described by Diveley, *et al.*[8] The product was obtained as a dark liquid, wt. 63 g. (64% yield).

Anal. Calcd. for $C_{12}H_{26}O_5P_2S_5$: S, 33.9. Found: S, 33.2.

Catalytic Procedure.—A 17-g. (0.1 mole) sample of 2,3-dichloro-*p*-thioxane was treated with O,O-diethyl hydrogen phosphorodithioate in refluxing benzene using anhydrous zinc chloride as catalyst according to the procedure described by Speck.[4] A 51% yield of product was obtained.

Anal. Calcd. for $C_{12}H_{26}O_5P_2S_5$: S, 33.9. Found: S, 33.0.

Disulfide Method.—Bis-(diethoxyphosphinethioyl) disulfide (XVIII) prepared by the method of Bartlett, *et al.*,[17] was added to 5 g. (0.05 mole) of thioxene according to the procedure of Diveley, *et al.*[8] A 76% yield of 2,3-*p*-thioxanedithiol S,S-bis-(O,O-diethyl phosphorodithioate) (IV) was obtained.

Anal. Calcd. $C_{12}H_{26}O_5P_2S_5$: S, 33.9. Found: S, 33.9.

2,6-Dimethyl-2,3-*p*-thioxanedithiol S,S-bis-(O,O-diethyl phosphorodithioate) (XI) was prepared by the ammonium salt method by treating 5 g. (0.025 mole) of 2,3-dichloro-2,6-dimethyl-*p*-thioxane with 11 g. (0.054 mole) of ammonium O,O-diethyl phosphorodithioate in refluxing acetone. The product was a viscous yellow oil, wt. 9.1 g., 72% yield.

Anal. Calcd. for $C_{14}H_{30}O_5P_2S_5$: P, 12.4. Found: P, 11.5.

3-*p*-Thioxanethio S-(O,O-Diethyl Phosphorodithioate) (VII).—A solution of 3-chloro-*p*-thioxane (XX) in carbon tetrachloride was prepared by adding 35 g. (0.5 mole) of chlorine to 57 g. (0.55 mole) of thioxane in 150 ml. of carbon tetrachloride at −10°. The suspension was sparged at 5 to 10° with nitrogen until no more hydrogen chloride was evolved (2 hr.). To this was added a solution of 0.49 mole of the pyridine salt of O,O-diethyl hydrogen phosphorodithioate in 250 ml. of benzene. The reaction mixture was stirred at room temperature for 2 hr. and refluxed for 4 hours. The product, isolated in the manner described for the pyridine method, was a yellow liquid, wt. 120 g. (85% yield). The chromatogram of this material as determined by the method of Diveley, *et al.*,[8] shows this material to be 75.6% of one constituent.

Anal. Calcd. for $C_8H_{17}O_3PS_3$: P, 10.7; S, 33.3; Cl, 0.0. Found: P, 11.2; S, 33.8; Cl, 0.3.

2-*p*-Thioxanethiol S-(O,O-Diethyl Phosphorodithioate) (IX). From 2-Chloro-*p*-thioxane (XXII).—To the solution of 2-chloro-*p*-thioxane in chloroform prepared above was added a solution of 0.2 mole of the pyridine salt of O,O-diethyl hydrogen phosphorodithioate (XXI) in 100 ml. of benzene. The reaction mixture was stirred for 2 hr. at room temperature and 4 hr. at reflux. The product was isolated as described for the pyridine method to give 41 g. of yellow liquid whose infrared absorption curve was identical with the product obtained by the addition of O,O-diethyl hydrogen phosphorodithioate to *p*-thioxene.

Anal. Calcd. for $C_8H_{17}O_3PS_3$: P, 10.7; S, 33.3. Found: P, 11.5; S, 32.9.

From Thioxene (XVII).—To 10 g. of thioxene containing 50% thioxane (0.05 mole thioxene) in 50 ml. of benzene was added 3 drops of triethylamine and 10 g. (0.051 mole) of 96% O,O-diethyl hydrogen phosphorodithioate. The solution was refluxed for 4 hr. Titration of an aliquot of the solution with standard base to phenolphthalein end-point showed that 0.047 mole of acid had reacted. The reaction mixture was washed with 10% aqueous base and with water, and dried over anhydrous sodium sulfate. Solvent was removed at 18 mm. to a pot temperature of 60°. The residue was topped at 80° (0.5 mm.) to leave a yellow liquid residue of 8 g. (62% yield).

Anal. Calcd. for $C_8H_{17}O_3PS_3$: P, 10.7. Found: P, 11.3.

2,6-Dimethyl-3-*p*-thioxanethiol S-(O,O-Diethyl Phosphorodithioate) (XIV).—Using the pyridine procedure 29 g. of 3-chloro-2,6-dimethyl-*p*-thioxane was treated with 0.2 mole of the pyridine salt of O,O-diethyl hydrogen phosphorodithioate XXI. The product was a yellow liquid, wt. 39 g. (71% yield).

Anal. Calcd. for $C_{10}H_{21}O_3PS_3$: P, 9.8; S, 30.3. Found: P, 10.4; S, 30.5.

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

[CONTRIBUTION FROM THE CHEMICAL CORPS, CHEMICAL RESEARCH DIVISION, CHEMICAL WARFARE LABORATORIES]

Organic Phosphorus Compounds. V.[1] The Preparation of O-Alkyl Alkylphosphonothioic Acids

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The preparation of O-alkyl alkylphosphonothioic acids by limited hydrolysis of the corresponding O,O-dialkyl alkylphosphonothioates with alcoholic alkali was studied in order to determine the optimum reaction conditions. The O-alkyl alkylphosphonothioic acids were also prepared in good yield by the hydrolysis of the corresponding O-alkyl alkylphosphonochloridothioates with aqueous alkali.

The recent resolution of O-ethyl ethylphosphonothioic acid into its optical antipodes[3] which permits the synthesis of the pure enantiomorphs of a number of sulfur-containing organophosphorus inhibitors of cholinesterase and their study in the stereospecific, irreversible inactivation of the enzyme[4] made it desirable to have available a series of O-alkyl alkylphosphonothioic acids.

Kabachnik and co-workers[5] describe the first four members of the series of O-ethyl alkylphosphonothioic acids, $[RP(O)(S)OC_2H_5]H$, where R represents methyl, ethyl, *n*-propyl and *n*-butyl. These homologous monoacids were prepared by a limited, alkaline hydrolysis of the corresponding O,O-diethyl alkylphosphonothioates, $RP(S)(OC_2H_5)_2$ (I). Since our interest was mainly directed toward homologous members of the two series, $CH_3P(O)(OR)SH$ (II) and $C_2H_5P(O)(OR)SH$ (III), in which the R groups were lower alkyl

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[1] Paper IV of this series, THIS JOURNAL, **80**, 5937 (1958).

[2] To whom inquiries about this paper should be addressed.

[3] H. S. Aaron, T. M. Shryne and J. I. Miller, THIS JOURNAL, **80**, 107 (1958).

[4] H. S. Aaron, H. O. Michel, B. Witten and J. I. Miller, *ibid.*, **80**, 456 (1958).

[5] M. I. Kabachnik, N. I. Kurochkin, T. A. Mastryukova, S. T. Ioffe, E. M. Popov and N. P. Rodionova, *Doklady Akad. Nauk S.S.S.R.*, **104**, 861 (1955); *C.A.*, **50**, 11240*a* (1956).

groups, the preparative method described by the Russian investigators was chosen for the synthesis of the desired acids. However, the initial hydrolysis runs gave only low yields and were, therefore, for reasons unknown at that time rather unsatisfactory. Promising alternate starting materials for the preparation of the desired thio acids II and III appeared to be the O-alkyl methyl- and ethyl-phosphonochloridothioates, R'P(S)(OR)-Cl (IV), in which the chlorine was expected to be much more susceptible toward alkaline hydrolysis than the second alkoxy group of the dialkyl esters. A previously reported study[6] of preparative methods for I and IV from the appropriate alkylphosphonous and alkylphosphonothioic dichlorides furnished the required starting materials for the synthesis of the desired phosphonothioic acids II and III.

Preliminary runs for the alkaline hydrolysis of O,O-dialkyl alkylphosphonothioates with one mole equivalent of potassium hydroxide in 95% ethanol gave erratic results and furnished only mediocre yields of the O-alkyl alkylphosphonothioic acids. Frequently, attempted distillation of the crude mixture of acidic products from these runs resulted in decomposition with the formation of highly viscous, undistillable products which appeared to contain pyro (P–O–P) linkages. In these runs, the alkaline hydrolysis was performed at the reflux temperature of the reaction mixture and carried almost to neutrality. However, hydrolyses in which the alkali consumption was not allowed to progress beyond 70–80% of the calculated amount yielded consistently reproducible results. Under these conditions, yields up to 80% of the desired II or III could be obtained.

The difference in the rates of the hydrolysis of the various diesters made it necessary to obtain an approximate value for the rate of the alkali consumption in order to predetermine suitable reaction times for each starting material. The reflux periods required to achieve 50% consumption of one mole equivalent of alkali in alcoholic solutions are listed in Table I.

The rates of the alkali consumption in the runs in refluxing 95% ethanol using one mole equivalent of potassium hydroxide per mole of diester show that in both series, $CH_3P(S)(OR)_2$ (V) and $C_2H_5P(S)(OR)_2$ (VI), the saponification of the first P–OR grouping proceeds much faster for the *n*-alkyl derivatives than for the diisopropyl esters and that, in general, the rates decrease for corresponding esters when going from the V to the VI.

Although these approximate data for the saponification are not usable for an evaluation of the kinetics, they allow nevertheless a selection of suitable reaction conditions for the preparation of the individual acids.

Table I

Alcoholic Alkaline Hydrolysis of O,O-Dialkyl Alkylphosphonothioates with 1 Mole Equivalent of Potassium Hydroxide

$RP(S)(OR')_2$		Reaction medium	Temp., °C.	$t_{1/2}$,[a] hr.
R	R'			
CH_3	CH_3	CH_3OH	27	46
		CH_3OH	45	25
		CH_3OH	60	0.33
CH_3	C_2H_5	85% C_2H_5OH	83 ± 2	<0.5
		95% C_2H_5OH	83 ± 2	1
CH_3	*n*-C_3H_7	95% *n*-C_3H_7OH	75 ± 1	2
		95% *n*-C_3H_7OH	98 ± 1	<0.25
		95% C_2H_5OH	83 ± 1	0.9
CH_3	*i*-C_3H_7	99% *i*-C_3H_7OH	90 ± 2	1.75
		95% C_2H_5OH	83 ± 2	6.25
CH_3	*n*-C_4H_9	95% C_2H_5OH	83 ± 2	0.42
CH_3	*n*-C_5H_{11}	95% C_2H_5OH	83 ± 2	0.5
C_2H_5	CH_3	CH_3OH	64 ± 1	2.5
C_2H_5	C_2H_5	95% C_2H_5OH	83 ± 2	1.5
C_2H_5	*n*-C_3H_7	95% C_2H_5OH	83 ± 2	3.75
C_2H_5	*i*-C_3H_7	*i*-C_3H_7OH	90 ± 2	12.5
		95% C_2H_5OH	83 ± 2	54
C_2H_5	*n*-C_4H_9	95% C_2H_5OH	83 ± 2	6

[a] Time required to achieve consumption of 0.5 mole of potassium hydroxide/mole of $RP(S)(OR')_2$.

While the alkoxy group of compounds II and III is much more resistant toward alkaline hydrolysis than the first alkoxy group of the O,O-dialkyl alkylphosphonothioates, as far as primary ester groups are concerned, the isopropoxy groups of O-isopropyl methyl- and ethylphosphonothioic acid are susceptible to hydrolysis under the conditions of the limited alkaline hydrolysis of the corresponding O,O-diisopropyl esters in 95% ethanol. This results upon extended hydrolysis in a crude II or III, respectively, which is heavily contaminated with the thiophosphonic acid, $RP(S)(OH)_2$. It is necessary, therefore, in order to assure a good yield of the desired II or III not to carry the alkali consumption of the diisopropyl esters beyond 50% of the amount calculated for the hydrolysis of one ester group. In the *n*-alkyl ester series, where the differences in the rates of the first and second ester groups are very pronounced, the hydrolysis period can be extended to 2–3 times the period required for 50% alkali consumption without impairing the yield of the desired monoacid. However, prolonged reaction times will make the adverse effect of the second step hydrolysis noticeable and will lead to erratic results.

Reproducible results with good yields of the II and III were obtained by aqueous alkaline hydrolysis of the appropriate O-alkyl alkylphosphonochloridothioates IV. The difference in the rates of the hydrolysis of the chloridate group of the IV and the first alkoxy group of the V (or VI) is large enough to assure formation of the desired acid without its further hydrolysis under the prevalent experimental conditions. For the preparation of the thiol acids, the appropriate chloridothioates are added dropwise with stirring to two mole equivalents of 5 *N* sodium hydroxide solution at 80 to 100° at such a rate as to maintain a temperature of about 100° without further additional heating. Under these conditions, the water-insoluble chloridothioate goes rapidly into solution. The desired O-alkyl alkylphosphonothioic acid is readily isolated from the resulting clear aqueous solution of sodium chloride and the sodium salt of the acid by acidification and extraction with diethyl ether or benzene. The yields of the thioic acids are, in general, higher than those obtained from the corresponding dialkyl esters.

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(6) F. W. Hoffmann, D. H. Wadsworth and H. D. Weiss, This Journal, **80**, 3945 (1958).

TABLE II

PHYSICAL CONSTANTS AND ANALYSES OF O-ALKYL ALKYLPHOSPHONOTHIOIC ACIDS, RP(O)(OR')SH

R	R'	B.p. °C.	B.p. Mm.	n^{25}_D	d^{25}_4	Carbon, % Found	Carbon, % Calcd.	Hydrogen, % Found	Hydrogen, % Calcd.	Phosphorus, % Found	Phosphorus, % Calcd.	Sulfur, % Found	Sulfur, % Calcd.	Neut. equiv. Found	Neut. equiv. Calcd.
CH_3	CH_3 (VII)[a]	54.5–56	0.2	1.5005	1.3015	19.4	19.04	5.7	5.80	24.90	24.56	25.31	25.43	126.5	126.1
CH_3	C_2H_5 (VIII)[b]	63	.22	1.4912	1.1735	25.8	25.71	6.6	6.47	22.29	22.10	22.85	22.88	140.2	140.1
CH_3	n-C_3H_7 (IX)	74	.35	1.4820	1.124	31.3	31.16	7.1	7.19	20.38	20.09	20.86	20.80	154.9	154.2
CH_3	i-C_3H_7 (X)	61	.2	1.4810	1.1130	30.9	31.16	7.3	7.19	20.33	20.09	20.82	20.80	153.7	154.2
CH_3	n-C_4H_9 (XI)	83–84	.1	1.4829	1.0922	35.8	35.70	7.8	7.79	19.01	18.42	19.50	19.06	169.7	168.2
CH_3	n-C_5H_{11} (XII)	100–102	.05	1.4490	1.0655	39.8	39.55	8.3	8.30	17.02	17.00	17.82	17.60	183.4	183.2
C_2H_5	C_2H_5 (XIII)[c]	75–76	.4	1.4874	1.0999	31.3	31.16	7.0	7.19	20.47	20.09	20.97	20.80	154.4	154.2
C_2H_5	i-C_3H_7 (XIV)	79	.3	1.4776	1.0811	35.8	35.70	7.8	7.79	18.80	18.42	19.25	19.06	169.7	168.2
C_2H_5	n-C_4H_9 (XV)	95–98	.2	1.4790	1.0679	39.5	39.55	8.3	8.30	17.26	17.00	17.58	17.60	182.3	183.2

[a] Prepared in methanol as the reaction medium. [b] B.p. 85–86° (2.5 mm.), n^{20}_D 1.4927, d^{20}_4 1.1757; ref. 5. [c] B.p. 84.5–85.5° (2 mm.), n^{20}_D 1.4916, d^{20}_4 1.1337; ref. 5.

The physical properties and analyses of analytically pure cuts of the various O-alkyl alkylphosphonothioic acids are listed in Table II, while the percentage yields of the acids from the O-alkyl alkylphosphonochloridothioates and from the O,O-dialkyl alkylphosphonothioates as well as the reaction conditions for the limited hydrolysis of the diesters are given in Table III. All thioic acids were characterized as the dicyclohexylamine salts, the melting points and analyses of which are listed in Table IV.

Experimental

Alkali Consumption of O,O-Dialkyl Alkylphosphonothioates.—In order to determine the optimum conditions for the alcoholic, alkaline hydrolysis of the various O,O-dialkyl alkylphosphonothioates to O-alkyl alkylphosphonothioic acids, each individual ester was refluxed with one mole equivalent of potassium hydroxide in an appropriate alcohol. The consumption of the alkali was determined by direct titration of the unreacted alkali with standard 0.1 *N* hydrochloric acid against thymol blue as an indicator.

To 6.6 g. (0.1 mole) of 85% potassium hydroxide was added 50 cc. of 95% ethanol. The mixture then was refluxed until the potassium hydroxide was completely dissolved. The refluxing solution of alcoholic alkali was treated rapidly with 25.2 g. (0.1 mole) of O,O-di-*n*-amyl methylphosphonothioate at such a rate as to maintain reflux. Immediately after completion of the addition, a 1-cc. aliquot of the mixture was pipetted into 25 cc. of distilled water and titrated with 0.1 *N* hydrochloric acid using thymol blue as indicator. The resulting value for alkali present was taken as zero value. The consumption of the alkali was followed by titrating additional 1-cc. aliquots of the reaction mixture at suitable time intervals until approximately 90% of the alkali had been consumed. Approximately 25 minutes was required for the consumption of 50% of the alkali used.

TABLE III

YIELDS OF O-ALKYL ALKYLPHOSPHONOTHIOIC ACIDS, RP(O)(OR')SH

Acid	From diester Yield,[a] %	From diester Solvent	From diester Reflux period, hr.	From chloridothioate Yield,[b] %
VII	38.5	CH_3OH	1.5	. . .
VIII	87	C_2H_5OH	1.5	88.5
IX	56.5	n-C_3H_7OH	0.75	74.5
X	78.2	i-C_3H_7OH	5	65
XI	. . .	. . .	. . .	54.5
XII	51	C_2H_5OH	2	74.5
XIII	74	C_2H_5OH	4	80
XIV	44	i-C_3H_7OH	22	. . .
XV	. . .	. . .	. . .	60.5

[a] Based on reacted O,O-dialkyl alkylphosphonothioate. [b] Based on total charge of O-alkyl alkylphosphonochloridothioate.

The results of similar hydrolysis runs for a number of diesters are listed in Table I. O,O-Dimethyl methyl- and ethylphosphonothioate were hydrolyzed in methanol, while all other esters were subjected to the alkaline hydrolysis in 95% ethanol. Medium change from 95% ethanol to 95% *n*-propyl or isopropyl alcohol in the hydrolysis of the *n*-propyl and isopropyl esters, respectively, at reflux temperature resulted in an increased rate of hydrolysis as expected. The possibility of a transesterification with the formation of O-ethyl methyl- or ethylphosphonothioic acid during the hydrolysis of the higher dialkyl esters in ethanol was excluded by identification of the hydrolysis products through their dicyclohexylamine salts.

Preparation of O-Alkyl Alkylphosphonothioic Acids. A. Hydrolysis of O,O-Dialkyl Alkylphosphonothioates.—The hydrolysis of the O,O-dialkyl alkylphosphonothioates with potassium hydroxide to the O-alkyl potassium alkylphosphonothioates was carried out for preparative purposes in batches employing, in general, one to four moles of starting

TABLE IV

DICYCLOHEXYLAMINE SALTS

Acid	M.p., °C., salt	Carbon, %		Hydrogen, %		Phosphorus, %		Sulfur, %		Nitrogen, %	
		Calcd.	Found	Calcd.	Found	Calcd.	Found	Calcd.	Found	Calcd.	Found
VII	179.5–181[a]	54.69	55.0	9.84	9.9	10.08	10.09	10.43	10.93	4.56	4.54
VIII	159.5–161[a]	56.04	56.1	10.31	10.1	9.64	9.45	9.98	9.74	4.36	4.19
IX	143.5–144.5[a]	57.28	57.0	10.22	10.0	9.23	9.66	9.56	10.27	4.18	4.16
X	168.5–170.5[a]	57.28	57.7	10.22	10.3	9.23	9.40	9.56	9.88	4.18	4.27
XI	157.5–159.5[b]	58.42	58.3	10.38	10.4	8.86	9.09	9.17	9.36	4.01	3.98
XII	141.5–143[c]	59.47	59.3	10.54	10.5	8.52	8.87	8.82	9.23	3.86	3.83
XIII	168–170[b,d]	57.28	57.6	10.22	10.26	9.23	9.53	9.56	9.80	4.18	4.13
XIV	163–164.5[b]	58.42	58.3	10.38	10.5	8.86	8.61	9.17	9.16	4.01	3.98
XV	147.5–150[c]	59.47	59.5	10.54	10.4	8.52	8.95	8.82	9.10	3.85	3.89

[a] Recrystallized successively from absolute ethanol, benzene, and acetone–benzene mixture. [b] Recrystallized from acetone–benzene mixture. [c] Recrystallized from hot water. [d] Recrystallized successively from acetone, petroleum ether–acetone mixture (1:1), and water; reported[3] m.p. 166–168°.

material and approximately 10–25% less than the equivalent amount of alkali in 350–400 cc. of the appropriate alcohol per mole of the dialkyl ester. Only the preparation of O-*n*-amyl methylphosphonothioic acid was carried out in ethanol instead of amyl alcohol, but no alcohol exchange could be noticed.

The experimental conditions for the preparation of the various O-alkyl alkylphosphonothioic acids from the corresponding dialkyl esters are listed in Table III together with the yields based on reacted diester. The reflux periods for the individual runs were chosen on the basis of the results of the previous, orienting small-scale runs in such a manner that the reaction time was, in general, approximately 2–4 times the period required for 50% hydrolysis of the diester with one equivalent of potassium hydroxide. Using a deficiency of 10–25% of alkali in the preparative hydrolysis runs, the limited hydrolysis periods assured that interferences by hydrolysis of the second ester group did not occur.

The general procedure for the preparative limited hydrolysis of the O,O-dialkyl alkylphosphonothioates is illustrated by the following example for the preparation of O-ethyl methylphosphonothioic acid (VIII).

To a solution of 200 g. (3 moles) of 85% potassium hydroxide in 1400 cc. of 95% ethanol was added 672 g. (4 moles) of O,O-diethyl methylphosphonothioate in one portion. The mixture was refluxed with stirring for 1.5 hr. and cooled to room temperature, and the solvent was removed under reduced pressure. The residual salt cake was dissolved in 500 cc. of water and the aqueous solution extracted twice with 200-cc. portions and once with a 100-cc. portion of diethyl ether. The combined ether extracts were evaporated to leave 160.5 g. (*ca.* 0.96 mole) of crude unreacted diester. The aqueous solution was acidified with 340 cc. of concd. hydrochloric acid while being cooled with an ice–salt-bath. The organic layer of the resulting two-phase mixture was separated and the aqueous layer was extracted with two 200-cc. portions of ether. The washings and the organic layer were combined and dried over Drierite, and the ether was removed under reduced pressure. The residual crude product was distilled *in vacuo* to give 293 g. of VIII, b.p. 69° (0.4 mm.) to 77° (0.5 mm.), $n^{25}\mathrm{D}$ 1.4915. This represents a yield of 69% based on reacted diester.

A similar run (see Table III) employing 3 moles of diester and 2.5 moles of potassium hydroxide in 1050 cc. of 95% ethanol gave 0.89 mole of unreacted ester and 87% (based on reacted diester) of VIII, b.p. 71° (0.38 mm.), $n^{25}\mathrm{D}$ 1.4909.

B. **Hydrolysis of O-Alkyl Alkylphosphonochloridothioates.**—The preparation of O-*n*-amyl methylphosphonothioic acid (XII) is described in the following as an example of the general procedure.

A solution of 40 g. (1 mole) of sodium hydroxide in 200 cc. of water was heated to 80°. The dropwise addition of 100 g. (0.5 mole) of O-*n*-amyl methylphosphonochloridothioate to the hot alkali solution was started. Heating of the mixture was continued until the pot temperature reached 102°. At this temperature the reaction became self-sustaining and external heating was discontinued. The addition of the chloridothioate was completed in 40 minutes at a pot temperature of 102–107°. After cooling to room temperature, the solution was extracted with diethyl ether, but no unreacted organic material was obtained.

The aqueous solution was then acidified with a 100% excess of 50% (by vol.) sulfuric acid and extracted twice with 100-cc. portions and twice with 50-cc. portions of ether. The combined extracts were dried over Drierite, the ether was removed under reduced pressure and the residual crude product kept at 40° under a vacuum of 0.4–0.5 mm. for a period of 6 hr. Distillation *in vacuo* gave 69.4 g. (74.5%) of XII.

In the distillation of the crude O-alkyl alkylphosphonothioic acids it is imperative that the residues from the benzene or ether extracts be kept under a high vacuum at temperatures not exceeding 45° for several hours in order to remove the last traces of moisture. If distillation is attempted without this precaution, decomposition of the acid occurs with a considerable increase in the viscosity of the charge, apparently as a result of intermolecular dehydration with formation of the corresponding pyroesters. A successful distillation of the O-alkyl alkylphosphonothioic acids requires pressures below 1 mm. in order to assure a minimum distillation temperature which does not result in dehydration. In the presence of moisture, low pressures cannot be maintained and the pot temperatures rise above the point where pyroester formation is at a tolerable level.

Preparation of Dicyclohexylamine Salts of O-Alkyl Alkylphosphonothioic Acids.—All acids were characterized as their well crystallized dicyclohexylamine salts[3] which were obtained by mixing a solution of the acid in approximately twice its volume of dry benzene with 10–20% excess of dicyclohexylamine in an equal volume of benzene. The mixture was allowed to stand at room temperature until the amount of crystalline salt did not increase further. The crude salt was then recrystallized to a constant melting point. The melting points, the solvents used for recrystallization and the analyses of the various dicyclohexylamine salts are listed in Table IV.

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