The Chemistry of Diphosphine Disulfides. III. Influence of Structure on the Course of Phosphinothioic Halide–Grignard Reactions

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Reactions of dimethyl-, diethyl-, or di(n-propyl)phosphinothioic halides with Grignard reagents give trisubstituted phosphine sulfides in high yield. In conflict with results reported by Bogolyubov, it was not possible to obtain diphosphine disulfides from these reactions. Methylphosphinothioic chloride reacts with aliphatic or aromatic Grignard reagents to yield both trisubstituted phosphine sulfides and meso-1,2-dimethyl-1,2-diphenyldiphosphine disulfide. Diphosphinophosphiniothioic chloride reacts with aliphatic Grignard reagents to yield tetraphenyldiphosphine disulfide, but it reacts with aromatic Grignard reagents to yield trisubstituted phosphine sulfides. These results indicate that metal-halogen exchange processes precede the P-P coupling step involved in diphosphine disulfide formation. The high stereoselectivity of the coupling step can be explained by the mechanism

\[
\begin{align*}
RR'PCl + R'MgX & \rightarrow RR'MgX + R'Cl \\
RR'PMgX + RR'PCl & \rightarrow RR'MgX + R'Cl
\end{align*}
\]

The reactions of Grignard reagents with thiophosphorus halides can take several courses, depending on the structures of the thiophosphorus halide and the Grignard reagent. Thiophosphoryl chloride reacts with simple aliphatic Grignard reagents to yield diphosphine disulfides in high yield, but this reagent reacts with acetylenic, vinyl, aromatic, arylphosphonothioic dihalides parallels, in general, the behavior toward PSCl\(_3\), except that diphosphine disulfides have been obtained from the reactions of alkylphosphinothioic dihalides (instead of trisubstituted phosphine sulfides) with aromatic and benzyl Grignard reagents, which are initiators for the stereospecific polymerization of methyl methacrylate. The parallelism noted for the behavior of various Grignard reagents in these two widely different reactions is extremely good.

The behavior of Grignard reagents toward alkyl- or arylphosphinothioic dialdehydes parallels, in general, their behavior toward PSCl\(_3\), except that diphosphine disulfides (instead of trisubstituted phosphine sulfides) have been obtained from the reactions of alkylphosphinothioic dialdehydes with aromatic and benzyl Grignard reagents. Racemic and meso forms of dialkylidiphosphine disulfides have been obtained by these latter reactions. Interestingly, alkynyl Grignard reagents yield only phosphine sulfides in these reactions.

Harwood and Pollart observed that disubstituted phosphinothioic halides, in contrast to thiophosphoryl halides or unsubstituted phosphinothioic halides, yield only phosphine sulfides when treated with Grignard reagents. On the basis of this observation, these workers concluded that either reduction or metal-halogen exchange processes precede the P-P coupling step involved in diphosphine disulfide formation. Recently, however, Bogolyubov obtained results which are inconsistent with such an interpretation; he reported isolating tetraethyldiphosphine disulfide in 50% yield and tetra-n-propyldiphosphine disulfide in 24% yield from reactions of the corresponding phosphinothioic chlorides with Grignard reagents.

In order to resolve the conflicting results obtained by Bogolyubov and by Harwood and Pollart, to define better the scope of the stepwise phosphine sulfide synthesis outlined by the latter workers, and to obtain additional information related to the mechanism of the reaction yielding diphosphine disulfide derivatives, the reactions of a series of substituted phosphinothioic halides with Grignard reagents were investigated in the present study.

Results

Aliphatic Grignard–Dialkylphosphinothioic Halide Reactions.—Because of its significance to previous interpretations of the mechanism and scope of Grignard–thiophosphoryl halide reactions, it seemed important to check Bogolyubov’s claim that some dialkylphosphinothioic chlorides react with alkynyl Grignard reagents to yield diphosphine disulfides. When reactions of di-
ethylphosphinothioic chloride with ethylmagnesium bromide (or chloride) were conducted in the present study, triethylphosphine sulfide was obtained in yields ranging from 70 to 90%, and there was no indication that any diphosphine disulfide derivatives were present among the reaction products. Since Bogolyubov's paper did not provide specific reaction conditions, we varied our conditions extensively in an effort to obtain results similar to his. Reaction temperature, reagent concentrations, and order of addition were changed, but in no instance was any tetraethylphosphine disulfide obtained. Excess magnesium, in various forms, was added to some of the reaction systems, but the reaction course was not changed.

Similarly, we obtained tri(n-propyl)phosphine sulfide in 73% yield from the reaction of dipropylphosphinothioic chloride with propylmagnesium chloride, and found no evidence for the presence of tetrapropylphosphine disulfide in the reaction mixture. In addition, the reactions of dimethylphosphinothioic bromide, di-ethlyphosphinothioic bromide, or dipropylphosphinothioic bromide with methyl-, ethyl-, or n-propylmagnesium bromide produced trisubstituted phosphine sulfides in yields ranging from 44 to 77% (cf. Table I). No diphosphine disulfide derivatives were obtained from these reactions, although their properties are such that they should be easily isolated.

We are unable to explain the results of Bogolyubov at this point and believe that the general course of dialkylphosphinothioic halide-Grignard reactions leads to trisubstituted phosphine sulfides and not to diphosphine disulfide derivatives.14

Grignard Reactions Involving Alkylaryl- or Diarylphosphinothioic Halides.—In contrast to the results described above, we obtained both diphosphine disulfide derivatives and trisubstituted phosphine sulfides from the reactions of Grignard reagents with aryl-substituted phosphinothioic halides. The relative yields of these products seem to depend on the structures of the reactants. For example, diphenylphosphinothioic chloride reacted with phenylmagnesium bromide to yield only15 triphenylphosphine sulfide, whereas the corresponding reaction with ethylmagnesium bromide yielded only15 the diphosphine disulfide derivative. The reactions of methylphenylphosphinothioic chloride with ethyl- or phenylmagnesium bromide, however, yielded both types of products, the phosphine sulfide derivative predominating in both cases. It is important to note that only16 the meso form of 1,2-dimethyl-1,2-diphenylphosphine disulfide was obtained from these latter reactions. The results obtained in these studies cast considerable light on the mechanism of the reaction yielding diphosphine disulfide derivatives, as will be discussed next.

**Discussion**

In an earlier paper,14 we concluded that the P–P coupling step in reactions yielding diphosphine disulfides is preceded either by a reduction step yielding an RP=S-type intermediate or else by a metal–halogen exchange reaction. Either process was consistent with the observation that triphosphorus compounds containing two or more phosphorus–halogen bonds tend to yield diphosphine disulfide when treated with Grignard reagents, whereas other triphosphorus compounds usually yield phosphine sulfides in such reactions. Since several phosphinothioic halides were noted in the present study to yield diphosphine disulfides when treated with Grignard reagents, it is no longer necessary to require the participation of a reduced intermediate, such as RP=S, in the P–P coupling process. Instead, it seems much more likely that a metal–halogen exchange process precedes the coupling step.

![Chemical Reaction Diagram](attachment:image)

Evidence that metal–halogen processes occur during these reactions was obtained by submitting the reaction mixtures to gas–liquid partition chromatographic analysis. We observed that ethyl chloride is formed in the initial stages of ethylmagnesium bromide–diphenylphosphinothioic chloride reactions. Once formed, ethyl chloride rapidly disappears, presumably owing to subsequent reaction with ethylmagnesium bromide. If one assumes that metal–halogen exchange must be favorable, both kinetically and thermodynamically, for diphosphine disulfide formation to take place, then the results obtained in previously reported triphosphorus halide–Grignard reactions can be explained. Metal–halogen exchange between a Grignard agent and a phosphorus halide should be favored thermodynamically when electronegative atoms or groups (phenyl, vinyl, alkynyl) are attached to the phosphorus atom and when alkyl Grignard reagents are employed. Aromatic, alkenyl, and alkynyl Grignard reagents should be less likely to exchange with a given triphosphoryl halide than alkyl Grignard reagents, and the tendency of triphosphoryl halides to exchange with a given Grignard reagent should decrease according to the series18 thiophosphoryl chloride, arylthiophosphonic dichloride, diarylthiophosphinic chloride, and arylthiophosphinothioic chloride.
chloride, alkylphosphonothioic chloride, alkylarylphosphinothioic chloride, and dialkylphosphinothioic chloride.

If metal–halogen exchange must precede the P–P coupling step leading to diphosphine disulfide formation, the expectations outlined above are consistent with the general behavior of thiophosphoryl halide–Grignard reactions: (a) thiophosphoryl bromide usually yields phosphine sulfides when treated with aliphatic Grignard reagents, but thiophosphoryl chloride usually yields diphosphine disulfides in analogous reactions; (b) most alkyl Grignard reagents react with thiophosphoryl chloride to yield diphosphine disulfides, but aryl, alkenyl, and alkynyl Grignard reagents yield only phosphine sulfides in such reactions; (c) dialkylphosphinothioic chlorides react with both alkyl and aryl Grignard reagents to yield only phosphine sulfides, whereas diarylphosphinothioic chlorides yield diphosphine disulfides with alkyl Grignard reagents, although they yield phosphine sulfides when treated with aromatic Grignard reagents; and (d) both types of products result from reactions involving alkylarylphosphinothioic halides.11

Phosphine sulfides are obtained as the principal products of some reactions in which metal–halogen interchange should be thermodynamically favorable and diphosphine disulfide formation should be expected. Typical of such cases are the reactions of cycloalkyl, secondary, and higher alkyl Grignard reagents with PSCl,

In such cases, metal–halogen exchange is probably unfavorable kinetically, owing to steric effects. According to the scheme outlined above, metal–halogen exchange (path A) competes with a substitution reaction (path B) leading to phosphine sulfide. Since metal–halogen exchange probably involves a four-center transition state, it should be more sensitive to steric effects than the substitution (displacement) reaction. Grignard reagents having large steric requirements should thus prefer to engage in displacement reactions rather than in metal–halogen exchange reactions, and they should yield phosphine sulfides in these reactions rather than diphosphine disulfides.22 Steric effects are probably also responsible for the stereo-regulating influence of secondary and higher alkyl Grignard reagents on some vinyl polymerizations.3 The parallel effects shown by such reagents in their behavior toward PSCl or vinyl monomers are thus understandable.

Also related to the kinetic aspects of these reactions is the rate of the competing displacement process (path B). Any factors which would enhance the rate of this process relative to the metal–halogen exchange reaction would favor phosphine sulfide formation. Since charge separation is undoubtedly much greater in the transition state for path B than it is for metal–halogen exchange, the use of solvents with high dielectric constants should favor the displacement reaction, and phosphine sulfide formation should prevail. This factor may explain why appreciable phosphine sulfide formation is observed when reactions are conducted in tetrahydrofuran. Also, diphosphine dioxide formation does not occur when phosphoryl halides are allowed to react with Grignard reagents; this may be a result of the ease with which phosphoryl halides participate in nucleophilic displacement reactions.

Finally, the stereochemistry of these reactions will be considered. Previously alkylphosphonothioic halides were reported13 to react with alkyl or aryl Grignard reagents to yield meso- and dl-diphosphine disulfide derivatives. Similar results were obtained in the present study; phenylphosphonothioic dichloride formed meso- and dl-1,2-dimethyl-1,2-diphenyldiphosphine disulfide when allowed to react with methylmagnesium bromide. However, when methylphenylphosphinothioic chloride was treated with ethyl- or phenylmagnesium bromide, only meso-dimethylidiphenyldiphosphine disulfide and phosphine sulfides were recovered from these reactions. Formation of the meso product can be explained by a similar transition state such as the following, where the displacing \([C_6H_{14}P=S]^-\) ion may be separated from its MgX₂ counterpart at the start of reaction. Should the \([C_6H_{14}P=S]^-\) ion be independent of MgX₂, it would be a planar ion; the configuration that its phosphorus atom adopted in the product would be determined by the configuration of the phosphorus atom undergoing displacement. The latter should suffer inversion, as is common24 for nucleophilic displacement reactions involving pentavalent phosphorus compounds. The transition state depicted above is the most energetically favorable one of its type that can be drawn; similar structures leading to the dl product would be much more sterically hindered.

The formation of both dl- and meso-diphosphine disulfide derivatives in the reactions of Grignard reagents with RPSCl₂-type compounds is probably due to epimerization of meso coupled products of the type shown.

(21) Not in accord with expectation is the relative behavior of reactions involving aromatic Grignard reagents and thiophosphoryl halides or alkylphosphinothioic halides. Although unsubstituted diphosphine disulfides result from aryl Grignard–alkylphosphonothioic dithiolate reactions, only trisulfide sulfides result from aryl Grignard–PSCl₂ reactions. This anomaly can be explained by the fact that tetraaryldiphosphine disulfides react with aryl Grignard reagents to form triaryltetraphosphate sulfides and other products. Presumably, tetraaryldiphosphine disulfides can form in aryl Grignard–PSCl₂ reactions, but such products are not stable in the reaction system.

(22) It should be noted at this point, however, that both processes are subject to steric inhibition. We thus failed in several attempts to effect any reaction between t-butylmagnesium chloride and methylenphosphinothioic chloride.

phosphine sulfide derivatives). The former process is favored when phosphorus derivatives containing electronegative substituents and when electropositive Grignard reagents are reactants; the latter process is favored when sterically hindered reactants are employed and when the reactions are conducted in highly polar solvents. The process establishing P-P bonds seems to be a nucleophilic displacement by a thiophosphorus anion on a thiophosphoryl halide.

**Experimental Section**

**Dialkylphosphinothioic Halides.**—Dimethylphosphinothioic chloride (bp 76–78° (15 mm)), diethylphosphinothioic chloride, (bp 80–85° (1.0 mm)), di(n-propyl)phosphinothioic chloride, (bp 100–102° (3 mm)), diisopropylphosphinothioic chloride (bp 108–110° (7 mm)), and dimethylethylphosphinothioic chloride (bp 124–126° (5 mm)) were prepared by adding slightly less than a stoichiometric amount of the halogen to a solution or suspension of the appropriate diphosphine disulfide at temperatures below 10°. Dimethylethylphosphinothioic chloride could only be prepared at room temperature, however. The products were isolated by distillation and the yields ranged from 78 to 85%.

**Diphenylphosphinothioic Chloride.**—A mixture of sulfur (10.0 g, excess) and chlorodiphenylphosphine (55.3 g, 0.25 mole) in 125 ml of carbon disulfide was refluxed (40–50°), with stirring, for 12 hr. Carbon disulfide was then distilled off, excess sulfur was separated from the residue by filtration, and the residual liquid was distilled under reduced pressure. Diphenylphosphinothioic chloride (53.0 g, 85%) was collected at 186–200° (1.5 mm), lit.¹⁰ bp 275–280° (15 mm).

**Phenylphosphinothioic Dichloride.**—A mixture of dichloro-phenylphosphine (90 g, 0.5 mole) and excess thiophosphoryl chloride was refluxed for 3 hr at 115°. Phosphorus trichloride which formed in the reaction was removed by distillation and the heavy, oily residue was distilled. Phenylphosphinothioic dichloride was collected at 110–116° (4 mm) (lit.¹⁸ bp 270° (1 atm)). The yield was 80 g (76%).

**Reaction of Phenylphosphinothioic Dichloride with Methylenemagnesium Bromide.**—Methylenemagnesium bromide (0.75 mole) was prepared from magnesium turnings (18.24 g, 0.75 g-atom) and excess methyl bromide in ether at 0–5°. A solution of phenylphosphinothioic dichloride (52.7 g, 0.25 mole) in ether was then added dropwise to the stirred Grignard solution at such a rate that the reaction mixture could be maintained at 0–5° by ice cooling. When the addition was complete, the mixture was refluxed for about an hour. The mixture was then again cooled in an ice bath and dilute hydrochloric acid was added slowly to the reaction mixture. After this treatment, ether, aqeous, and solid phases were present in the reaction vessel. The ether phase was separated and the solid phase (12.8 g) was separated from the aqueous phase. The latter was extracted with fresh ether and the ether phases were combined, dried, and evaporated to obtain an additional 12.5 g of solid material. Both solids proved to be mixtures of dl- and meso-dimethyldiphenyldiphosphine disulfide. The products were separated by fractional crystallization from ethanol and (later) chloroform. The dl product melted at 144–146° (lit.¹⁰ mp 145–146°) and the meso product melted at 216–218° (lit.¹⁰ mp 206–208°). The combined yield of recrystallized products was 62%.

**Reactions of Disubstituted Phosphinothioic Halides with Grignard Reagents. General Procedure.**—A solution of phosphinothioic halide (0.035 mole) in 20 ml of dry ether was added to a solution of 0.06 mole of Grignard reagent at such a rate that the stirred reaction mixture could be maintained at 0–5° by an ice bath. After the addition was complete, the reaction mixture was allowed to warm to room temperature and was refluxed for 3 hr. The reaction mixture was then cooled in an ice bath and excess Grignard reagent was decomposed by the addition of an aqeous ammonium chloride solution. The ether phase present in the reaction mixture was separated and the aqueous phase was extracted with fresh ether. The combined ether phases were dried and the ether was evaporated to obtain products. These were separated or purified by either fractional crystallization or distillation. Phosphine sulfide derivatives were usually recrystallized from cyclohexane or ethanol, whereas diphenephosphine disulfide derivatives were recrystallized from ethanol.

**Table I**

<table>
<thead>
<tr>
<th>Phosphinothioic halide</th>
<th>Grignard</th>
<th>Bp, °C (mm)</th>
<th>Mp, °C</th>
<th>Registry no.</th>
<th>Yield, %</th>
<th>Phosphine disulfide</th>
<th>Chemical identification</th>
<th>Registry no.</th>
<th>Yield, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>(CH₃)₂P=S(=S)Cl</td>
<td>CH₃MgBr</td>
<td>106–109 (1.5)</td>
<td>105–106</td>
<td>4319-0-88</td>
<td>69</td>
<td>No reaction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(C₂H₅)₂P=S(=S)Br</td>
<td>C₂H₅MgBr</td>
<td>108–110 (1.0)</td>
<td>109–105</td>
<td>1369-72-0</td>
<td>73</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(C₅H₅)₂P=S(=S)Cl</td>
<td>C₅H₅MgBr</td>
<td>194–196 (1.0)</td>
<td>195–200</td>
<td>527-29-0</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


This material proved to be triethylphosphine sulfide. The yield of product, after recrystallization from cyclohexane, was 3.4 g (90%), mp 93-96°. No diporphine disulfide derivative was isolated or detected.

**Reaction at Elevated Temperatures.**—The reaction was conducted according to the general procedure (conventional order of addition) as described above, except that the addition reaction occurred while the ether solution was maintained at reflux. Using the general work-up procedure, triethylphosphine sulfide was obtained in 70% yield. No tetraethyldiphosphine disulfide was found.

**Reaction at Low Temperature.**—Following the general procedure, a solution of diethylphosphinothioic chloride in ether was added, with stirring, to a solution of ethylmagnesium bromide in ether, the temperature being maintained between -10° and -5°. Work-up of the reaction mixture after 12 hr of stirring yielded 70% triethylphosphine sulfide, but no tetraethyldiphosphine disulfide was found.

**Effect of Excess Magnesium.**—Ethylmagnesium bromide was prepared by treating ethyl bromide (0.04 mole) with 0.044 g-atom of magnesium and then with 0.016 mole of diethylphosphinothioic chloride. No diporphine disulfide resulted from this reaction; but triethylphosphine sulfide was obtained in 89% yield. In another experiment, ethylmagnesium bromide (0.0045 mole) was allowed to react with 0.04 g-atom of magnesium turnings and the reaction mixture was further treated with 0.02 mole of diethylphosphinothioic chloride. The reaction mixture was refluxed for 30-min stirring, however, the ethyl chloride had disappeared. When addition was complete, the mixture was warmed to room temperature and stirred for 10 min. Gas-liquid partition chromatographic examination of the reaction mixture yielded tetraphenyldiphosphine dichloride, 0.78 g (9%), unreacted diphenylphosphinothioic chloride, 6.3 g (36%), and diethylphosphinothioic chloride, 1.5 g (15.5%), mp and mmp 190-192°. When this reaction was conducted with an excess (0.067 mole) of ethylmagnesium bromide, the yield of tetraethyldiphosphine disulfide was 58%.

**Reaction of Diphenylphosphinothioic Chloride with Ethylmagnesium Bromide.**—A solution of diethylphosphinothioic chloride (11.5 g, 0.045 mole) in ether was added dropwise to a stirred solution of ethylmagnesium bromide (0.025 mole) in ether at 5°. When addition was complete, the mixture was warmed to room temperature and stirred for 10 min. Gas-liquid partition chromatographic examination of the reaction mixture indicated the presence of ethyl chloride. After another 30-min stirring, however, the ethyl chloride had disappeared. Work-up of the reaction mixture yielded tetraphenyldiphosphine disulfide, 0.78 g (9%), unreacted diphenylphosphinothioic chloride, 6.3 g (36%), and diethylphosphinothioic acid, 1.5 g (15.5%), mp and mmp 190-192°. When this reaction was conducted with an excess (0.067 mole) of ethylmagnesium bromide, the yield of tetraethyldiphosphine disulfide was 58%.

**Reaction of Tetraphenyldiphosphine Disulfide with Phenylmagnesium Bromide.**—A solution of tetraphenyldiphosphine disulfide, 1.8 g (0.040 mole), in tetrahydrofuran (20 ml) was added slowly, with stirring, to a solution of phenylmagnesium bromide (0.050 mole) in ether at room temperature. The reaction mixture was stirred for another 12 hr and then worked up in the standard way. No tetraphenyldiphosphine disulfide was recovered. Instead, triphenylphosphine sulfide, 0.386 g (35%), mp and mmp 160-162° (lit.13 mp 161°); and an unidentified liquid were obtained.

**Reaction of Methylphenylphosphinothioic Chloride with Ethylmagnesium Bromide.**—Methylphenylphosphinothioic chloride (3.80 g, 0.02 mole) was added dropwise to a well-stirred solution of ethylmagnesium bromide (0.035 mole) in ether at 10°. After the addition was complete, the mixture was warmed and refluxed for 2 hr. After being cooled to room temperature, the mixture was treated with dilute H_2SO_4. The solid which separated was filtered and the ether and water phases present in the filtrate were separated. The aqueous phase was extracted three times with ether and discarded. The combined ether portions were dried over MgSO_4 and concentrated. The concentrate consisted of an oil and a suspended solid. This solid was identical with the solid recovered from the reaction mixture.

The solid fractions were combined and recrystallized from chloroform to obtain shining crystals of meso-1,2-dimethyl-1,2-diphenylphosphine disulfide, 0.90 g (10%), mp 220° (lit.11 mp 206-208°). Anal. Calcd for C_{18}H_{15}PS_2 (310.4): C, 54.20; H, 5.15; P, 20.00; S, 20.60. Found: C, 54.26; H, 5.25; P, 19.98; S, 20.51.

The oil was distilled to obtain methylphenyldiphenylphosphine sulfide, bp 155-158° (6 mm), 2.8 g (94%) (lit.12 bp 103-105° (0.04 mm)). After reaction with thionyl chloride in benzene, the corresponding oxide was obtained, bp 112-115° (0.3 mm).

**Reaction of Methylphenylphosphinothioic Chloride with Phenylmagnesium Chloride.**—This reaction was conducted in exactly the same manner as the reaction of ethylmagnesium bromide with methylphenylphosphinothioic chloride. The yield of 1,2-dimethyl-1,2-diphenylphosphine disulfide obtained was 13%, mp 217-219°. The principal product of the reaction was methyl diphenylphosphine sulfide (52%), bp 210-220° (6 mm) (lit.7 mp 157-159° (0.1 mm)). This product reacted with thionyl chloride in benzene to form methylphenyldiphenylphosphine oxide, mp 112-115° (lit.11 mp 109-109°).

**Registry No.**—Dimethylphosphinothioic chloride, 993-12-4; diethylphosphinothioic chloride, 3982-89-6; di(n-propyl)phosphinothioic chloride, 2524-18-7; diethylphosphinothioic bromide, 3981-49-2; methylphenylphosphinothioic chloride, 13639-62-8; diethylphosphinothioic chloride, 1015-37-8; phenylphosphinothioic dichloride, 3497-90-0; (CH_3)_2PSBr, 6839-83-6; methylmagnesium bromide, 75-16-1; phenylmagnesium bromide, 925-90-6; CH_3MgBr, 927-77-5; phenylmagnesium bromide, 100-59-4; phenylmagnesium chloride, 100-59-4; methylthiophosphinothioic sulfide, 13639-73-1; dl-dimethyldiphenylphosphine disulfide, 13639-75-3; meso-dimethyldiphenylphosphine disulfide, 13639-76-4; tetraphenyldiphosphine disulfide, 1054-00-0.

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