

ture was allowed to cool, and hydrolyzed by pouring cautiously upon a mixture of cracked ice and 50 ml. of concd. sulfuric acid. The ether layer was separated immediately, washed three times with 100-ml. portions of water, and dried over calcium sulfate. After removal of the solvent by distillation, the products were distilled under reduced pressure and 87.1 g. (68.5%) of impure dibenzylsilane, n_D^{20} 1.5731, was obtained. On redistillation, 53.8 g. (32.6%) of slightly impure dibenzylsilane was collected, b.p. 174–180° (25–29 mm.), n_D^{20} 1.5740. Further distillation yielded 15.0 g. (11.8%) of pure dibenzylsilane, b.p. 160° (14 mm.), n_D^{20} 1.5746, d_4^{20} 0.9917.

Anal. Calcd. for $C_{14}H_{16}Si$: Si, 13.22; *M*_R*D*, 70.30. Found: Si, 13.16, 12.98; *M*_R*D*, 70.72.

From lower boiling fractions, benzylsilane was isolated and identified, b.p. 65–68° (35–40 mm.), n_D^{20} 1.5208, d_4^{20} 0.8922.

Anal. Calcd. for $C_7H_{10}Si$: Si, 22.98; *M*_R*D*, 41.49. Found: Si, 22.83, 22.40; *M*_R*D*, 41.66.

Some tribenzylsilane was obtained from the distillation residue.

Allyldibenzylsilane.—To 12.8 g. (0.06 mole) of dibenzylsilane in 25 ml. of THF was added rapidly 0.08 mole of allylmagnesium chloride¹⁰ in 80 ml. of THF solution. The reaction mixture was refluxed for 16 hr., and hydrolyzed by the slow addition of 50 ml. of dilute acid. The organic layer was separated and the aqueous layer washed twice with ether. The combined organic layer and ether washings were dried over calcium sulfate and the solvents removed by distillation. The products were distilled under reduced pressure to give 3.1 g. (20.5%) of allyldibenzylsilane, b.p. 130–134° (0.8 mm.), n_D^{20} 1.5690, d_4^{20} 0.9855.

Anal. Calcd. for $C_{17}H_{20}Si$: Si, 11.13; *M*_R*D*, 84.01. Found: Si, 11.02, 10.94; *M*_R*D*, 83.92.

A higher boiling fraction and the distillation residue were recrystallized from petroleum ether (b.p. 60–70°) to give 3.0 g. (16.5%) of tribenzylsilane, m.p. 89–91°, which was identified by mixed melting point and infrared spectrum.

Benzylmagnesium Chloride and Dibenzylsilane.—To 3.7 g. (0.017 mole) of dibenzylsilane in 50 ml. of THF was added 0.017 mole of benzylmagnesium chloride in 25 ml. of THF solution. The reaction mixture was refluxed for 15 min., after which Color Test I¹³ was slightly positive. Color Test I was strongly positive after another equivalent of the Grignard reagent was added and the mixture refluxed for 20 hr. The reaction mixture was worked up in a manner similar to that

used in the preceding experiment. Crude tribenzylsilane, m.p. 84–89°, wt. 4.4 g. (82.7%), was obtained by crystallization from petroleum ether (b.p. 60–70°). Upon recrystallization, 3.8 g. (71.5%) of tribenzylsilane, m.p. 89–91°, was obtained and identified by mixed melting point. No tetrabenzylsilane was isolated.

Carbonation after Refluxing Allylmagnesium Chloride¹⁰ and Triphenylsilane in THF.—Allylmagnesium chloride (0.07 mole) in 75 ml. of THF was added to 15.6 g. (0.06 mole) of triphenylsilane, the reaction mixture refluxed for 168 hr., and carbonated. The products obtained from the carbonation were worked up in a manner similar to previously described carbonation reactions. There was no solid acid obtained from the basic extract. From the organic layer, after removal of the solvents, 12.4 g. (67.8%) of allyltriphenylsilane, m.p. 89–90°, was obtained after crystallization from ethanol. The identification was made by mixed melting point and infrared spectrum.

Carbonation after Refluxing Allylmagnesium Chloride¹⁰ and Tetrabenzylsilane in THF.—Tetrabenzylsilane (15.7 g., 0.04 mole) and 0.06 mole of allylmagnesium chloride in 90 ml. of THF were refluxed for 168 hr., and carbonated. No phenylacetic acid was isolated, and 14.3 g. (91.1%) of tetrabenzylsilane, m.p. 126–128°, was recovered.

Carbonation after Refluxing Allylmagnesium Chloride¹⁰ and Tetraphenylsilane in THF.—Allylmagnesium chloride (0.06 mole) in 90 ml. of THF, and 13.44 g. (0.04 mole) of tetraphenylsilane were refluxed 168 hr. and carbonated. No benzoic acid was isolated, and 12.1 g. (90%) of tetraphenylsilane, m.p. 236–238°, was recovered.

Carbonation after Refluxing Allylmagnesium Chloride¹⁰ and Tri- γ -phenylpropylsilane⁶ in THF.—Tri- γ -phenylpropylsilane (15.4 g., 0.04 mole) and 0.05 mole of allylmagnesium chloride in 65 ml. of THF were refluxed for 168 hr. and carbonated. No γ -phenylbutyric acid was isolated.

Acknowledgment.—This research was supported in part by the United States Air Force under Contract AF 33(616)-3510 monitored by Materials Laboratory, Directorate of Laboratories, Wright Air Development Center, Wright-Patterson AFB, Ohio. The authors wish to express their appreciation to Dr. V. A. Fassel, Mr. E. M. Layton, Mr. R. Kniseley, Miss E. Conrad and Miss S. Trusdell of the Institute of Atomic Research, Ames, Iowa, for infrared spectra.

(13) H. Gilman and F. Schulze, *THIS JOURNAL*, **47**, 2002 (1925).

AMES, IOWA

[CONTRIBUTION FROM THE RESEARCH CENTER, HERCULES POWDER CO.]

Two Organophosphorus Derivatives of *p*-Dioxane with Insecticidal and Acaricidal Activity¹

BY W. R. DIVELEY, A. H. HAUBEIN, A. D. LOHR AND P. B. MOSELEY

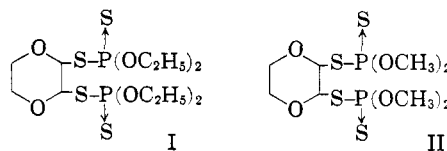
RECEIVED MAY 15, 1958

Two organophosphorus derivatives of *p*-dioxane, namely, 2,3-*p*-dioxanedithiol S,S-bis-(O,O-diethyl phosphorodithioate) (I), and the corresponding methyl ester II, were found to be exceptionally toxic to certain insects and mites. These compounds may be synthesized from 2,3-dichloro-*p*-dioxane and the appropriate O,O-dialkyl hydrogen phosphorodithioates in the presence of molecular equivalents of certain bases or catalytic quantities of certain catalysts, or from *p*-dioxene and bis-(dialkoxyphosphinothioyl) disulfide in the presence of catalytic quantities of iodine. The products made from O,O-diethyl hydrogen phosphorodithioate contained about 70% of the ethyl ester I as a mixture of *cis* and *trans* isomers (2:3 ratio) which were isolated using partition chromatography and tentatively assigned configurations based on chemical, physical and biological data. A mechanism involving ionic intermediates is proposed for the formation of these isomers.

During the course of a systematic search for compounds with pesticidal activity, two organophosphorus derivatives of *p*-dioxane, namely, 2,3-*p*-dioxanedithiol S,S-bis-(O,O-diethyl phosphorodithioate) (I), and the corresponding methyl ester II, were found to be exceptionally toxic to certain pests.²

(1) Presented in part before the Division of Agricultural and Food Chemistry at the 131st Meeting of the American Chemical Society, Miami, Fla., April, 1957.

(2) W. R. Diveley and A. D. Lohr, U. S. Patent 2,725,328 (1955).

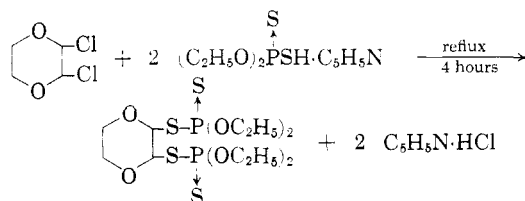


The pesticidal activity of one of these compounds, the ethyl ester I, also known as Delnav,³ is reported

(3) Delnav is a registered trademark of Hercules Powder Co.

in detail elsewhere.⁴⁻⁶ This compound is outstanding because of its high toxicity to certain insects, mites and ticks at low concentrations, and its pronounced ovicidal action and long residual activity against mites.

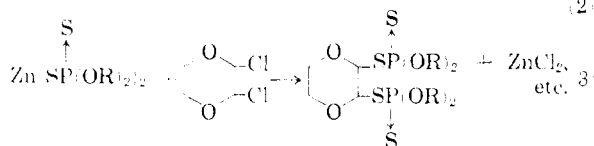
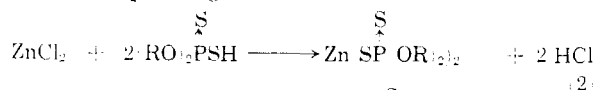
Synthesis of the ethyl ester I was first accomplished by a reaction between *trans*-2,3-dichloro-*p*-dioxane and two moles of the pyridine salt of *O,O*-diethyl hydrogen phosphorodithioate in benzene at reflux temperatures.



Other salts such as the sodium, potassium and ammonium salts of *O,O*-diethyl hydrogen phosphorodithioate can also be used successfully in this reaction provided a suitable solvent is employed. Salts of *O,O*-dimethyl hydrogen phosphorodithioate, however, gave low yields of the methyl ester II.

Later, in a search for simpler and more practical ways of effecting this reaction, it was found that catalytic amounts of zinc, tin and iron chlorides would accomplish the condensation. Usually 0.01 molar equivalent of catalyst, based on dichlorodioxane, was adequate. The ethyl and methyl esters (I and II) can be prepared equally well by this catalytic method.

Some observations made indicated the catalyst was accomplishing the reaction

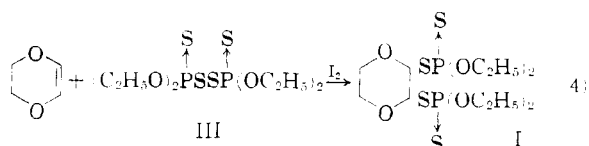


R = CH₃ or C₂H₅

Thus, the catalyst is regenerated and continues to react until the reactants are consumed. That eq. 2 occurred was demonstrated by the fact that two moles of hydrogen chloride were evolved for each mole of zinc chloride added to an excess of *O,O*-diethyl hydrogen phosphorodithioate in refluxing benzene. That eq. 3 occurred was shown by effecting the coupling with catalytic amounts of zinc *O,O*-diethyl phosphorodithioate. The reaction proceeded similarly and yielded a product identical to that obtained using zinc chloride.

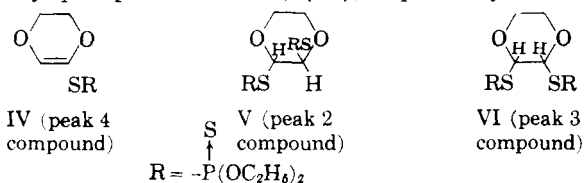
Still another method for the preparation of the ethyl ester I involves the addition of an organophosphorus disulfide (III) to *p*-dioxene in the presence of catalytic quantities of iodine.

The ethyl esters, prepared by either the pyridine salt or catalytic procedures described above, were tan, semi-viscous liquids which were separable into their components by use of partition chromatog-

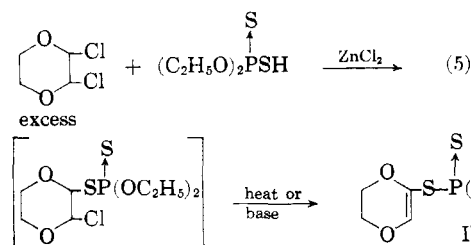


raphy. Using an acetonitrile-heptane-on-Celite system, both products were shown to contain about 70% of the ethyl ester I as a mixture of *cis* and *trans* isomers in a 2:3 ratio. Four peaks were obtained in the chromatographic separation of the product made by the pyridine salt procedure: peak 1 (cuts 1-9 of 15 ml. each, 10.7% of total weight), peak 4 (cuts 10-14, 6.1%), peaks 2 and 3 (cuts 15-24, 67.7%) which were not completely separated, and a methanol eluent (cut 25, 9.5%).

Some evidence indicated that peak 1 contained two closely related esters, *O,O,O*-triethyl phosphorothioate and *O,O,S*-triethyl phosphorodithioate. The former probably is present because it is a known by-product in the synthesis of *O,O*-diethyl hydrogen phosphorodithioate,⁷ whereas the latter is probably formed by the reported self-alkylation of *O,O*-diethyl hydrogen phosphorodithioate in the presence of pyridine.⁵ Because peak 1 materials had minor biological activity, conclusive identification of these components was not made. Peaks 2, 3 and 4 compounds, however, were resolved by further chromatographic separation of the fractions described above and of pyrolysates described later, and tentatively identified as the *trans* (V) and *cis* (VI) isomers of I, and 2-*p*-dioxenethiol *S*-(*O,O*-diethyl phosphorodithioate) (IV), respectively.



The peak 4 compound was identified by elemental analyses, molecular weight determination and infrared data. It was also synthesized by two independent methods: (a) by pyrolysis of the diethyl ester I which is discussed below and (b) by dehydrochlorinating 3-chloro-2-*p*-dioxanethiol *S*-(*O,O*-diethyl phosphorodithioate), prepared *in situ*, either thermally or with various bases.



The compounds making up peaks 2 and 3 were identified as follows. They had the same molecular weights and elemental analyses. Their infrared spectra were very similar, the major difference being that their ether bands were slightly offset from

(4) L. R. Jeppson, M. J. Jesser and J. O. Complin, *J. Econ. Entomol.*, **50**, 307 (1957).

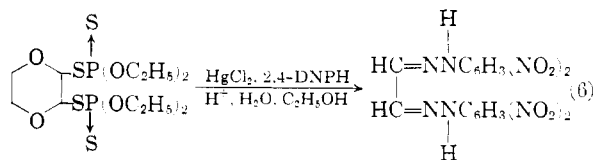
(5) F. A. Gunther, L. R. Jeppson, J. H. Barkley, L. M. Elliott, R. C. Blinn and C. L. Dunn, *J. Agr. Food Chem.*, **6**, 210 (1958).

(6) J. Wilson and A. F. Howland, *J. Econ. Entomol.*, **50**, 128 (1957).

(7) W. E. Bacon and W. M. LeSuer, *THIS JOURNAL*, **76**, 675 (1954).

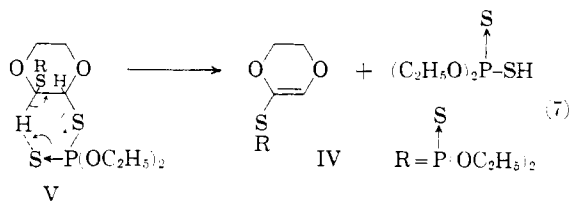
(8) N. A. Meinhardt and P. W. Vogel, Abstracts of Papers Presented before the Division of Organic Chemistry, 126th Meeting of the American Chemical Society, New York, N. Y., September, 1954.

each other, being at 8.86 and 9.12 μ , respectively. That both compounds were 2,3-disubstituted dioxanes was demonstrated by their quantitative cleavage and hydrolysis, in the presence of mercuric chloride and 2,4-dinitrophenylhydrazine, to one mole of the 2,4-dinitrophenylosazone of glyoxal. A 2,5- or a 2,6-isomer is reported to yield two moles of osazone and a 2,2-isomer none.⁹



These results indicated the peak 2 and peak 3 compounds were *cis* and *trans* isomers and the problem then became that of identifying which was *cis* and which *trans*.

In pyrolytic experiments, when the ethyl ester I was heated slowly to 135–140° *in vacuo*, the peak 2 compound pyrolyzed completely, whereas the peak 3 compound remained essentially intact. As the peak 2 compound decomposed, two fragments, compound IV and O,O-diethyl hydrogen phosphorodithioate, were formed.



The latter compound distilled from the reaction mixture as formed. Separation of the pyrolysate using the same partition chromatographic system previously described showed that the peak 2 compound was absent, that the peak 4 compound had correspondingly increased, and that the peak 3 compound was present in substantially the same amount as in the starting material. This pyrolysis is believed to be similar to the Chugaev reaction. A majority of evidence in the literature indicates the Chugaev reaction to be predominantly a *cis* elimination.^{10,11} Therefore, by analogy, the *trans* isomer V, having a configuration suited for *cis* elimination, should pyrolyze easier. Because the peak 2 compound pyrolyzed first, at a lower temperature, it was believed to have the *trans* configuration (eq. 7).

Continued pyrolysis of both isomers at high temperatures (160–165°) resulted in the decomposition of both to IV and O,O-diethyl hydrogen phosphorodithioate.

Other evidence which indicated that the peak 2 compound was *trans* and the peak 3 *cis* was that the latter was more active biologically as determined by toxicity to mites; *cis* isomers are generally more active biologically than their *trans* counter-

(9) R. K. Summerbell and H. Lunk, *THIS JOURNAL*, **79**, 4802 (1957).

(10) J. Hine, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1956, p. 462; E. R. Alexander and A. J. Mudrak, *THIS JOURNAL*, **72**, 1810 (1950).

(11) D. J. Cram, *ibid.*, **71**, 3883 (1949).

parts.^{12–14} Also the peak 3 compound was more polar, as evidenced by its behavior on the partition chromatographic column used, which would be predicted for the *cis* isomer, by analogy with the 1,2-dihalocyclohexanes,¹⁵ and by inspection of molecular models of the two isomers. Finally, one of the methyl isomers (II) was isolated in pure, crystalline form, whereas the other isomer could not be crystallized. The infrared spectrum of the crystalline isomer was nearly identical to that of the peak 2 compound (of the ethyl isomer), whereas the spectrum of the liquid isomer closely resembled that of the peak 3 compound. The biological activity of the solid methyl isomer was also less than that of the liquid isomer. Because *trans* isomers generally have less biological activity, this was interpreted as another indication that the peak 2 compound was *trans*.

Because the evidence all appeared to point in one direction, the tentative assignments of the peak 3 compound as the *cis* isomer and the peak 2 compound as the *trans* were made.

It is proposed that the formation of these isomers proceeds through ionic intermediates, as shown in Fig. 1, inasmuch as the same proportion of isomers, that is, 2:3 *cis:trans*, is obtained whether one starts with pure *cis*- or pure *trans*-2,3-dichloro-*p*-dioxane.

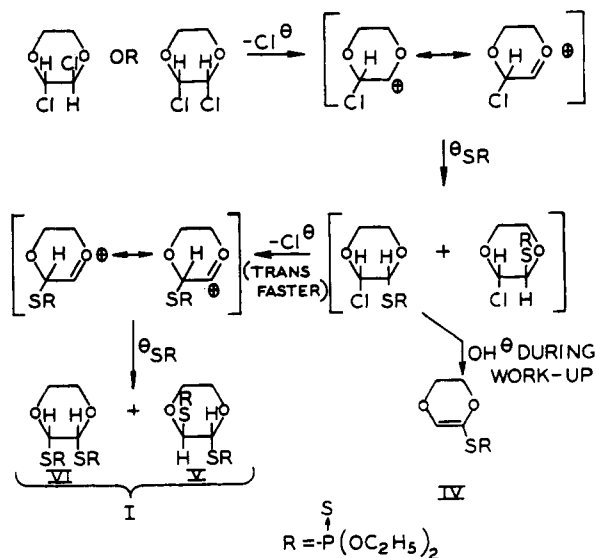


Fig. 1.—Proposed route for formation of *cis* and *trans* isomers of 2,3-*p*-dioxanedithiol S,S-bis-(O,O-diethyl phosphorodithioate).

Compound IV, making up peak 4 in the chromatogram, is believed to arise chiefly from the dehydrochlorination of *cis*-3-chloro-2-*p*-dioxanedithiol S-(O,O-diethyl phosphorodithioate) during the base wash in work-up of the reaction mixture. The configuration of this intermediate is ideally suited for a

(12) H. D. Baldrige, Jr., W. J. McCarville and S. L. Friess, *ibid.*, **77**, 739 (1955).

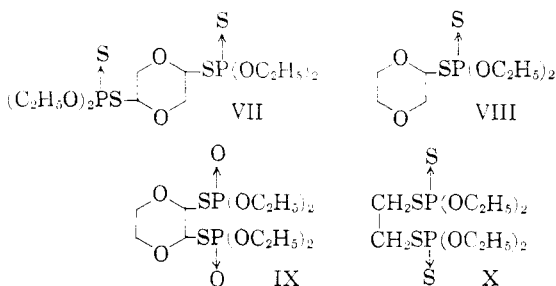
(13) J. E. Casida, P. E. Gotterdam, L. W. Getzin, Jr., and R. K. Chapman, *J. Agr. Food Chem.*, **4**, 236 (1956).

(14) S. L. Friess and H. D. Baldrige, Jr., *THIS JOURNAL*, **78**, 2482 (1956).

(15) H. L. Goering, D. I. Relyea and D. W. Larsen, *ibid.*, **78**, 348 (1956).

base-induced, *trans* elimination of the elements of hydrogen chloride.

A number of *p*-dioxane analogs of I, the formulas of which are given below, were prepared and tested to determine the effect of structure on activity.



None was more active than I and II.

Experimental

2,3-*p*-Dioxanedithiol S,S-Bis-(O,O-diethyl Phosphorodithioate) (I). (a) **Pyridine Salt Procedure.**—A solution of pyridine salt of O,O-diethyl hydrogen phosphorodithioate¹⁶ was made by adding 85.5 g. (0.44 mole) of 96% acid slowly with stirring and cooling to 33.2 g. (0.42 mole) of pyridine in 300 ml. of benzene. After 31.4 g. (0.20 mole) of *trans*-2,3-dichloro-*p*-dioxane⁹ had been added, the resultant mixture was stirred and refluxed for 4 hours. The salt which formed was removed by filtration and the filtrate washed with 5% sodium hydroxide and twice with 15% brine. Ether was added to aid in separating the layers. The organic layer was dried over sodium sulfate, the solvent removed by aspiration, and the residue topped *in vacuo* to a pot temperature of 90° (<1 mm.). At 60–68° (0.5 mm.), 7.2 g. of pale yellow liquid distilled. The residue, a tan liquid, weighed 61.7 g. (68% yield), n_{D}^{20} 1.5425. Subsequent partition chromatographic separation, described below, showed this to be an impure compound.

Anal. Calcd. for $\text{C}_{12}\text{H}_{26}\text{O}_6\text{P}_2\text{S}_4$: Cl, 0.0; S, 28.1; P, 13.6. Found: Cl, 0.3; S, 27.9; P, 14.1 (Parr bomb-ammonium phosphomolybdate volumetric method).

Partition Chromatographic Separation Procedure.—The system used was acetonitrile equilibrated with *n*-heptane as the stationary phase and *n*-heptane equilibrated with acetonitrile as the mobile phase on a Celite base (20–23 cm. high) in a 2-cm (i.d.) tube.¹⁷

A 100-mg. sample of technical ester was placed on the column and the chromatogram developed under 2 pounds per square inch pressure. A total of 25 cuts of 15 ml. each was collected and evaporated to dryness. This removed peak 1, 2, 3 and 4 compounds (see text). Elution with 100 ml. of methanol removed the remaining components.

Analytical Procedures. Infrared Method.—The crude product was purified by weighing an approximate 100-mg. sample and passing it through a 2 × 5 cm. column of alumina (Harshaw Chemical Co. catalytic grade ALOIOL P), using 50 ml. of benzene as a developer. The benzene was evaporated from the eluate and an infrared spectrum made from the residue in carbon disulfide. The absorption bands used to calculate the amount of *cis* and *trans* isomers present were 9.12 and 8.86 μ , respectively. A series of mixtures with known compositions of *cis* and *trans* isomers ranging from all *cis* to all *trans* was used to obtain the curve used in these analyses.

Cleavage-Hydrolysis Procedure.—An approximate 50-mg. sample of technical ethyl ester I was weighed, purified by passing through an alumina-packed column as described under infrared method above, cleaved and hydrolyzed in the presence of mercuric chloride and 2,4-dinitrophenylhydrazine according to Dunn.¹⁸ Using this procedure, the purified product yielded 95–97% of the theoretically possible amount of the 2,4-dinitrophenylosazone of glyoxal.

A peak 2 compound cut, which was shown to be 98% pure by infrared analysis, was analyzed.

Anal. Calcd. for $\text{C}_{12}\text{H}_{26}\text{O}_6\text{P}_2\text{S}_4$: C, 31.6; H, 5.7; mol. wt., 456. Found: C, 32.0; H, 5.9; mol. wt. (acetone ebullioscopic method), 461.

This isomer, when cleaved and hydrolyzed as described above, yielded 98% of the theoretically possible amount of the 2,4-dinitrophenylosazone of glyoxal.

(b) **Catalytic Procedure (I).**—A solution of 7200 ml. of 40.1% O,O-diethyl hydrogen phosphorodithioate in benzene was stirred and heated at 70° and 8.9 g. (0.066 mole) of crushed, anhydrous zinc chloride added. When the mixture was homogeneous, 1051 g. (6.7 moles) of *trans*-2,3-dichloro-*p*-dioxane was added dropwise with stirring during 2.25 hours. Hydrogen chloride was evolved copiously. Reflux temperatures were maintained until (a) hydrogen chloride evolution had essentially ceased and (b) the reflux temperature was 80° or above. This required 4–5 hours after the addition was completed. The mixture was then worked up by washing with 1% hydrochloric acid in 15% brine, neutralizing with 10% sodium hydroxide using phenolphthalein indicator, removing the benzene by aspiration, and finally topping the residue at 80° (15–25 mm.) for 2 hours. The weight of tan liquid product obtained was 2660 g. (87% yield), n_{D}^{20} 1.5420.

Anal. Calcd. for $\text{C}_{12}\text{H}_{26}\text{O}_6\text{P}_2\text{S}_4$: S, 28.1; P, 13.6. Found: S, 28.4; P, 13.7.

In a similar experiment, but on a smaller scale, use of *cis*-2,3-dichloro-*p*-dioxane⁹ resulted in a product which, by infrared data, toxicity to mites and cleavage-hydrolysis data, was identical to that obtained from the *trans* isomer. The reaction, however, occurred at a faster rate as determined by measuring the rate of hydrogen chloride evolved by direct titration. When 0.01 molar equivalent of stannous and ferric chlorides, and of zinc O,O-diethyl phosphorodithioate, based on 2,3-*p*-dichloro-*p*-dioxane, were used in place of zinc chloride, the reaction proceeded similarly and the products were identical as determined by infrared analysis and by bioassay using two-spotted spider mites.

The zinc O,O-diethyl phosphorodithioate was prepared by the following procedure. To a solution of 6.6 g. (0.165 mole) of sodium hydroxide in 150 ml. of water was added dropwise 32 g. (0.172 mole) of O,O-diethyl hydrogen phosphorodithioate with cooling. To this mixture was added a solution of 19 g. (0.087 mole) of zinc acetate [$\text{Zn}(\text{OC}(\text{O})\text{CH}_3)_2 \cdot 2\text{H}_2\text{O}$] in 100 ml. of water. The white precipitate which separated was removed by filtration, water-washed, and dried in a vacuum desiccator above phosphorus pentoxide. The dried white zinc salt weighed 25.4 g. (76% yield).

(c) **The Addition of Bis-(diethoxyphosphinothioyl) Disulfide to *p*-Dioxene (I).**—Bis-(diethoxyphosphinothioyl) disulfide was prepared by the method of Bartlett, *et al.*¹⁹

Anal. Calcd. for $\text{C}_8\text{H}_{20}\text{O}_4\text{P}_2\text{S}_4$: S, 34.6. Found: S, 34.7; n_{D}^{20} 1.5595.

To a stirred mixture of 18.5 g. (0.05 mole) of the disulfide and 1.3 g. (0.005 mole) of finely crushed iodine was added 4.2 g. (0.05 mole) of *p*-dioxene.²⁰ The temperature rose rapidly and cooling was necessary to keep the temperature below 60°. When the reaction subsided, the mixture was taken up in 125 ml. of benzene, washed with 15% brine, dilute sodium thiosulfate, again with 15% brine, and dried over sodium sulfate. The solvent was removed by aspiration and the residue topped at 60° (0.5 mm.). The residue, a dark liquid, weighed 8.0 g. Infrared analysis indicated it contained both isomers of the expected product I. That the product was the expected one was also indicated by its cleavage and hydrolysis (see procedure above) to yield 72% of the theoretically possible amount of 2,4-dinitrophenylosazone of glyoxal and by its toxicity to two-spotted spider mites, which was essentially equivalent to products made by the other methods.

2,3-*p*-Dioxanedithiol S,S-Bis-(O,O-dimethyl Phosphorodithioate) (II).—The reaction was carried out according to the catalytic procedure described above for the ethyl ester I using 24 g. (0.15 mole) of *trans*-2,3-dichloro-*p*-dioxane, 144 ml. of 40.0% O,O-dimethyl hydrogen phosphorodithioate in

(16) J. H. Fletcher, J. C. Hamilton, I. Hechenbleikner, E. I. Hoegberg, B. J. Sertl and J. T. Cassaday, *THIS JOURNAL*, **72**, 2461 (1950).

(17) K. Gardner and D. F. Heath, *Anal. Chem.*, **25**, 1849 (1953).

(18) C. L. Dunn, *J. Agr. Food Chem.*, **6**, 203 (1958).

(19) J. H. Bartlett, H. W. Rudel and E. B. Cyphers, U. S. Patent 2,705,694 (1955).

(20) R. K. Summerbell and R. R. Umhoefer, *THIS JOURNAL*, **61**, 3016 (1939).

benzene, and 0.2 g. (0.0015 mole) of anhydrous zinc chloride. The crude product weighed 45.1 g. (75% yield) and, based on infrared analysis, consisted of the same ratio of *cis* and *trans* isomers, that is, 2:3, respectively, as was present in the technical ethyl ester (I).

Anal. Calcd. for $C_8H_{18}O_6P_2S_4$: S, 32.0; P, 15.5. Found: S, 31.9; P, 15.8; n_D^{20} 1.5690.

In one case, the crude product partially crystallized. Some of these crystals were purified by pouring a portion (8.3 g.) on a porous plate and recrystallizing the crystals (5.5 g.) so obtained from methanol. The resultant white crystals (4.2 g.) melted at 80–81° and their infrared spectrum was almost identical with the spectrum of the peak 2 compound (V), especially at the 8.86- μ band.

Anal. Calcd. for $C_8H_{18}O_6P_2S_4$: C, 24.10; H, 4.50; P, 15.5; S, 32.0; mol. wt., 400. Found: C, 24.21; H, 4.45; P, 15.5; S, 32.2; mol. wt. (acetone ebullioscopic method), 396.

The liquid was extracted from the porous plate with ether, the ether removed by evaporation and the residue, a tan, semi-viscous liquid, shown to consist primarily of one isomer whose infrared spectrum was almost identical to the spectrum of the peak 3 compound (VI).

Partial Pyrolysis of 2,3-*p*-Dioxanedithiol S,S-Bis-(O,O-diethyl Phosphorodithioate).—The apparatus consisted of a 100-ml. single-neck round-bottom flask equipped with capillary for nitrogen and a thermometer well, with the flask attached to a cooled receiver *via* a short distillation head. The flask was charged with 53.2 g. of technical ethyl ester I and the system evacuated. The flask was heated slowly to 135–140° and maintained there until no more material distilled. The distillate weighed 19.5 g. The material remaining in the flask (30.8 g.) was taken up in benzene, washed with 5% sodium bicarbonate and with 15% brine until neutral, then dried over sodium sulfate. The solvent was removed by aspiration and the residue topped at 50° (<1 mm.); weight of dark liquid residue 24.2 g. Using the same partition chromatographic system described above, a sample of the residue was separated and shown to consist primarily of the peak 3 compound VI and the peak 4 compound IV. An infrared spectrum of the pyrolysate indicated no peak 2 compound was present. Pure VI (*cis* isomer) was analyzed.

Anal. Calcd. for $C_{12}H_{26}O_6P_2S_4$: C, 31.6; H, 5.7; mol. wt., 456. Found: C, 32.0; H, 5.8; mol. wt. (acetone ebullioscopic method), 436, 439.

Using the cleavage-hydrolysis procedure described above, this isomer yielded the theoretically possible amount of the 2,4-dinitrophenylsazone of glyoxal. Compound IV had characteristic infrared peaks at 6.1, 7.65, and 10.90 μ . The 7.65- μ band was used for quantitative determinations. Pure IV, isolated by partition chromatography from the above pyrolysate, was analyzed.

Anal. Calcd. for $C_8H_{18}O_4P_2S_2$: C, 35.4; H, 5.5; S, 23.6; mol. wt., 270. Found: C, 35.6; H, 5.8; S, 23.8; mol. wt. (acetone ebullioscopic method), 287.

The *cis* isomer VI was found to be at least twice as toxic to two-spotted spider mites as the *trans* isomer V.

Complete Pyrolysis of 2,3-*p*-Dioxanedithiol S,S-Bis-(O,O-diethyl Phosphorodithioate).—Using the same apparatus described for the partial pyrolysis, 54.6 g. of technical ester I was slowly heated *in vacuo* (<1 mm.) to about 165° at which temperature vacuum was lost and the pot temperature rose rapidly. During this time, 34.7 g. of distillate was collected and 4.1 g. of volatile material condensed in a Dry Ice trap in the system. The remainder of the material was a carbonaceous substance in the distillation flask. The distillate was redistilled *in vacuo* and two fractions collected: (1) 17.4 g. of light yellow liquid at 48–104° (0.15 mm.) and (2) 10.0 g. at 104–112° (0.15 mm.). A residue of 4.2 g. remained in the distillation flask.

Titration of fraction 1 using phenolphthalein indicator required 67.1 meq. of standard base. A slight excess of base was added, the resultant mixture extracted twice with ether, and the combined extracts dried over sodium sulfate. Removal of the ether left 4.9 g. of neutral material, which, based on infrared analysis, was primarily triethyl esters of di- and monothiophosphoric acids. The aqueous layer was made strongly acid with concentrated hydrochloric acid and similarly extracted twice with ether, the combined ether extracts dried over anhydrous sodium sulfate, and the ether

removed by evaporation, leaving 6.2 g. of an acidic material which by infrared analysis and neutralization equivalents was slightly impure O,O-diethyl hydrogen phosphorodithioate.

Anal. Calcd. for $C_4H_{11}O_2PS_2$: neut. equiv., 186. Found: neut. equiv., 183.

Fraction 2, by infrared analysis, consisted almost entirely of 2-*p*-dioxanedithiol S-(O,O-diethyl phosphorodithioate) (IV).

2-*p*-Dioxanedithiol S-(O,O-Diethyl Phosphorodithioate) (VIII).—To a stirred mixture of 17.2 g. (0.2 mole) of *p*-dioxene²⁰ and 50 ml. of benzene heated at 50° was added dropwise 37.2 g. (0.2 mole) of O,O-diethyl hydrogen phosphorodithioate. This mixture was heated at 50° for 3 more hours and then permitted to stand at room temperature overnight. Benzene (100 ml.) was added and the mixture washed with 5% potassium hydroxide and twice with water, then dried over sodium sulfate. The solvent was removed by aspiration and the residue topped at 50° (0.25 mm.); weight of almost clear liquid product 39.6 g. (73% yield), n_D^{20} 1.5242.

Anal. Calcd. for $C_8H_{17}O_4PS_2$: S, 23.6. Found: S, 23.7.

2,5-*p*-Dioxanedithiol S,S-Bis-(O,O-diethyl Phosphorodithioate) (VII).—This reaction was carried out as described above for the 2,3-isomer using 27 g. (0.14 mole) of 96% O,O-diethyl hydrogen phosphorodithioate, 100 ml. of benzene, 10 g. (0.125 mole) of pyridine and 10 g. (0.064 mole) of 2,5-dichloro-*p*-dioxane.²¹ The yellow solid product weighed 22.0 g. (75% yield).

Anal. Calcd. for $C_{12}H_{26}O_6P_2S_4$: S, 28.1. Found: S, 27.3.

2-*p*-Dioxanedithiol S-(O,O-Diethyl Phosphorodithioate) (IV). Thermal Dehydrochlorination.—A mixture of 45.0 g. (0.28 mole) of 2,3-dichloro-*p*-dioxane, 30 g. (0.153 mole) of 95% O,O-diethyl hydrogen phosphorodithioate and 0.2 g. (0.0015 mole) of zinc chloride was stirred and heated at reflux temperatures. Nitrogen was bubbled slowly through the reaction mixture and the hydrogen chloride in the off-gas continuously titrated with sodium hydroxide using phenolphthalein indicator. After 40 minutes, 0.15 mole of base had been consumed and after 7 hours, 0.26 mole. Because the gas evolution had ceased at this point, the mixture was worked up as described above for the catalytic procedure. The product, which weighed 30 g., was about 65% of IV by infrared analysis.

Dehydrochlorination with Base.—The above reaction was repeated except when 0.15 mole of hydrogen chloride had been evolved, the mixture was cooled and worked up as described above for the pyridine procedure. The product weighed 31 g. and by infrared analysis contained about 40% IV.

Bis-(diethoxyphosphinyl) Disulfide.—Using the procedure described by Bartlett, *et al.*,¹⁹ 40.7 g. (65% yield) was synthesized from 77.1 g. (0.37 mole) of potassium O,O-diethyl phosphorothioate²² in 60 ml. of water, 26.9 g. (0.39 mole) of sodium nitrite and 39.2 (0.38 mole) of 96% sulfuric acid in 18.5 ml. of water.

Anal. Calcd. for $C_8H_{20}O_6P_2S_2$: S, 18.9; P, 18.4. Found: S, 19.6; P, 18.8; n_D^{20} 1.4880.

2,3-*p*-Dioxanedithiol S,S-Bis-(O,O-diethyl Phosphorodithioate) (IX).—Using the procedure described above for the addition of a phosphorus-containing disulfide to *p*-dioxene, 5.3 g. (42% yield) of dark liquid product was made from 10.1 g. (0.03 mole) of bis-(diethoxyphosphinyl) disulfide, 0.8 g. (0.003 mole) of iodine and 3.0 g. (0.035 mole) of *p*-dioxene. Cleavage and hydrolysis of the product as described above yielded 83% of the theoretically possible amount of 2,4-dinitrophenylsazone of glyoxal for the structure assigned.

1,2-Ethanedithiol S,S-Bis-(O,O-diethyl Phosphorodithioate) (X).—An ethanolic solution of sodium ethoxide was made from 9.7 g. (0.42 mole) of sodium and 300 ml. of 100% ethanol. To this solution was added dropwise 87.0 g. (0.45 mole) of 96% O,O-diethyl hydrogen phosphorodithioate with stirring and cooling to keep the temperature below 35°. Then 37.6 g. (0.2 mole) of ethylene dibromide was added and the resultant mixture refluxed for 20 hours. The salt was filtered off and the solvent removed from the filtrate by

(21) L. A. Bryan, W. M. Smedley and R. K. Summerbell, *This Journal*, **72**, 2206 (1950).

(22) T. W. Mastin, G. R. Norman and E. A. Weilmuenster, *ibid.*, **67**, 1662 (1945).

aspiration. The residue was taken up in benzene-ether, washed with 5% potassium hydroxide and with water until neutral, then dried over sodium sulfate. The solvent was removed by aspiration and the residue topped at 60° (0.3 mm.). The tan liquid product weighed 66.8 g. (84% yield).

Anal. Calcd. for $C_{10}H_{24}O_4P_2S_4$: S, 32.0; P, 15.3. Found: Br, 0.1; S, 32.1; P, 15.5; n_D^{20} 1.5368.

Reaction of Zinc Chloride with O,O-Diethyl Hydrogen Phosphorodithioate in Benzene.—A mixture of 100 g. of a 39% solution of O,O-diethyl hydrogen phosphorodithioate in benzene and 2.72 g. (0.02 mole) of crushed, anhydrous zinc chloride was stirred and refluxed, and the hydrogen chloride evolved titrated continuously with sodium hydroxide using phenolphthalein indicator. Nitrogen was passed through

the system to ensure the prompt removal of hydrogen chloride. In 30 minutes about 75% of the theoretical quantity of hydrogen chloride was evolved and after 40 more minutes, 100%. When about 50% of the hydrogen chloride was evolved, the mixture became homogeneous.

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WILMINGTON, DEL.

[CONTRIBUTION FROM THE RESEARCH CENTER, HERCULES POWDER CO.]

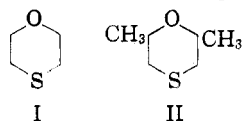
New Organophosphorus Derivatives of *p*-Thioxane and 2,6-Dimethyl-*p*-thioxane with Insecticidal and Acaricidal Activity

BY A. H. HAUBEIN¹

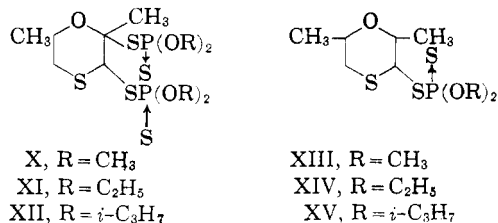
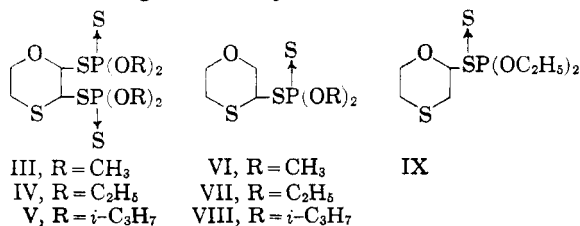
RECEIVED MAY 15, 1958

Several new organophosphorus derivatives of *p*-thioxane (I) and 2,6-dimethyl-*p*-thioxane (II) have been synthesized and found to have insecticidal and acaricidal activity. These compounds were prepared by reaction of the corresponding chloro-*p*-thioxanes with ammonium O,O-diethyl phosphorodithioate in acetone solution or with O,O-diethyl hydrogen phosphorodithioate in benzene solution using catalytic quantities of anhydrous zinc chloride. The synthesis of the chloro-*p*-thioxanes is described. Chlorination of *p*-thioxane in refluxing carbon tetrachloride produced 2,3-dichloro-*p*-thioxane (XVI). Chlorination at -10° in carbon tetrachloride produced an insoluble sulfonium chloride which rearranged at 0 to 25° to give 3-chloro-*p*-thioxane (XX) and hydrogen chloride. 3-Chloro-*p*-thioxane eliminates hydrogen chloride in refluxing benzene to produce thioxene, a new route to this compound. Hydrogen chloride added to thioxene to give 2-chloro-*p*-thioxane. Some structure-activity relationships of the organophosphorus compounds are postulated.

During the course of the synthesis of compounds related in structure to 2,3-*p*-dioxanedithiol S,S-bis-(O,O-diethyl phosphorodithioate),² a number of organophosphorus derivatives of *p*-thioxane (*p*-oxathiane) (I) and 2,6-dimethyl-*p*-thioxane (2,6-dimethyl-*p*-oxathiane) (II) were found to have insecticidal and acaricidal activity. The compounds, the general formulas of which are given below, were



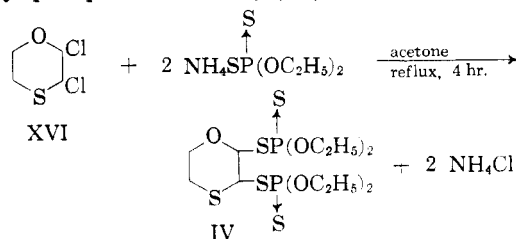
prepared and tested to determine the effect of structure on biological activity.



(1) Presented in part before the Division of Agricultural and Food Chemistry at the 133rd Meeting of the American Chemical Society, San Francisco, Calif., April, 1958.

(2) Also known as Delnav, a registered trademark of Hercules Powder Co.

The esters were synthesized from the corresponding chlorothioxanes by treatment with the ammonium salt of the dialkyl hydrogen phosphorodithioate in refluxing acetone as illustrated by the preparation of 2,3-*p*-thioxanedithiol S,S-bis-(O,O-diethyl phosphorodithioate) (IV).



Other salts such as pyridine, sodium or potassium may be used successfully in this reaction provided a suitable solvent is employed.³ The free acid may be used in refluxing benzene, employing anhydrous zinc chloride as catalyst.⁴

The 2,3-dichloro-*p*-thioxane (XVI) was prepared by chlorinating *p*-thioxane (I) in refluxing carbon tetrachloride. The product was isolated by vacuum distillation. During this operation it was difficult to maintain constant pressure because of elimination of hydrogen chloride. Once distilled, however, the product was thermally stable and could be fractionated readily. The distillate is water-white and reacts with the moisture of the air to liberate hydrogen chloride. On storage at 0°, crystals slowly form which, when recrystallized from ether-petroleum ether mixture, gave white crystals, m.p. 40.5–41°. These darken on storage unless care is taken to exclude moisture.

(3) A. H. Haubein, U. S. Patents 2,725,331 (1955) and 2,766,167 (1956).

(4) R. M. Speck, U. S. Patent 2,815,350 (1957).