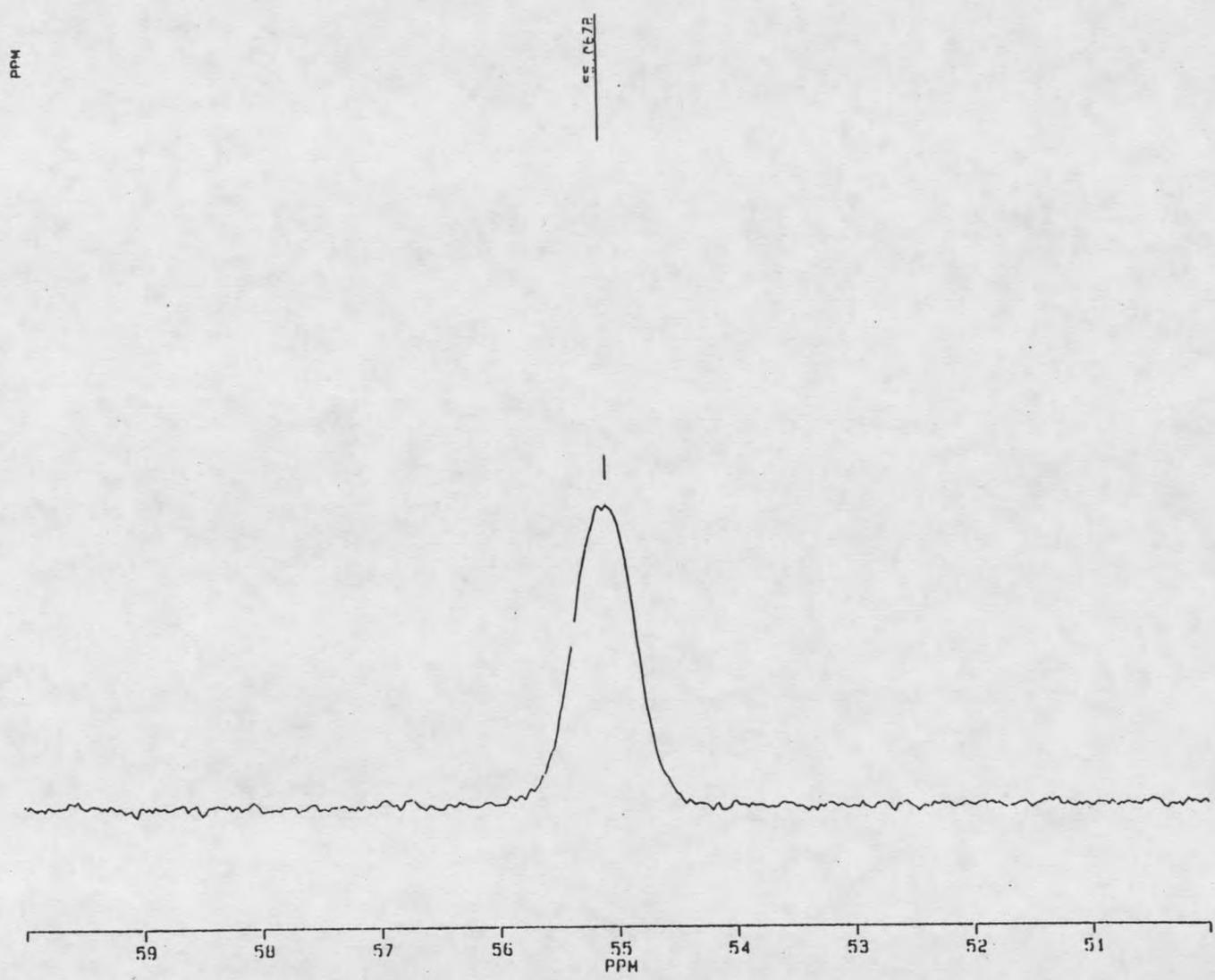


Figure 52.  $^{13}\text{C}$  NMR Spectrum of Phenyl-(2-trifluoromethylphenyl)-ethylthiophosphinite borane (68a)



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Figure 53.  $^{31}\text{P}$  NMR Spectrum of Phenyl-(2-trifluoromethylphenyl)-ethylthiophosphinite borane (68a)

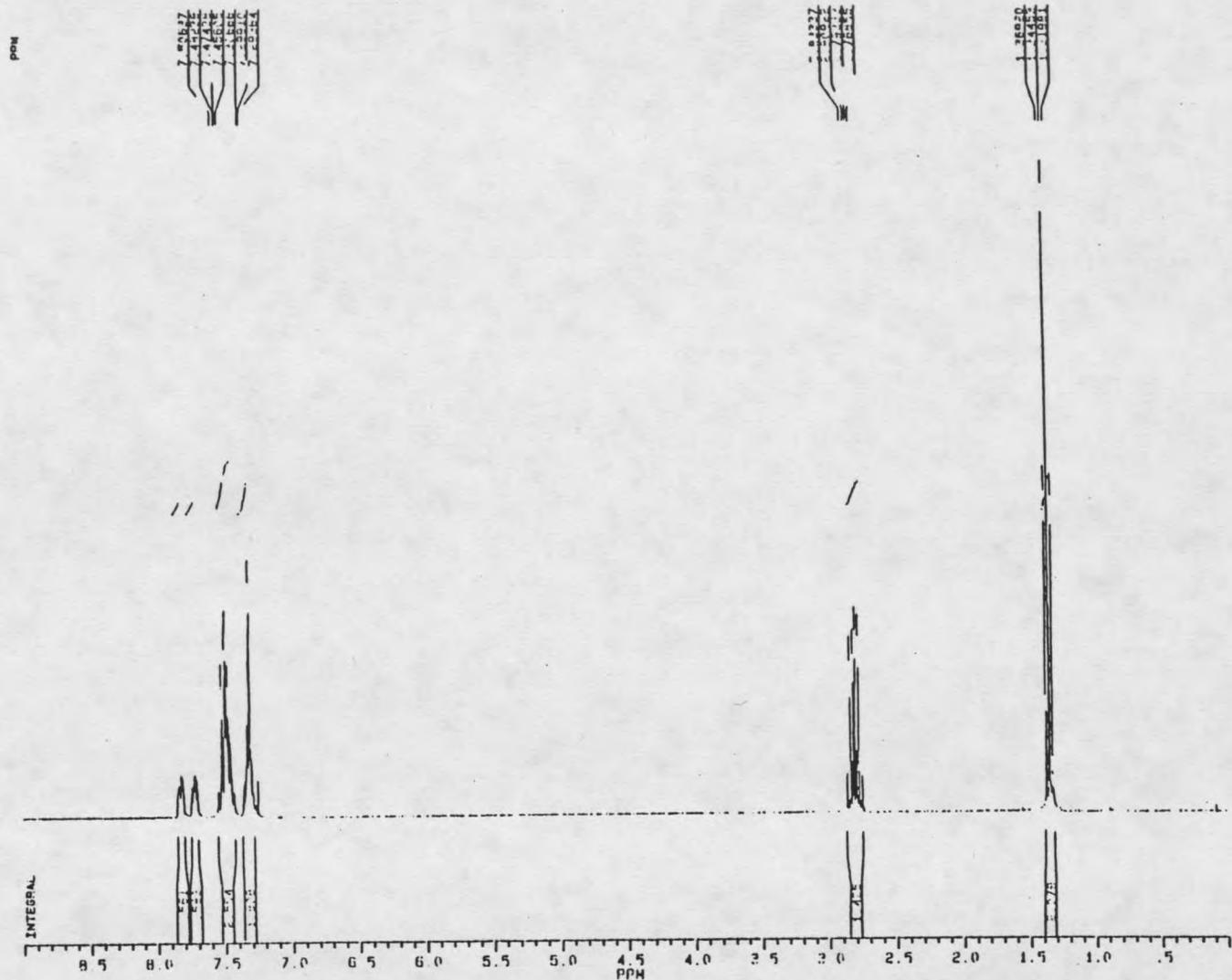
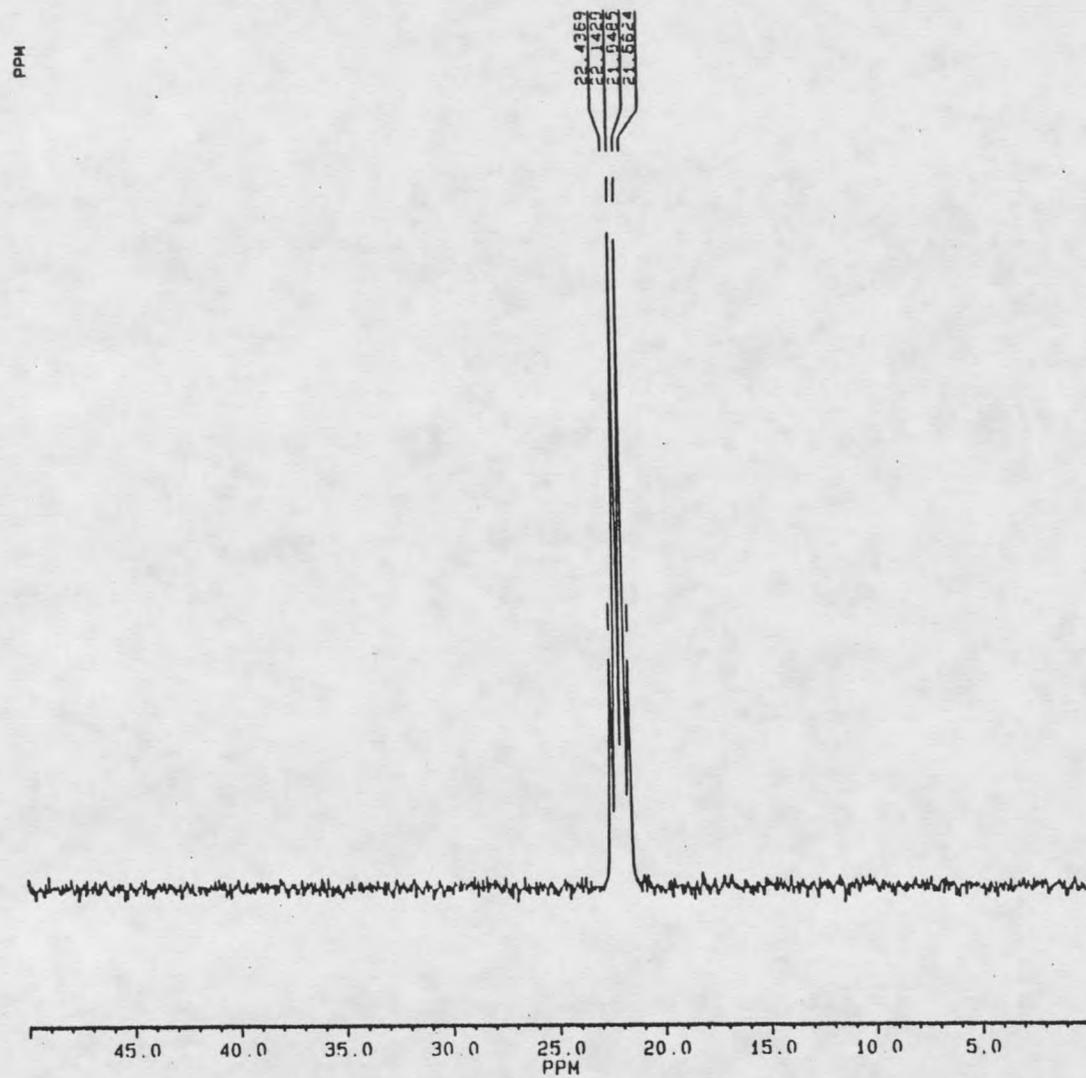


Figure 54.  $^1\text{H}$  NMR Spectrum of Phenyl-(2-trifluoromethylphenyl)-ethylthiophosphinite (68b)





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Figure 56.  $^{31}\text{P}$  NMR Spectrum of Phenyl-(2-trifluoromethylphenyl)-ethylthiophosphinite (68b)

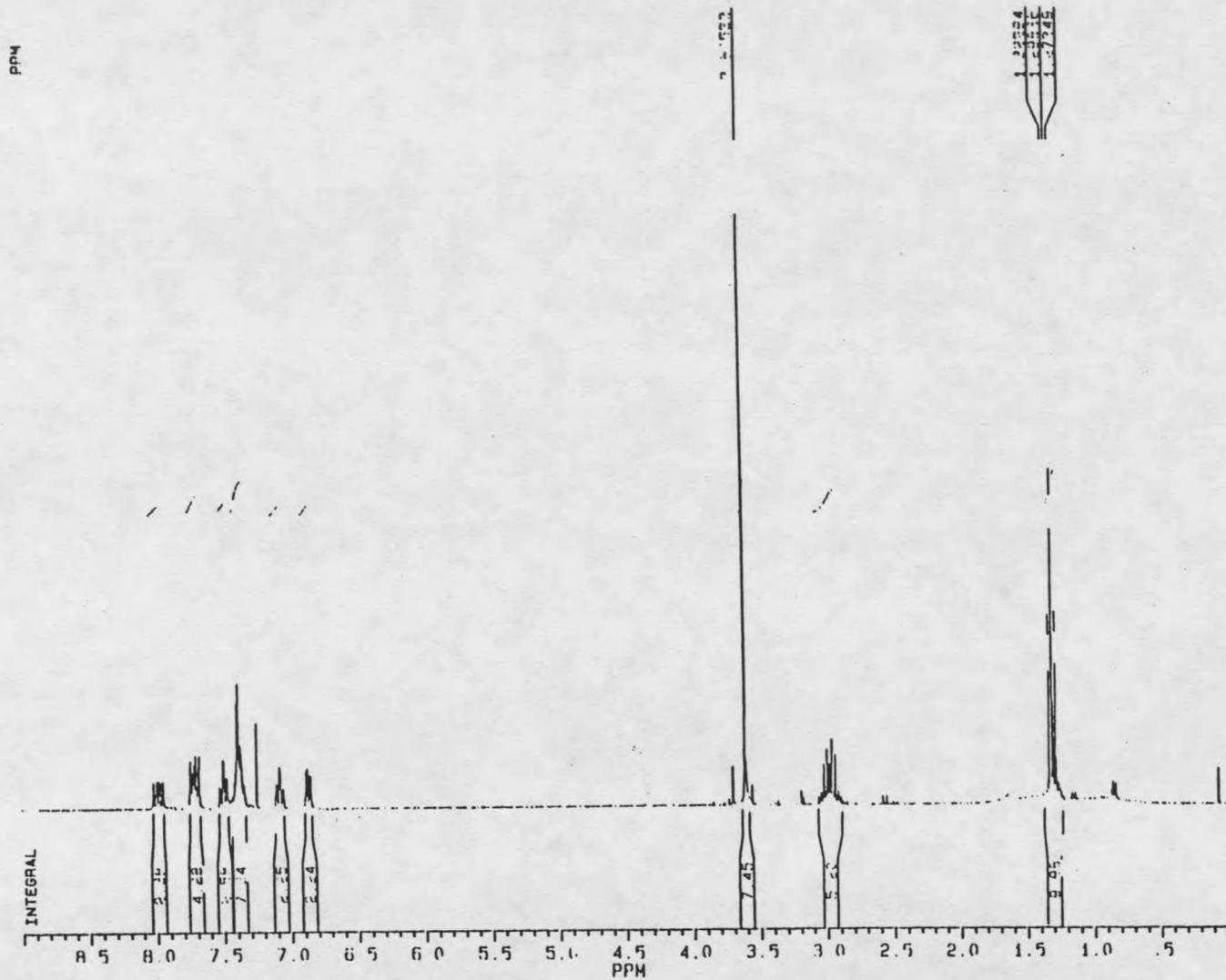


Figure 57.  $^1\text{H}$  NMR Spectrum of Phenyl-(2-methoxyphenyl)-ethylthiophosphinite borane (69a)

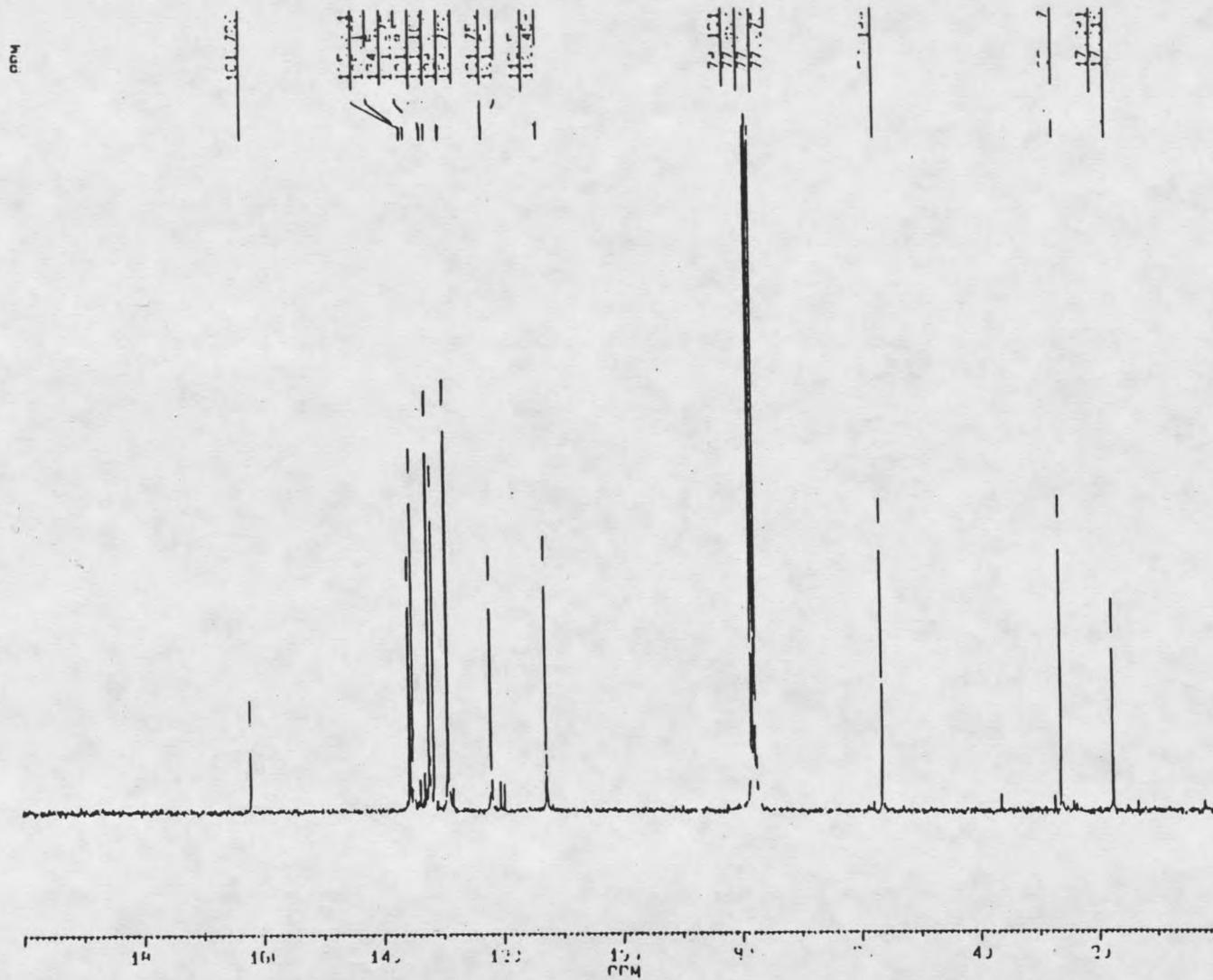
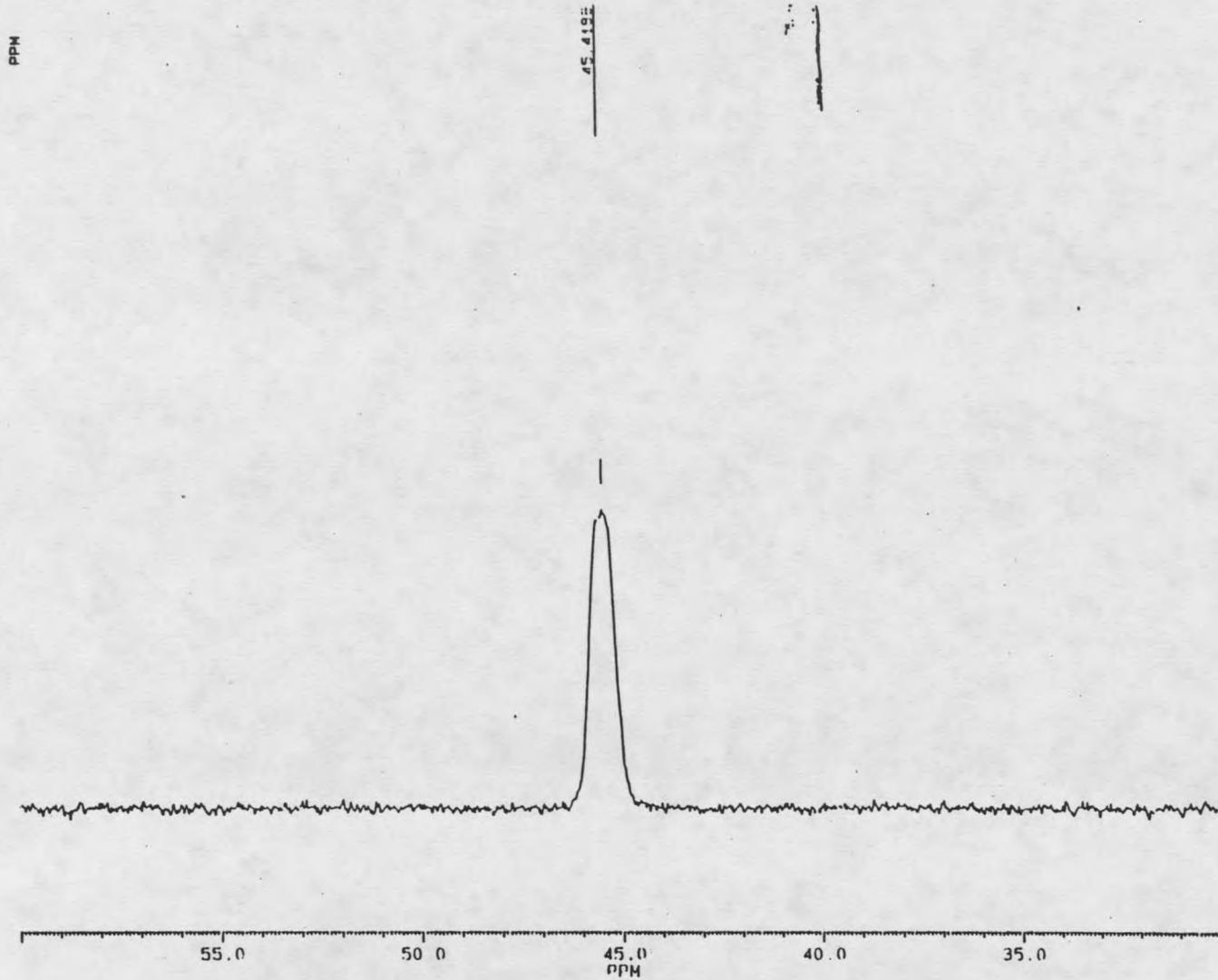


Figure 58.  $^{13}\text{C}$  NMR Spectrum of Phenyl-(2-methoxyphenyl)-ethylthiophosphinite borane (69a)



138

Figure 59.  $^{31}\text{P}$  NMR Spectrum of Phenyl-(2-methoxyphenyl)-ethylthiophosphinite borane (69a)

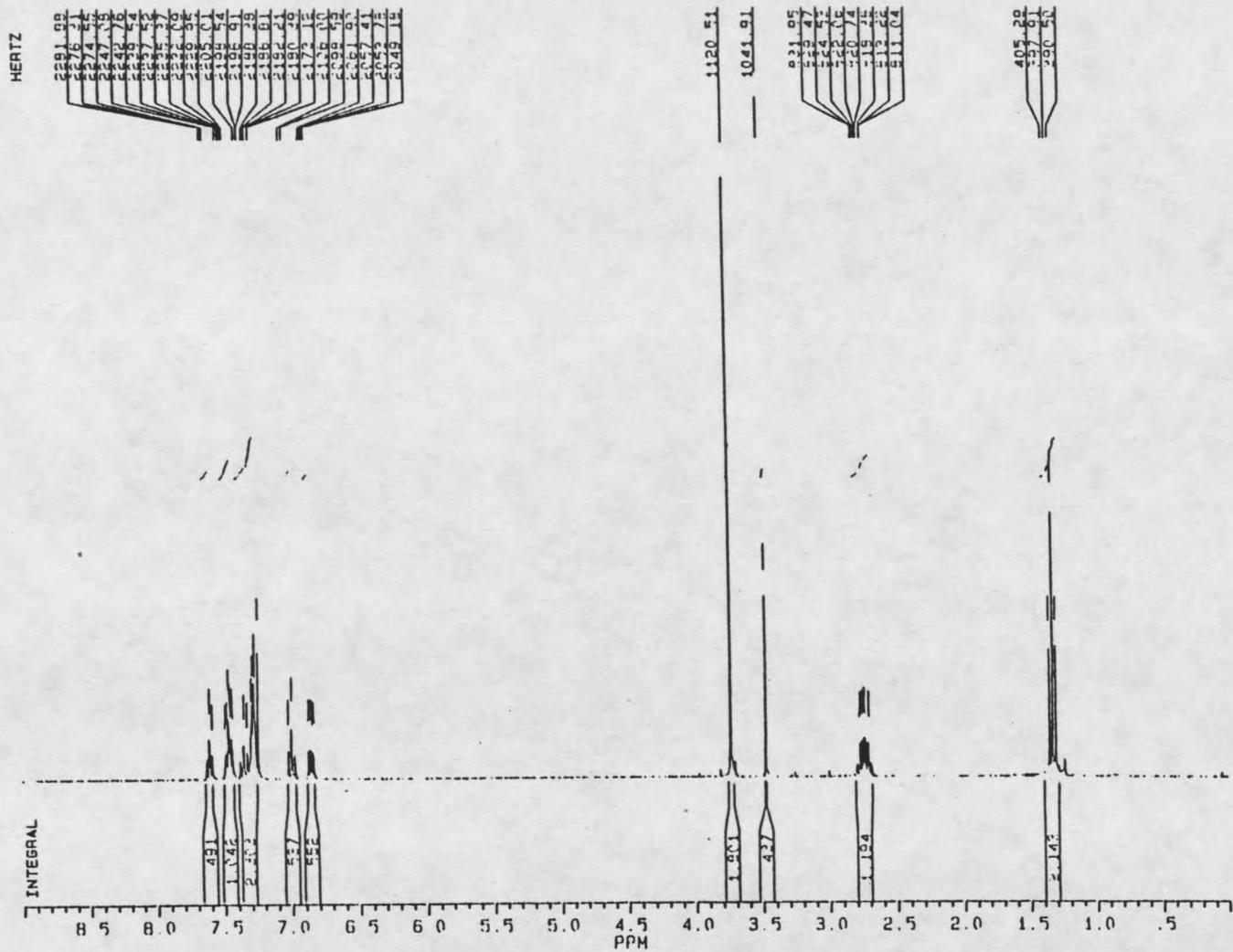


Figure 60.  $^1\text{H}$  NMR Spectrum of Phenyl-(2-methoxyphenyl)-ethylthiophosphinite (69b)

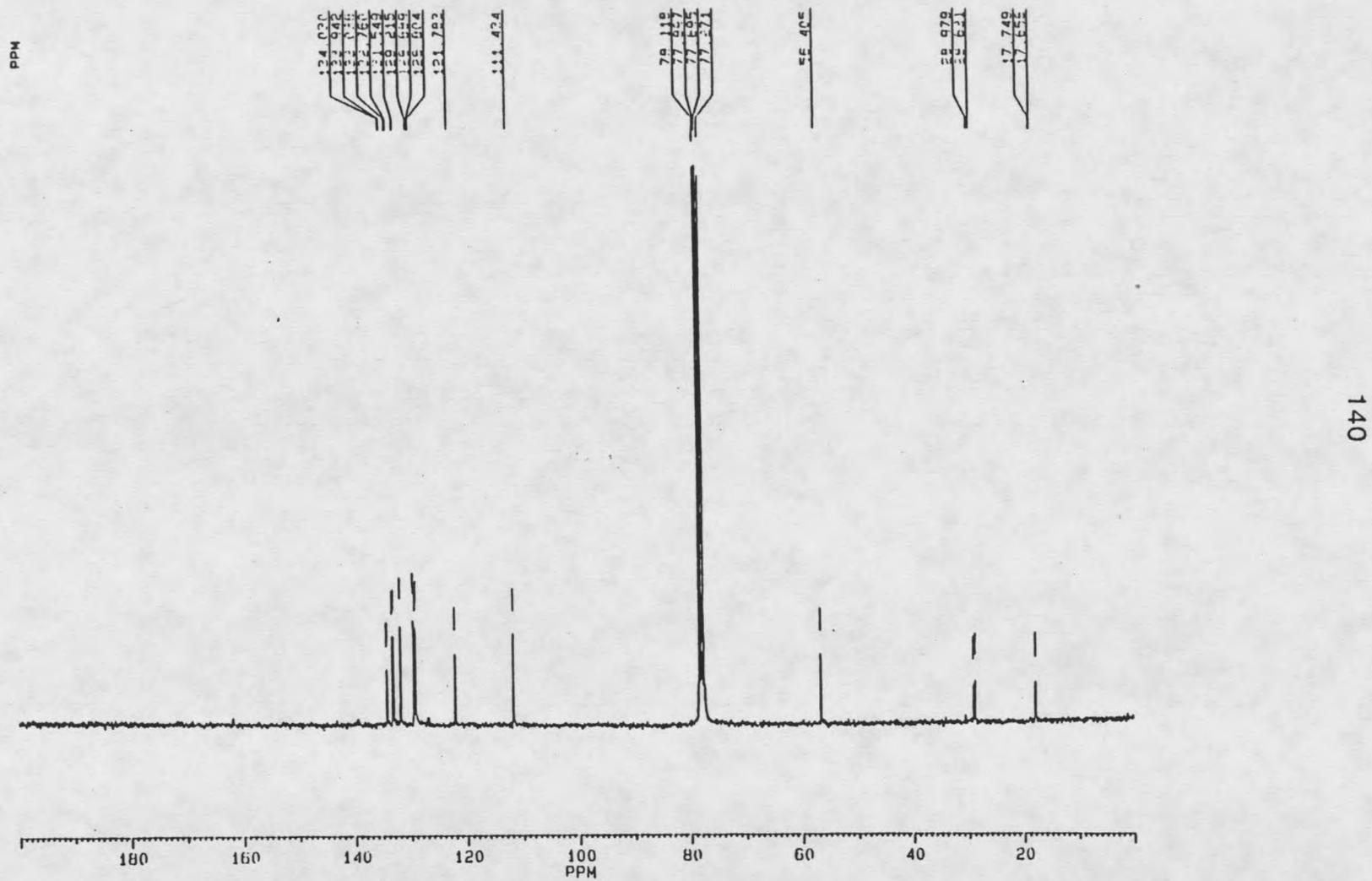


Figure 61. <sup>13</sup>C NMR Spectrum of Phenyl-(2-methoxyphenyl)-ethylthiophosphinite (69b)

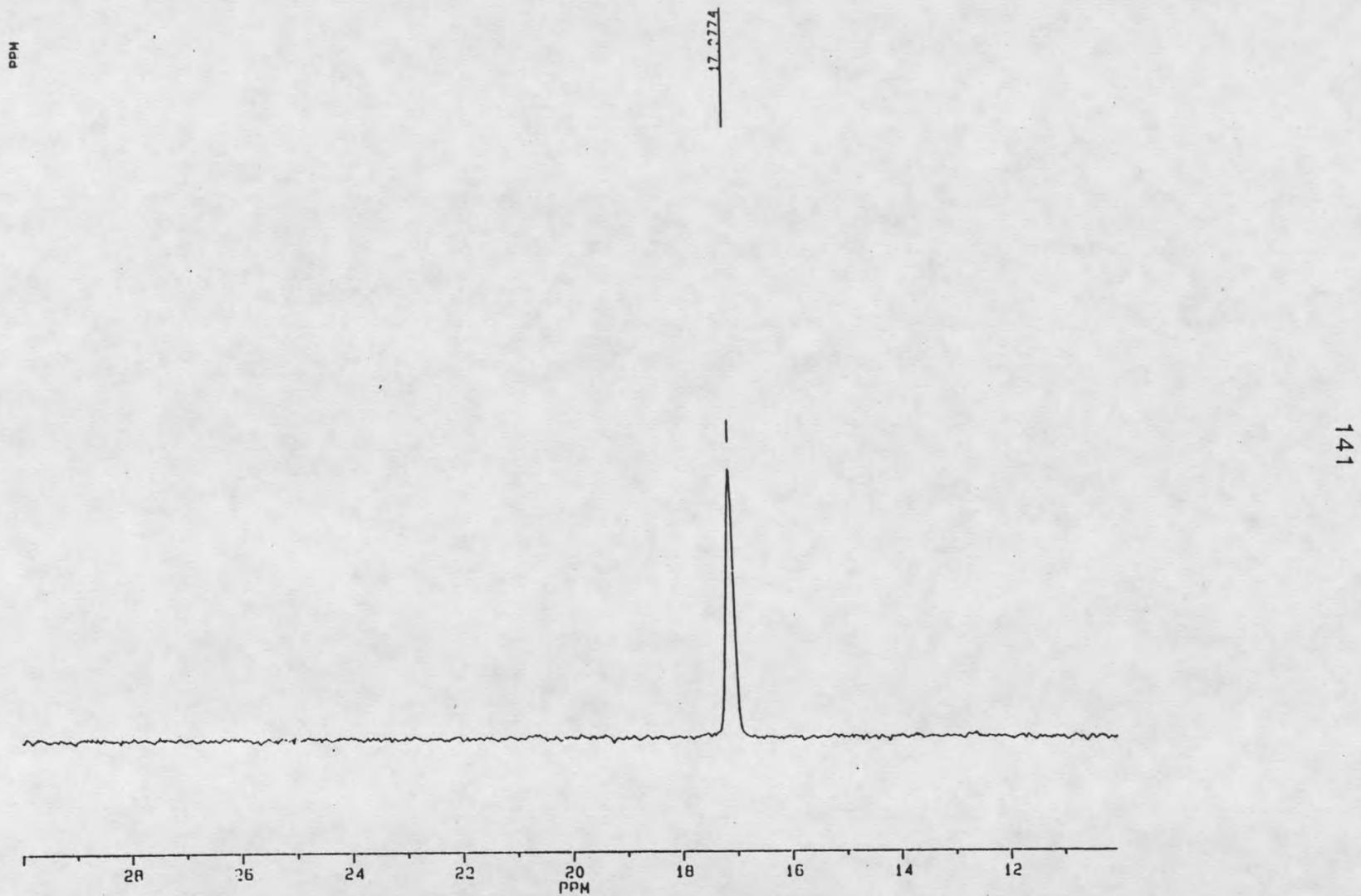


Figure 62.  $^{31}\text{P}$  NMR Spectrum of Phenyl-(2-methoxyphenyl)-ethylthiophosphinite (69b)

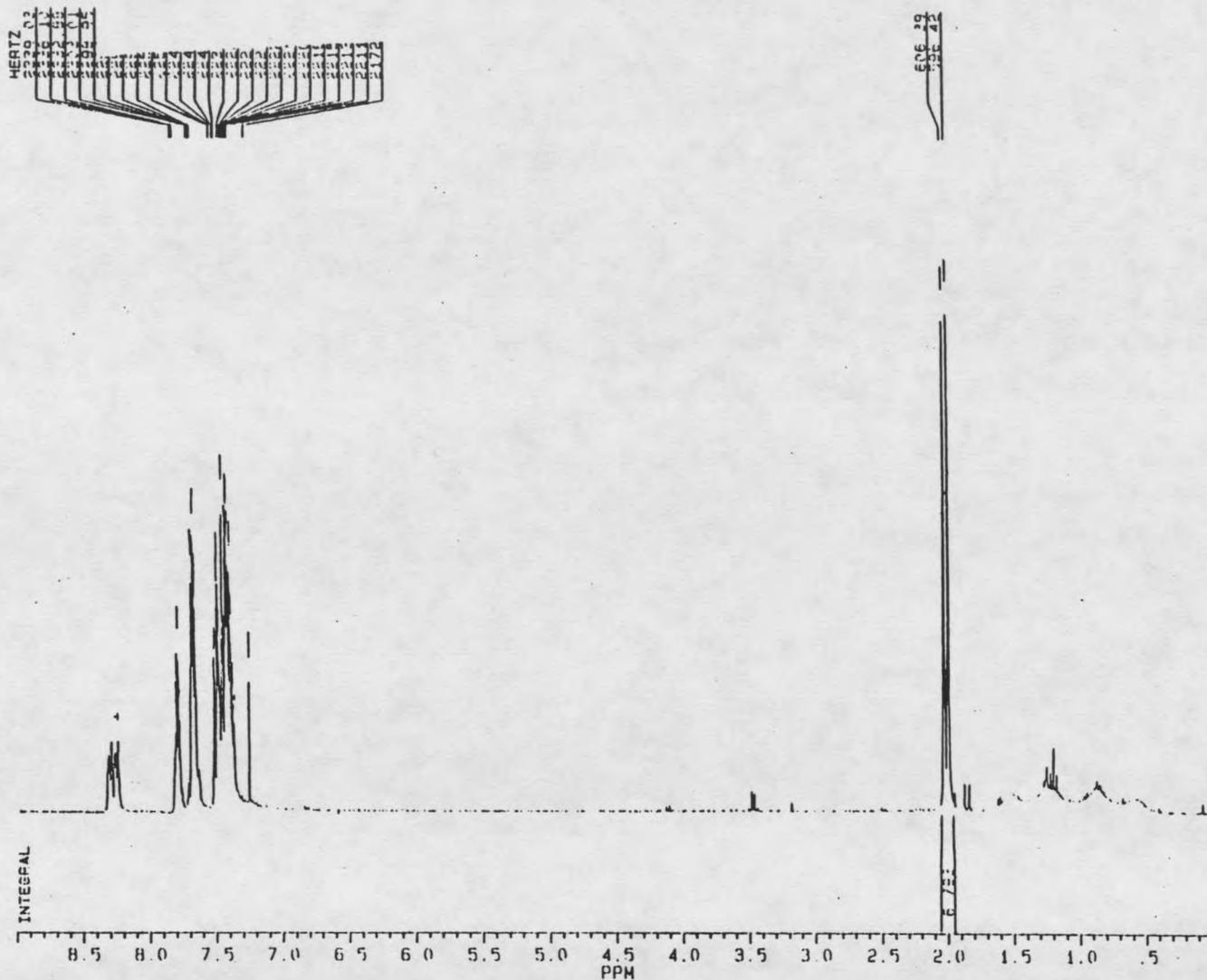


Figure 63. <sup>1</sup>H NMR Spectrum of (*S*)-Methyl-phenyl-(2-trifluoromethylphenyl)-phosphine borane (71)

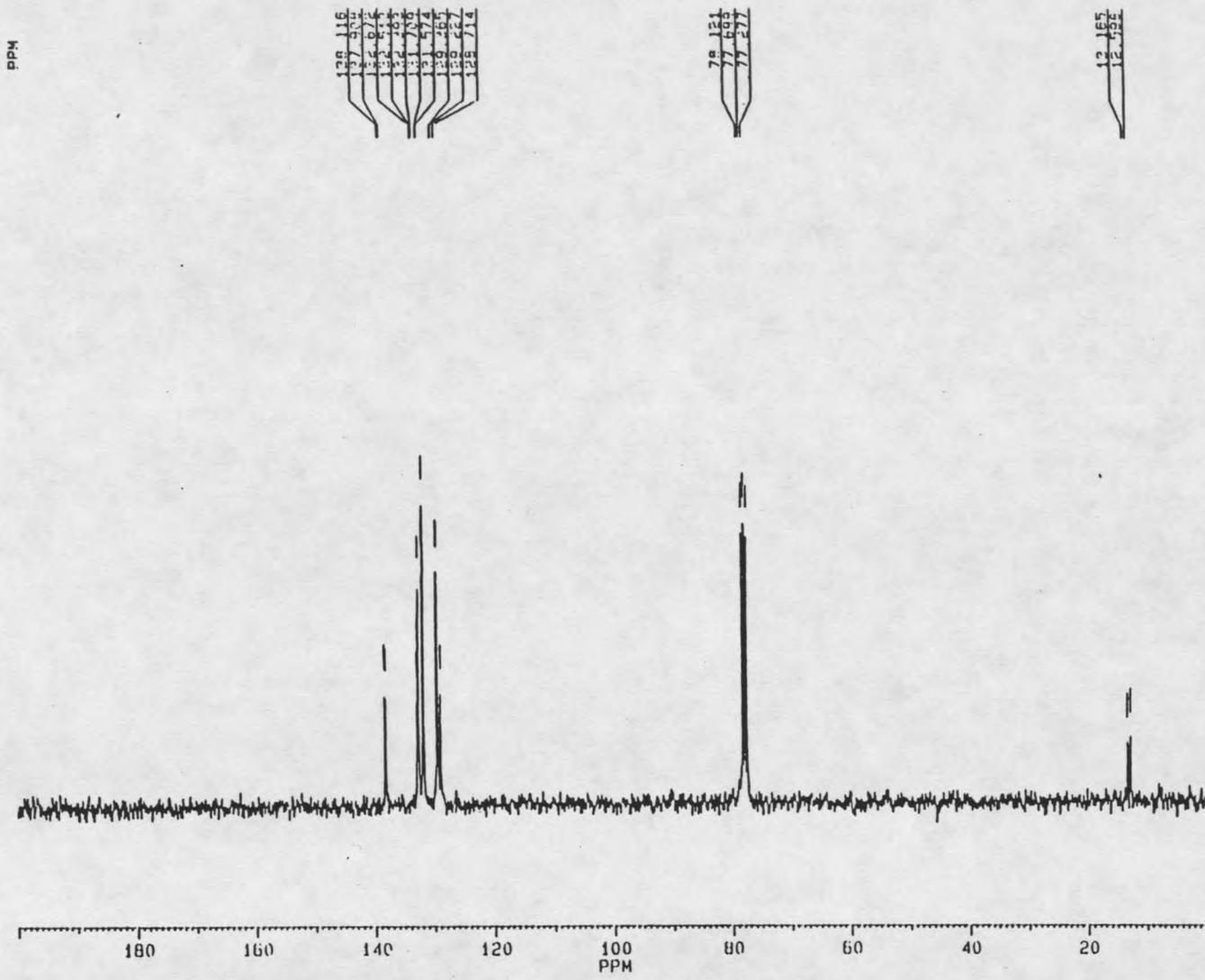
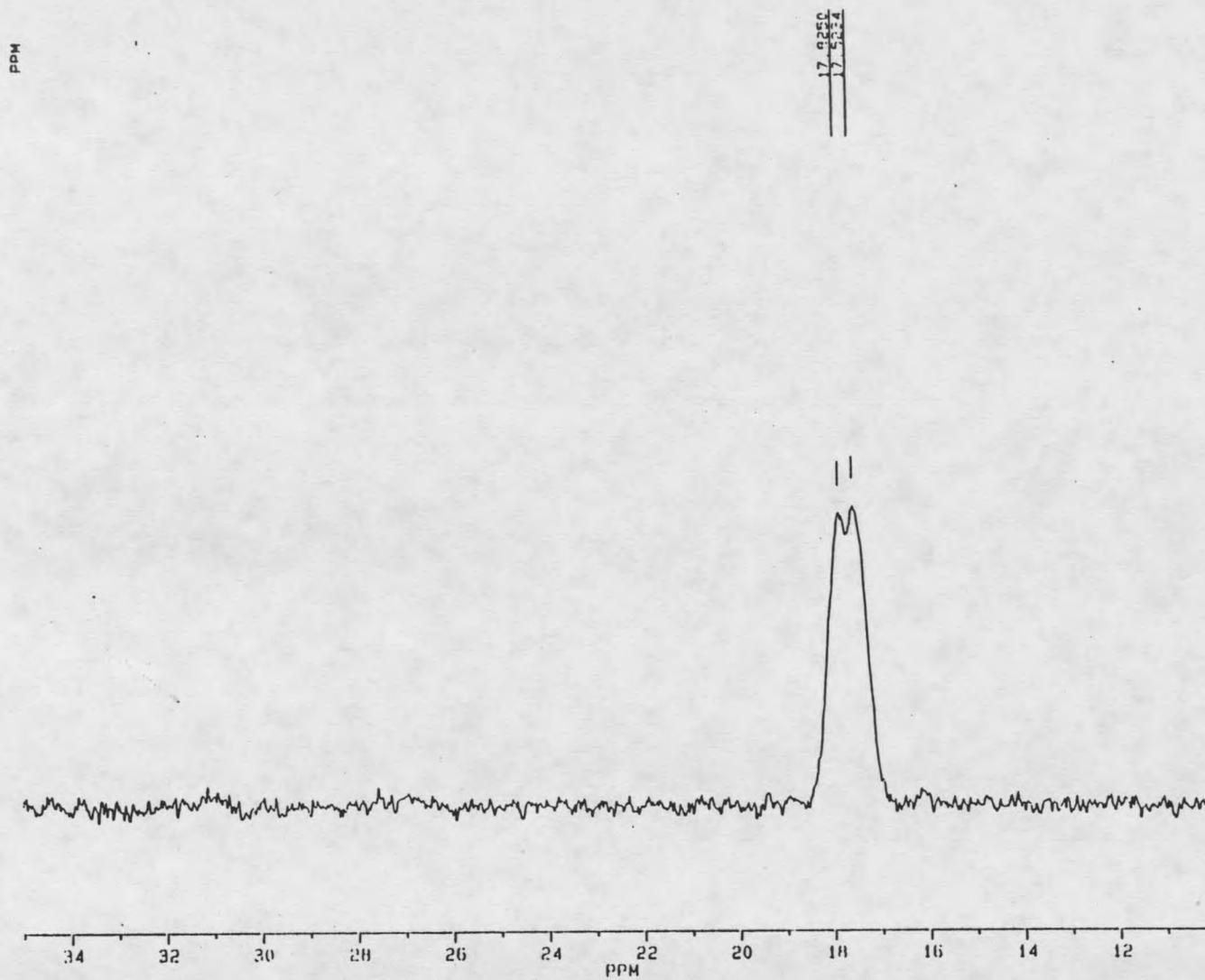


Figure 64. <sup>13</sup>C NMR Spectrum of (S)-Methyl-phenyl-(2-trifluoromethylphenyl)-phosphine borane (71)



144

Figure 65.  $^{31}\text{P}$  NMR Spectrum of (*S*)-Methyl-phenyl-(2-trifluoromethylphenyl)-phosphine borane (71)

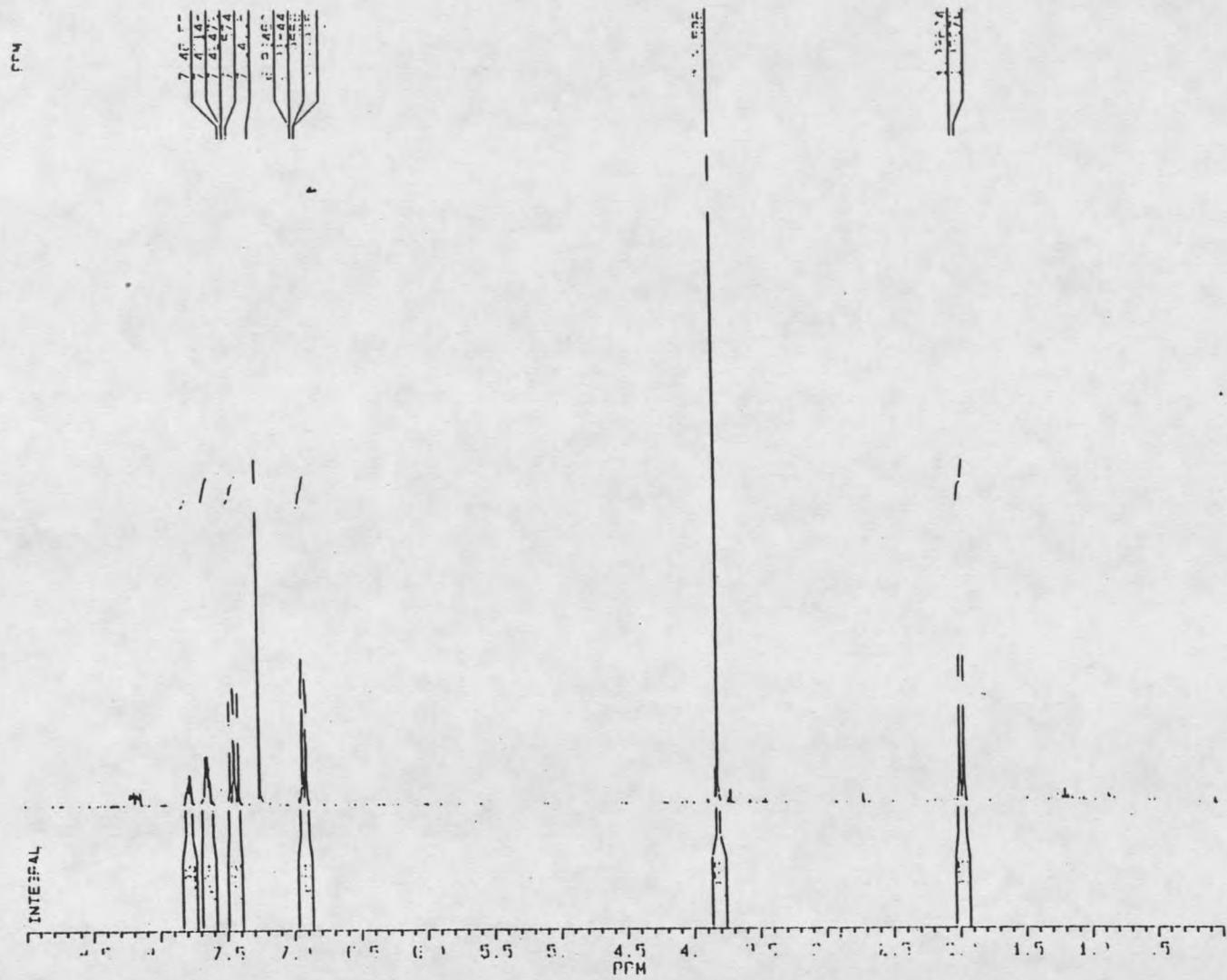
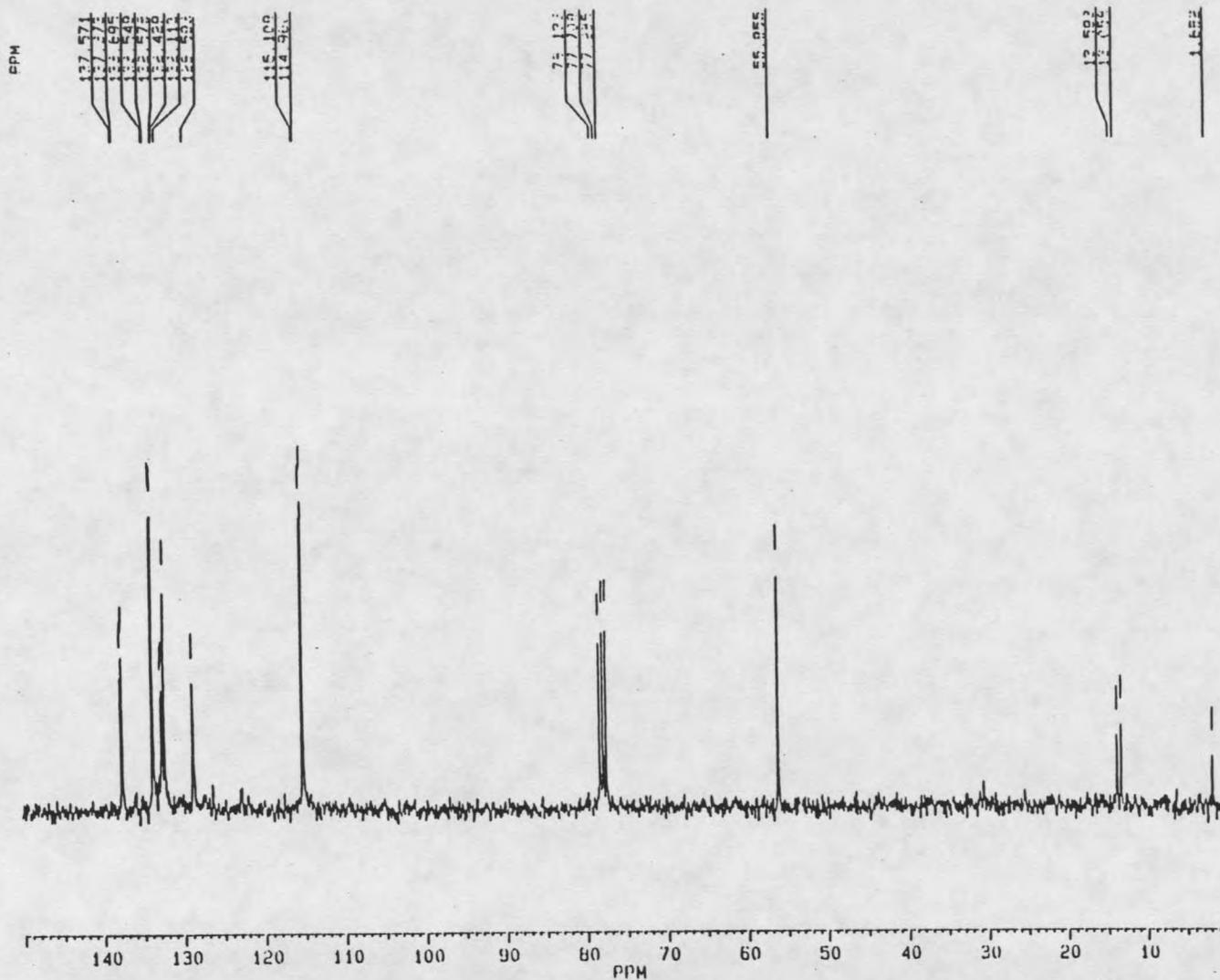
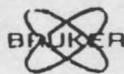


Figure 66.  $^1\text{H}$  NMR Spectrum of (S)-(4-Methoxyphenyl)-methyl-(2-trifluoromethylphenyl)-phosphine borane (72)



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Figure 67.  $^{13}\text{C}$  NMR Spectrum of (S)-(4-Methoxyphenyl)-methyl-(2-trifluoromethylphenyl)-phosphine borane (72)



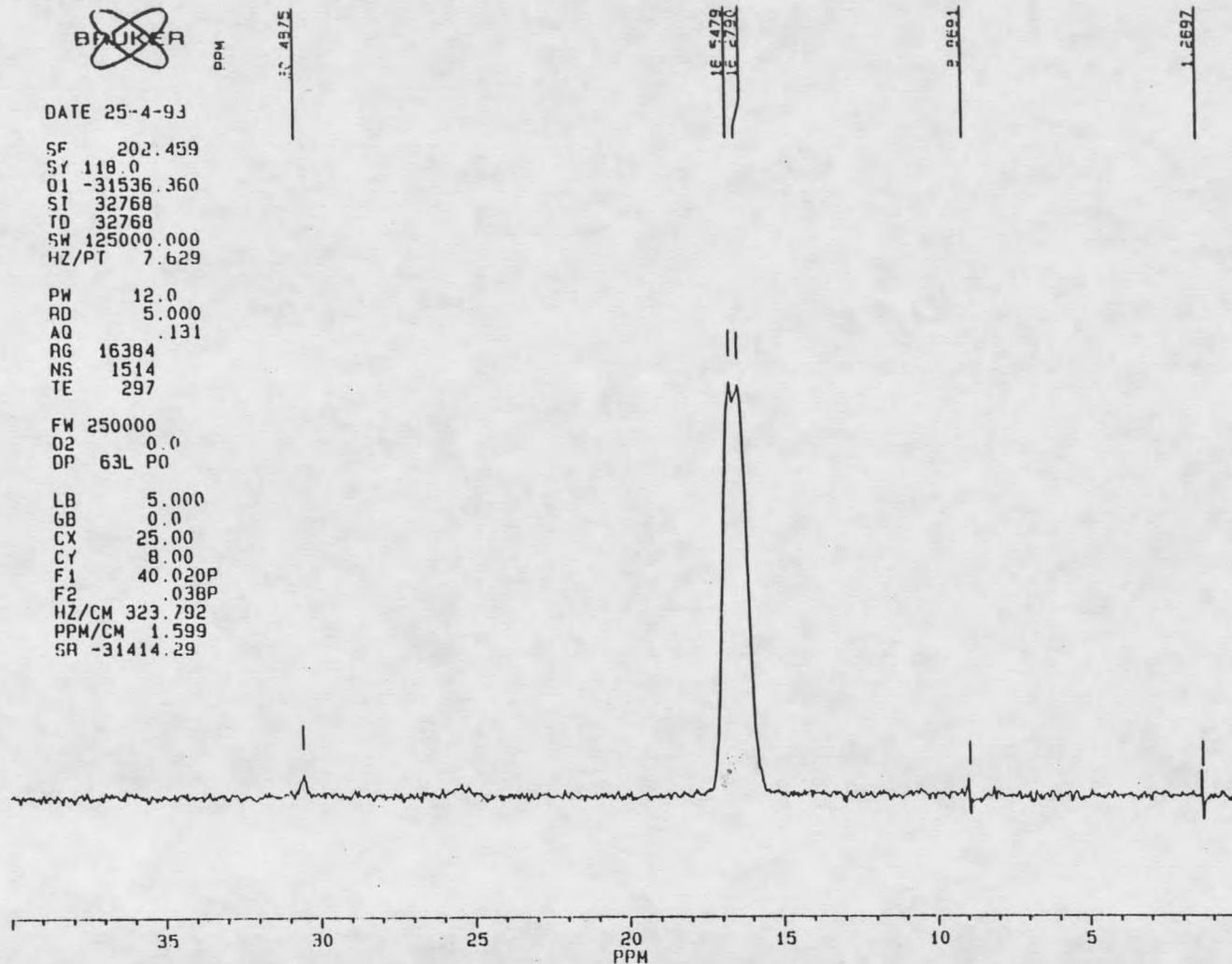
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Figure 68.  $^{31}\text{P}$  NMR Spectrum of (*S*)-(4-Methoxyphenyl)-methyl-(2-trifluoromethylphenyl)-phosphine borane (72)

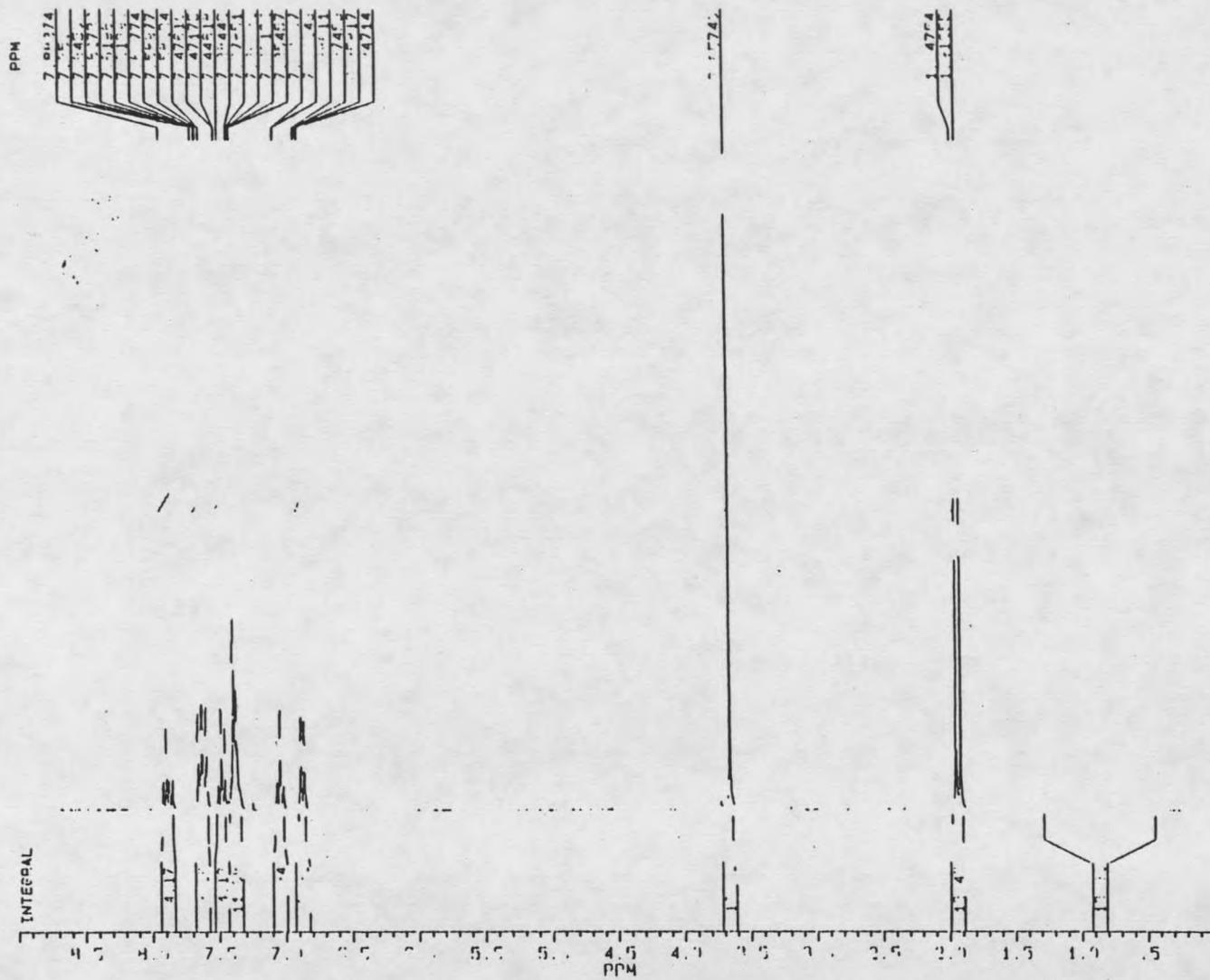


Figure 69.  $^1\text{H}$  NMR Spectrum of (S)-(2-methoxyphenyl)-methyl-phenyl-phosphine borane (73)

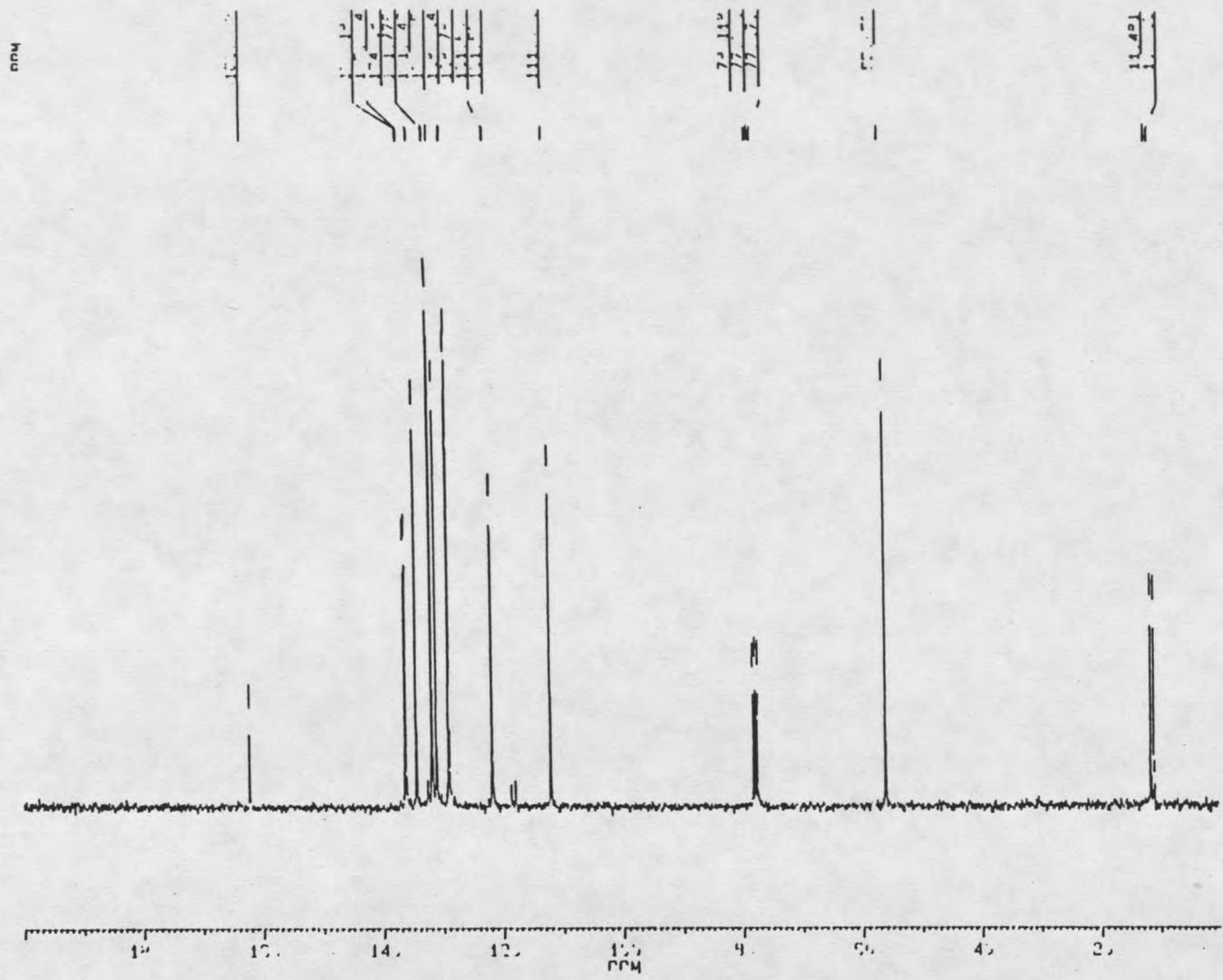


Figure 70.  $^{13}\text{C}$  NMR Spectrum of (*S*)-(2-methoxyphenyl)-methyl-phenyl-phosphine borane (73)

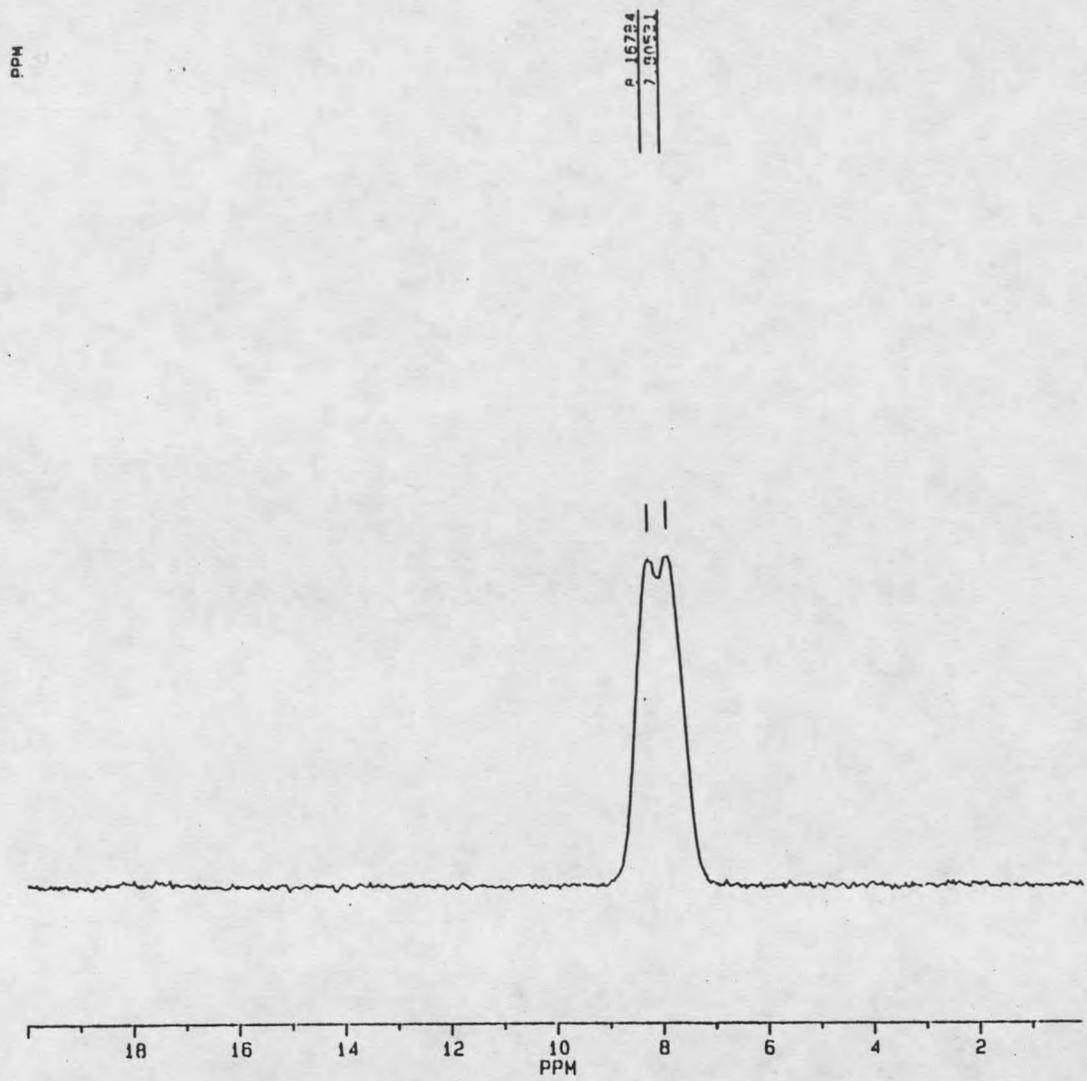


Figure 71.  $^{31}\text{P}$  NMR Spectrum of (*S*)-(2-methoxyphenyl)-methyl-phenyl-phosphine borane (73)

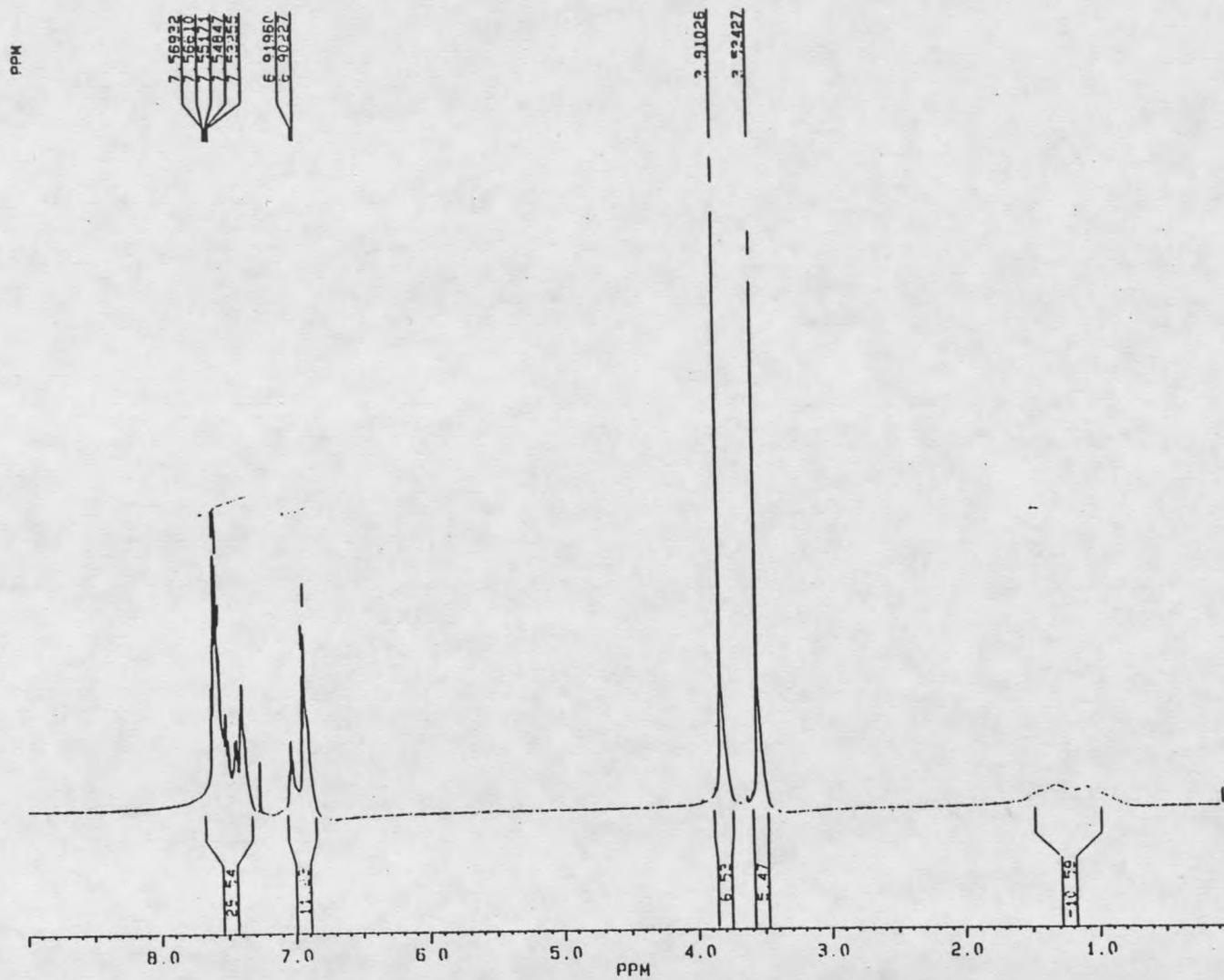
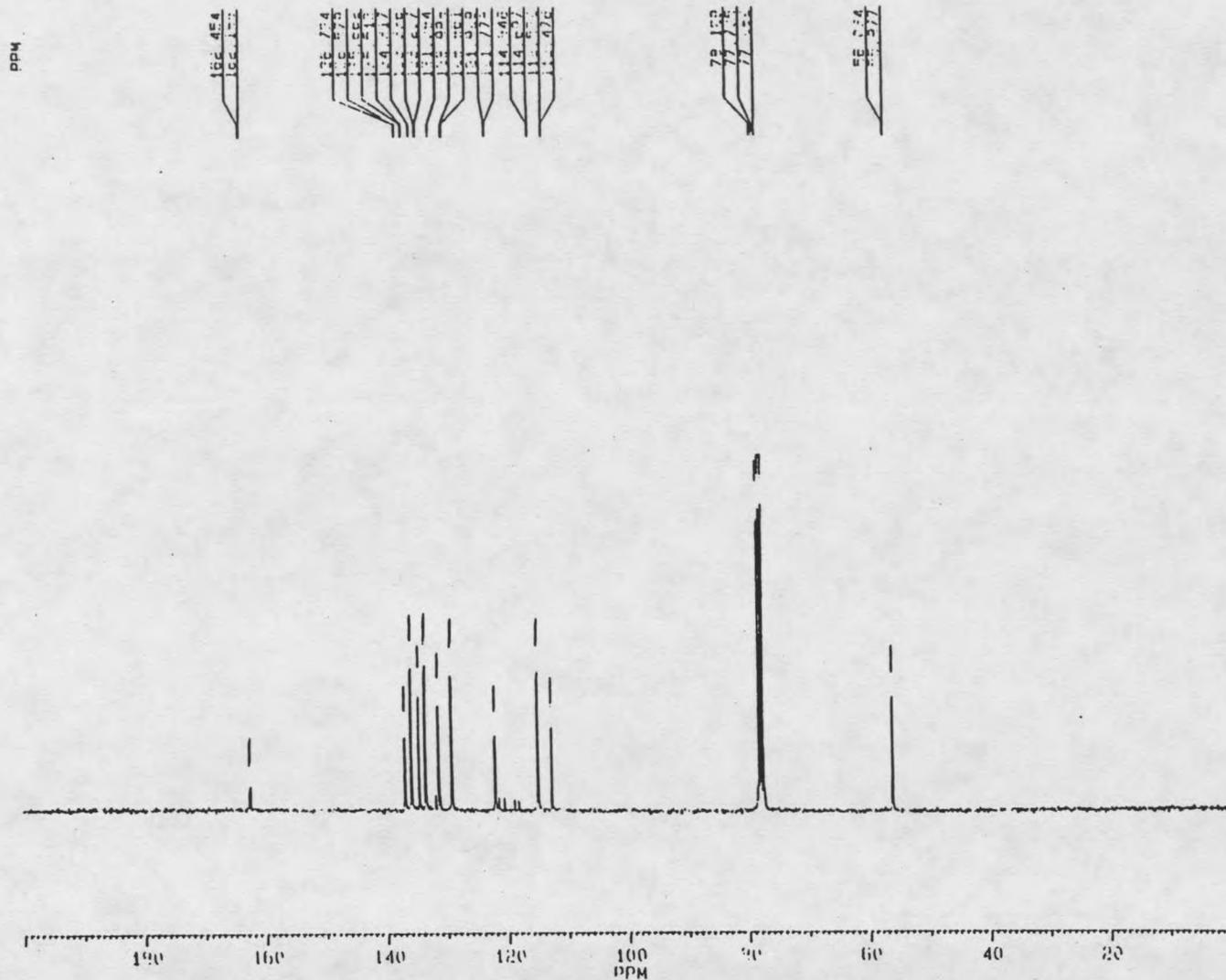
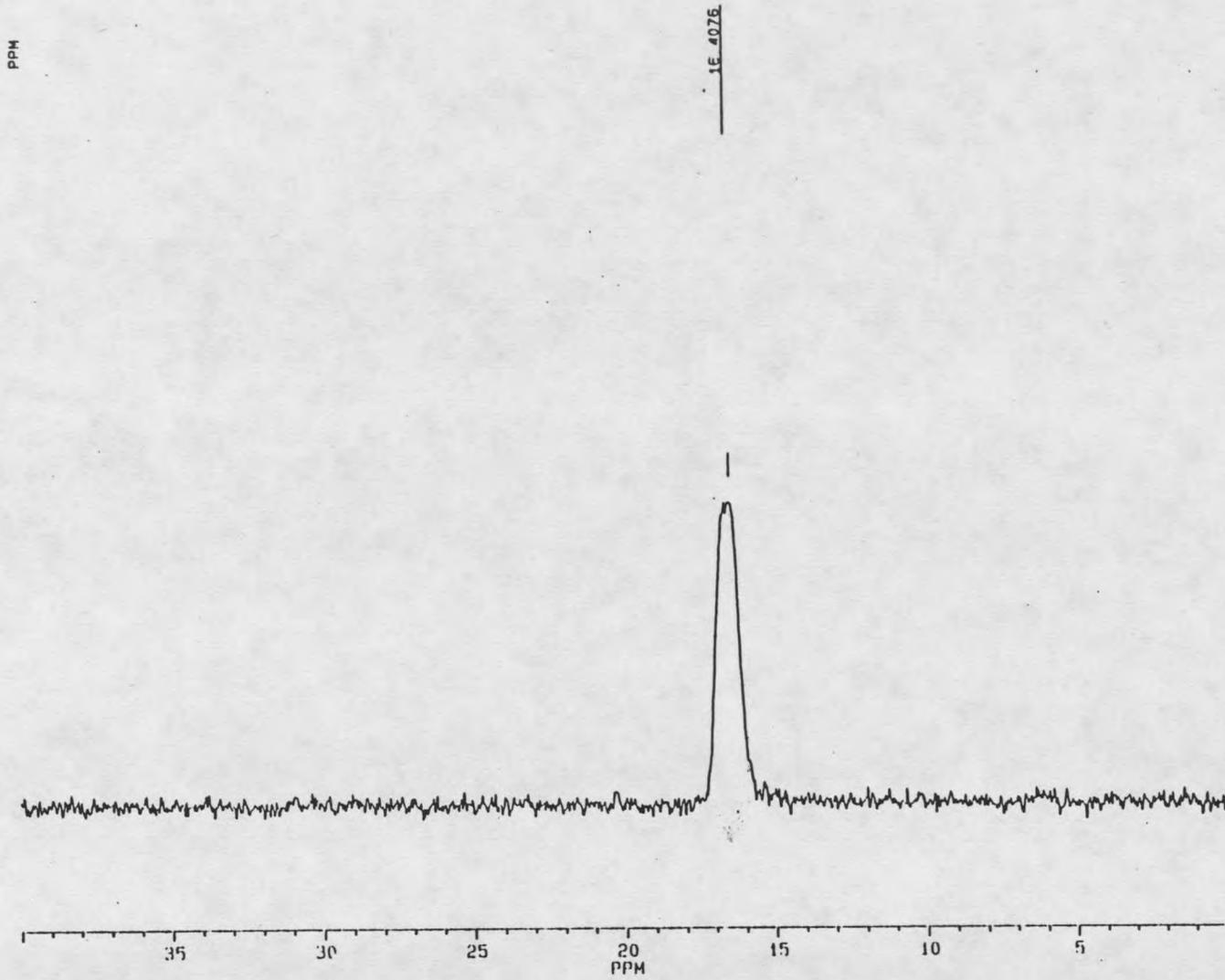


Figure 72.  $^1\text{H}$  NMR Spectrum of (*R*)-(2-methoxyphenyl)-(4-methoxyphenyl)-phenyl-phosphine borane (74)



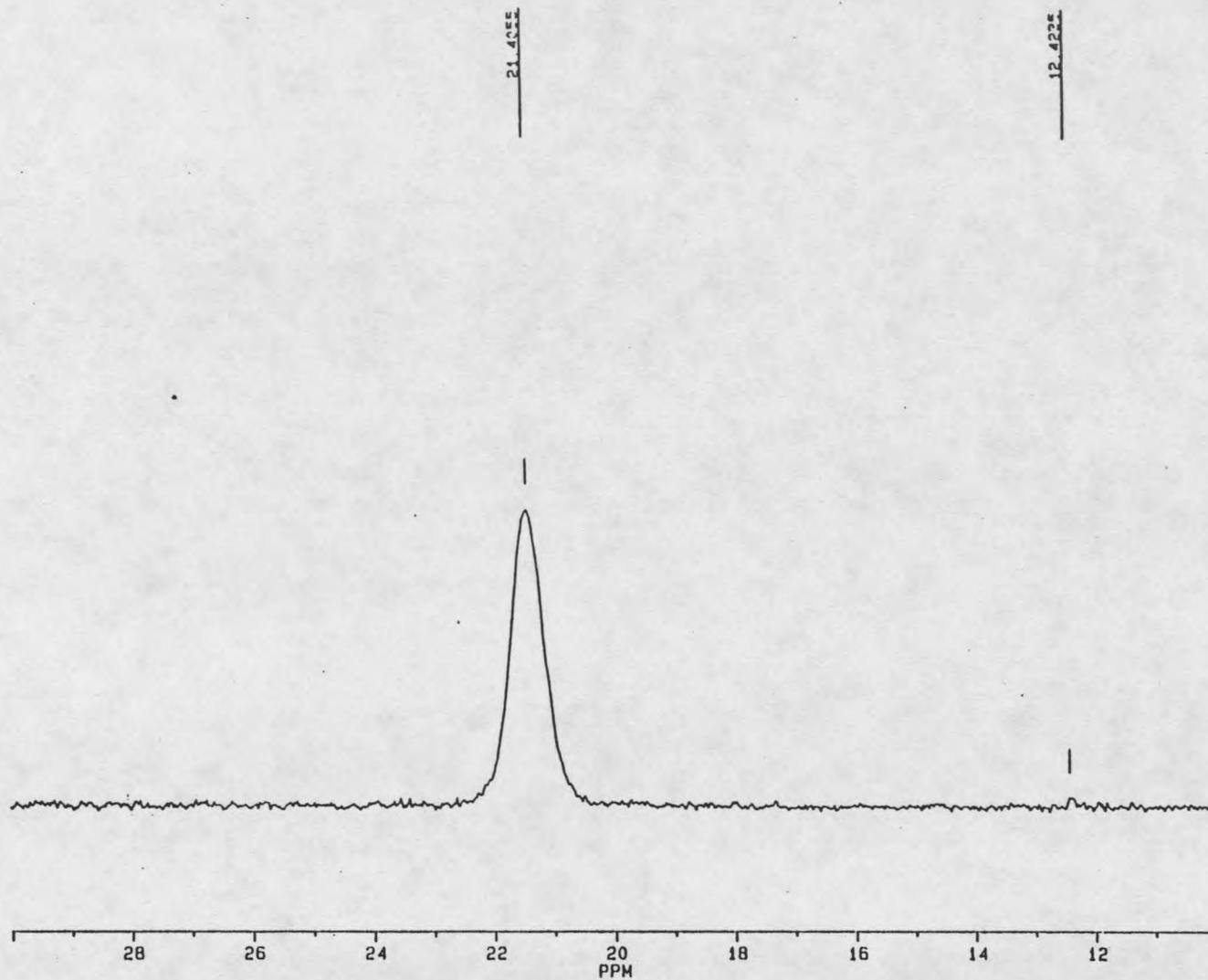


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Figure 74.  $^{31}\text{P}$  NMR Spectrum of (*R*)-(2-methoxyphenyl)-(4-methoxyphenyl)-phenyl-phosphine borane (74)

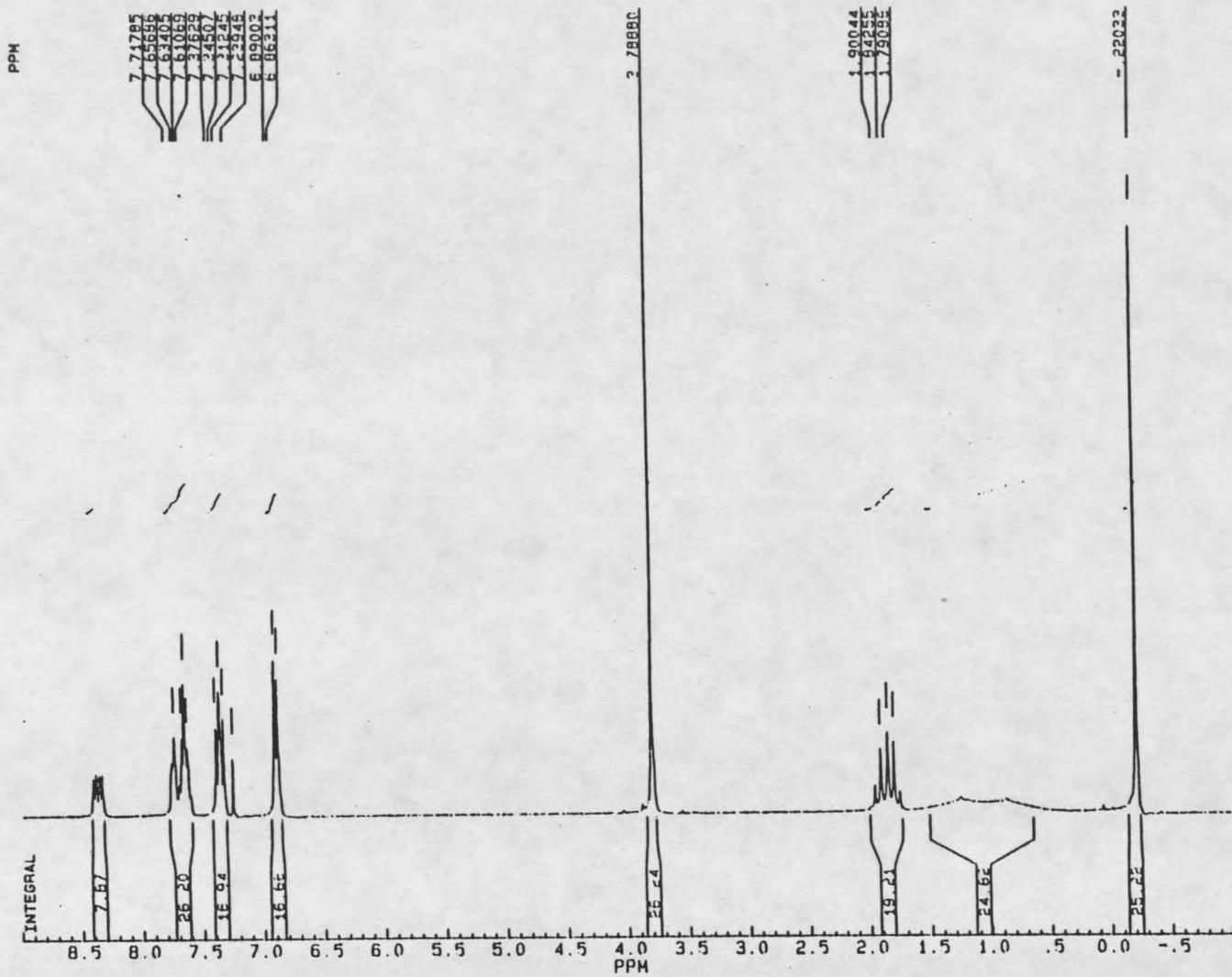






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Figure 77.  $^{31}\text{P}$  NMR Spectrum of (*S,S*)-Bis[(phenyl-(2-trifluoromethylphenyl)-phosphino-borane)-methylene] dimethylsilane (75)



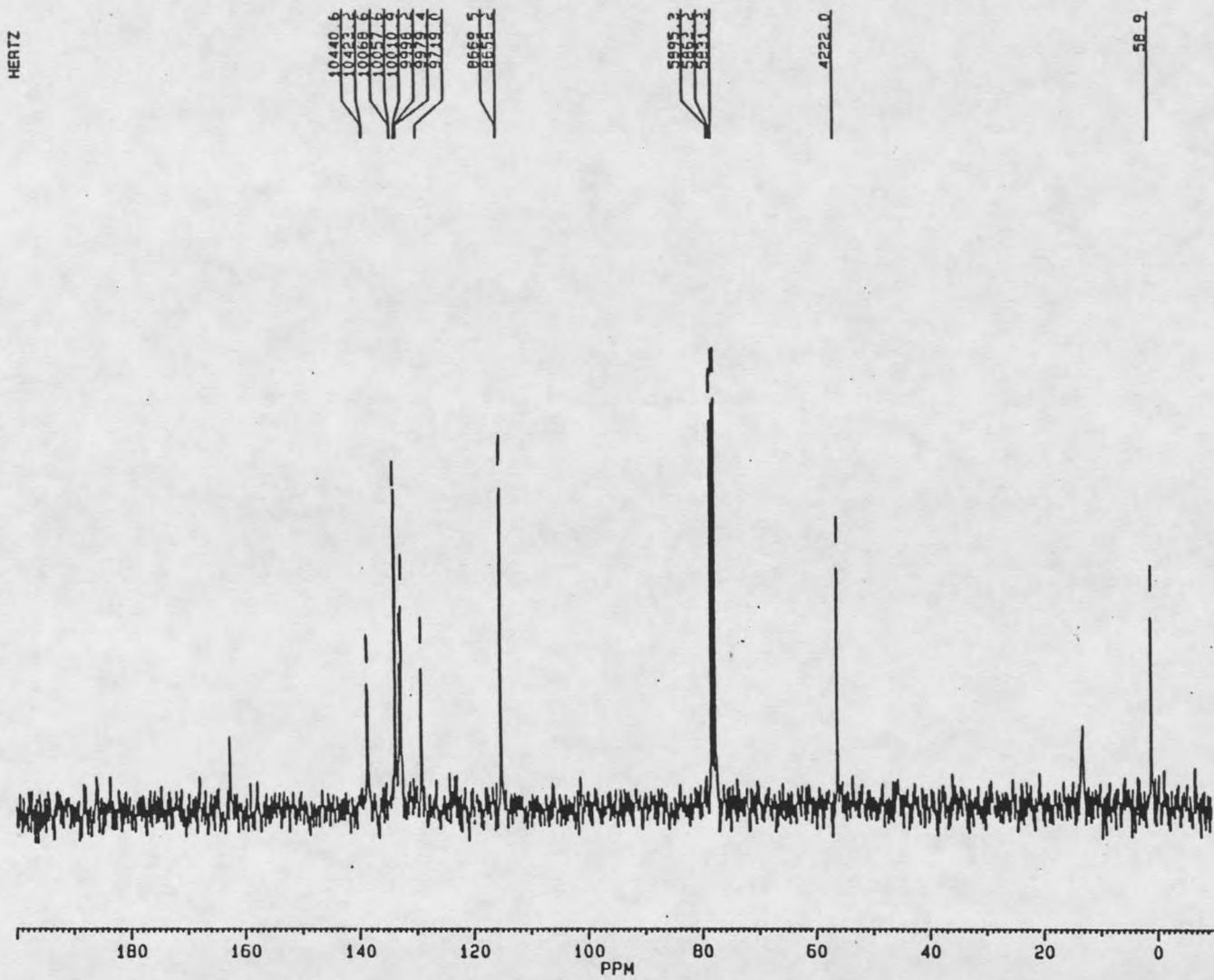
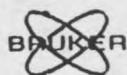


Figure 79.  $^{13}\text{C}$  NMR Spectrum of (*S,S*)-Bis[[(4-methoxyphenyl)-(2-trifluoromethylphenyl)-phosphino-borane)-methylene] dimethylsilane (76)



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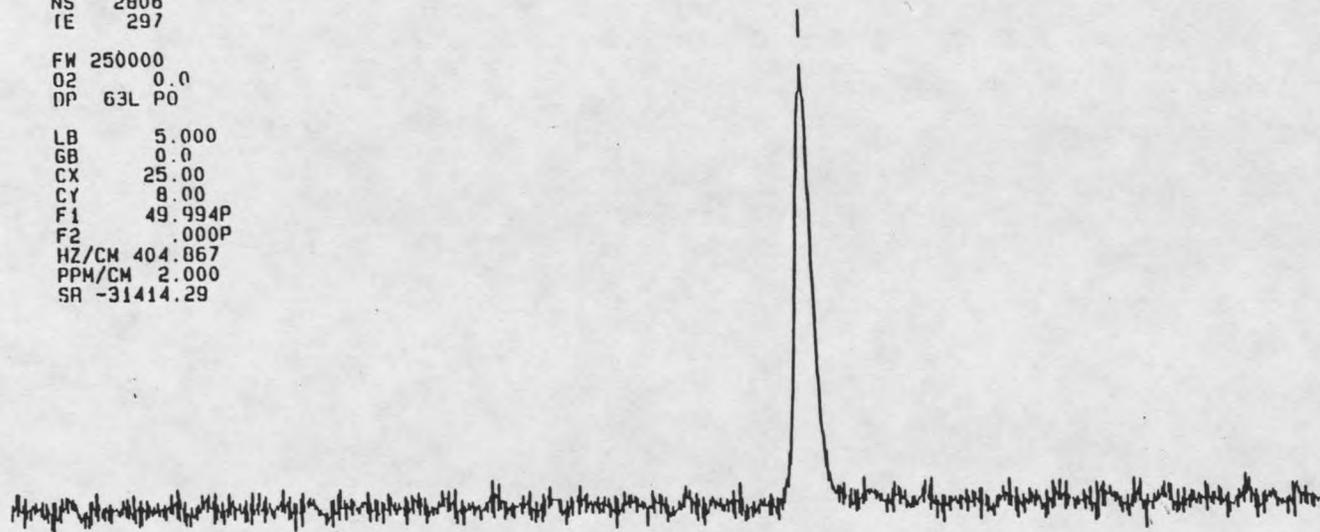
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Figure 80.  $^{31}\text{P}$  NMR Spectrum of (*S,S*)-Bis[[(4-methoxyphenyl)-(2-trifluoromethylphenyl)-phosphino-borane)-methylene] dimethylsilane (76)

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