Org.

Some Aliphatic Diphosphonic Tetrachlorides. Part II.¹ Some Reactions of Diphosphonic Tetrachlorides

By Gennady M. Kosolapoff and Alfred D. Brown, jun., School of Chemistry, Auburn University, Auburn, Alabama 36830, U.S.A.

Aliphatic diphosphonic tetrachlorides and Grignard reagents containing aryl groups readily gave diphosphine dioxides, of which several are described. In a similar reaction of the tetrachlorides with Grignard reagents containing branched alkyl groups the products were not the expected diphosphine dioxides, but the products of mono-substitution at each phosphorus atom accompanied by a reduction. A similar result was obtained from reactions of such Grignard reagents with phosphonic dichlorides. Factors affecting the synthesis of diphosphonic tetrachlorides containing interphosphorus bridges of varying lengths were studied.

In our recent Paper¹ on the synthesis of tetrachlorides of type $Cl_2P(O)[CH_2]_xP(O)Cl_2$ with x = 1-10, we noted that esters of diphosphonic acids of type $(RO)_2P(O)[CH_2]_xP(O)(OR)_2$ react readily with 4 mol. of phosphorus pentachloride and yield the expected diphosphonic tetrachlorides only if the value of x in the above formula is 5 or greater.

Esters with shorter interphosphorus bridges react with phosphorus pentachloride only partially and form the corresponding tetrachlorides only in reaction mixtures that also contain a molar proportion of the free diphosphonic acid. As we showed in our previous Paper that this latter reaction does not involve the formation of a dialkyl dihydrogen diphosphonate, the reason for the differences in behaviour of esters of diphosphonic acids with different lengths of interphosphorus bridges remains uncertain. Since the anomalous behaviour with phosphorus pentachloride occurs only for esters with x = 1-4, it seems reasonable that this behaviour is caused by some electronic or steric effect that operates in compounds with $x \neq 0$ or less. As this anomalous behaviour applies equally well to the compound with x = 4 as it does to that with x = 1, a simple inductive effect cannot explain the drastic change in chemical behaviour in passing from x = 4 to x = 5. Possibly some cyclic intermediate that might form between phosphorus pentachloride and the diphosphonate ester with x less than 5 can act to prevent the normal reaction between these compounds.

In order to verify the normal reactivity of diphosphonic tetrachlorides with various lengths of the interphosphorus bridge, we treated them with aromatic Grignard reagents and formed thereby a series of diphosphine dioxides of type $\operatorname{Ar_2P}(O)[\operatorname{CH_2}]_x P(O)\operatorname{Ar_2}$. Several new members of this group were thus obtained and no evidence was found that, in reactions of this nature, any great difference exists in the reactivity of diphosphonic tetrachlorides with x ranging from 1 to 10. We noted previously ¹ that these tetrachlorides with x an even number were noticeably less reactive with moisture than their analogues with x an odd number; this difference in reactivity is relatively small, however, and not at all apparent in reactions with aromatic Grignard reagents. In the reaction of a diphosphonic tetrachloride with a limited amount of an aromatic Grignard reagent, such as phenylmagnesium bromide, one may expect the following reaction schemes:



Reactions with either 1 or 3 mol. of the Grignard reagent should give one product only and it is only the reaction with 2 mol. of the reagent that can go in two possible directions. We found that only the (B) product is formed, with no evidence of (A). The product was identified by hydrolysis of the dichloride to the corresponding diphosphinic acid.

We also treated some of our diphosphonic tetrachlorides with Grignard reagents containing branched aliphatic groups, such as isopropyl or t-butyl. Regardless of the value of x in the tetrachloride, we were unable to force these to react with 4 mol. of such Grignard reagents, as the reaction with even a large excess of the latter resulted in symmetric disubstitution with one alkyl group attached to each of the phosphorus atoms. In order to explore further this difference in reactivity, we allowed these branched alkylmagnesium halides to react with some of the simple phosphonic dichlorides, such as ethylphosphonic dichloride and phenylphosphonic dichloride. These dichlorides have long been known to react with conventional Grignard reagents and to form either tertiary phosphine oxides or chlorides of phosphinic acids, convertible by hydrolysis into phosphinic acids, *i.e.*:

$$R^{1}P(O)Cl_{2} + 2R^{2}MgX \longrightarrow R^{1}R^{2}{}_{2}PO$$
 (C)

$$R^{1}P(O)Cl_{2} + R^{2}MgX \longrightarrow R^{1}R^{2}POCI + H_{2}O \longrightarrow R^{1}R^{2}P(O)OH (D)$$

depending largely on the reactant ratios employed.

We were interested in the possibility of preparing either the diphosphine dioxides of type $R_2P(O)[CH_2]_xP(O)R_2$, or tertiary phosphine oxides of type $R^1R_2^2PO$ and $R_2^1R^2PO$, in which R^1 would be a branched alkyl group such as isopropyl or t-butyl. As one may expect a degree of steric hindrance to the reaction of such branched Grignard reagents with two

¹ Part I, G. M. Kosolapoff and A. D. Brown, jun., J. Chem. Soc. (C), 1966, 757.

chlorine atoms on the phosphorus atom, so as to preclude reaction (C) in favour of reaction (D), we carried out several such reactions and showed that only one residue of the t-butylmagnesium halide reacts with each $POCl_2$ group, although the reaction of isopropylmagnesium halide can follow reaction path (C). We found that t-butylmagnesium chloride, in excess, reacts in equimolar proportion with the $POCl_2$ group and, evidently as a result of accompanying reduction, yields a secondary phosphine oxide, *i.e.*,

$$RPOCI_2 + Me_3CMgCI \longrightarrow Me_3C$$

with phosphoryl chloride, this reaction gave di-t-butylphosphine oxide which was readily characterised. The mechanism of this reduction of the expected phosphinic chloride to the secondary phosphine oxide is unknown, although numerous examples of reductions by Grignard reagents are known for carbonyl compounds, which have some structural similarity to the secondary phosphine oxides.

As organophosphorus compounds with tertiary alkyl substitutents are interesting compounds for the study of steric effects at the phosphorus atom, the above reaction provides a convenient route to secondary phosphine oxides, R_2HPO , and to phosphinic acids R_2PO_2H , in which one or both R groups are tertiary alkyl radicals.

Having thus shown that, except for possibly steric effects of branched alkyl Grignard reagents, there is no evidence of any notable difference in reaction of Grignard reagents with phosphonic chlorides and diphosphonic tetrachlorides, regardless of the length of the interphosphorus bridge, we investigated the reaction of phosphorus pentachloride with tetraethyl ethylene-1,2-diphosphonate. Equimolar proportions of these reactants readily yielded a molar equivalent of ethyl chloride and an undistillable triester-monochloride, of type $(EtO)_2P(O)CH_2CH_2P(O)(OEt)Cl.$ evidently Hydrolysis of this with water gave the expected ethylene-1,2-diphosphonic acid, while attempts to distil the substance in high vacuum resulted in a fairly vigorous reaction which gave ethyl chloride and a glassy residue of an apparent ester-anhydride of ethylene-1,2-diphosphonic acid, which could not be crystallised or distilled.

When a second mol. of phosphorus pentachloride was added to this crude monochloride-triester, the expected loss of another mol. of ethyl chloride was not spontaneous but required heating to approximately 50°. The product could have the constitution (E) or (F) below, depending

$\label{eq:eto} \begin{array}{l} (EtO)_2 P(O) CH_2 CH_2 POCI_2 \ (E) \\ (EtO) P(O) CICH_2 CH_2 POCI(OEt) \ (F) \end{array}$

on the site of attack by the second molecule of phosphorus pentachloride. The reaction product was rather unstable thermally and could not be made to distil slowly even in high vacuum. It was, however, stable

J. Chem. Soc. (C), 1967

enough to be distilled rapidly through a simple apparatus (b. p. $140^{\circ}/1 \text{ mm.}$) leaving a glassy residue.

Treatment of this diester-dichloride with the third mol. of phosphorus pentachloride failed to give any visible reaction even after 2 days at 90°. It was evident that the reason for failure of tetra-alkyl diphosphonates to be converted into diphosphonic tetrachlorides by phosphorus pentachloride (in the case of the substances with interphosphorus bridge of fewer than five methylene groups) lies in the complete unreactivity of the intermediate diester-dichloride. Hydrolysis of this with water gave a gum, apparently of the symmetric diethyl ester of ethylene-1,2-diphosphonic acid; potentiometric titration of this gum gave but a single break in the titration curve instead of the double break expected of an unsymmetric diethyl ester related to (E).

Reaction of (F) with phenylmagnesium bromide gave a readily separable mixture of ethylene-1,2-bis(diphenylphosphine oxide), formed by replacement of the ethoxygroups as well as the chlorine atoms by phenyl groups, and PP'-diphenylethylene-1,2-diphosphinic acid, resulting from replacement of only the chlorine atoms. The result confirmed the suggested structure of (F).

When (F) was treated with cold water to form the symmetric diethyl ester of ethylene-1,2-diphosphonic acid, and the product allowed to react with 2 mol. of phosphorus pentachloride, no ethyl chloride was formed, but the reaction yielded precisely 2 mol. of hydrogen chloride, indicating selective attack on the hydroxy-groups and no attack on the ethoxy-groups of the partial ester.

Reaction of free ethylene-1,2-diphosphonic acid with 4 mol. of phosphorus pentachloride in phosphoryl chloride was brisk initially but gave only slightly more than 2 mol. of hydrogen chloride after 2 days under reflux. After that no further reaction took place and the two-phase suspension persisted regardless of the duration of heating. After treatment with sulphur dioxide to destroy the residual phosphorus pentachloride, this mixture gave a very small amount of ethylene-1,2-diphosphonic tetrachloride which was isolated by vacuum sublimation; the remainder could not be distilled or crystallised.

The above results suggest that esters of diphosphonic acids with x = 1-4 react normally with phosphorus pentachloride only to the point of forming the symmetric diester-dichloride; a symmetric dichloride is formed from the corresponding free diphosphonic acid under similar conditions. In either case the reaction does not proceed further possibly owing to the formation of a cyclic structure through polar interaction of the phosphoryl groups, possibly between two adjacently placed molecules. That some form of cyclic association is involved can be reasoned from the fact that this phenomenon does not take place with diphosphonates which have longer polymethylene bridges. If the phenomenon were caused by some random polar association of adjacent molecules, one would not expect an abrupt difference in the behaviour of similar compounds differing in structure by but one methylene group; in reality the break in reaction of phosphorus pentachloride with the diphosphonate esters is most distinct and occurs between x = 4 and 5 very clearly. Cyclic associates as intermediates have been suggested for a similar reaction between phosphoryl chloride and triethyl phosphate by one of us some time ago.²

EXPERIMENTAL

Diphosphine Dioxides .--- In a typical reaction, phenylmagnesium bromide (from bromobenzene, 126 g., 0.8 mole, and magnesium, 19.4 g.), in ether was refluxed overnight with trimethylene-1,3-diphosphonic tetrachloride (27.8 g., 0.1 mole). Treatment with aqueous ammonium chloride, separation of the organic layer, and removal of magnesium ions from the latter by addition of alcoholic potassium hydroxide and filtration, gave trimethylene-1,3-bis(diphenylphosphine oxide) (61%), which after distillation at 293-305°/0·1 mm. was recrystallised from toluene, m. p. 142-143°, unchanged after mixing with a specimen prepared by a different method 3 by C. F. Baranauckas of Hooker Chemical Corp. The value 195-196° reported earlier 4 by one of us is therefore incorrect.

The following analogues were prepared similarly.

 $R_2P(O)[CH_2]_xP(O)R_2$

				Р		P
		Yield,		found,		calc.,
x	R	%	М. р.	%	Formula	%
2	Ph		276-278° ª			
3	Ph	61	142 - 143	13.95	$C_{27}H_{26}O_{2}P_{2}$	13.9
7	Ph	42	128 - 129	12.1	$C_{31}H_{34}O_2P_2$	12.4
8	Ph	56	170.5 - 172	12.1	$C_{32}H_{36}O_2P_2$	12.05
9	Ph	21	123 - 125	11.7	$C_{33}H_{38}O_2P_2$	11.7
10	\mathbf{Ph}	30	181 - 182	11.1	$C_{34}H_{40}O_2P_2$	11.4
6	p-MeOC ₆ H ₄	60	161 - 162	9.9	$C_{34}H_{40}O_6P_2$	10.2
5	p-MeC ₆ H ₄	51	156 - 158	11.55	$C_{33}H_{38}O_2P_2$	11.7
^a Lit., ⁵ 252-254°.						

Reactions of Phosphonic Dichlorides with Branched Grignard Reagents.--Reaction of isopropylmagnesium bromide (from isopropyl bromide, 44.3 g., 0.36 mole), and of phenylphosphonic dichloride (23.2 g., 0.12 mole) in ether, completed by refluxing for 30 hr., gave after quenching the mixture in ice-hydrochloric acid and separating the organic layer, only a trace of yellow oil after evaporation of the ether layer. The aqueous layer was treated with alcoholic potassium hydroxide to remove magnesium and the filtrate from this was evaporated to dryness in vacuum. The residue was extracted with dry acetone to yield 17 g. (62.5%) of diisopropylphenylphosphine oxide, a colourless oil, b. p. 94°/ 0.1 mm., which crystallised on cooling, m. p. 49-50° (Found: P, 15.0. Calc. for C₁₂H₁₉OP: P, 14.75%).

A similar reaction of t-butylmagnesium chloride (0.6 mole) with phenylphosphonic dichloride (0.1 mole) gave in 44 hr. in boiling ether no detectable amount of a tertiary phosphine oxide. However, the organic layer, obtained after treatment of the mixture with water, yielded 18.8 g. of phenyl-t-butylphosphine oxide, HPhBu^tPO, m. p. 53-55°, after distilling at $147-148^{\circ}/6$ mm. (Found: P, $16\cdot 8$. Calc. for $C_{10}H_{15}OP$: P, 17.0%). This product was oxidised with 30% hydrogen peroxide to phenyl-t-butylphosphinic

² G. M. Kosolapoff, *Science*, 1948, **108**, 485. ³ C. F. Baranauckas, R. D. Carlson, E. E. Harris, and R. J. Lisanke, ASD Technical Report 61-4, U.S. Air Force, 1961, p. 82.

acid, m. p. 160-161° (Found: P, 15.55. Calc. for C₁₀H₁₅O₂P: P, 15.6%). This acid (4 g.) was isolated also from the aqueous filtrate obtained after the removal of magnesium, as the hydroxide, from the aqueous layer of the original reaction mixture after hydrolysis. The phosphinic acid was purified by distillation at $160-170^{\circ}/0.1$ mm.

Reaction of t-butylmagnesium chloride (from t-butyl chloride, 156 g., 1.7 mole), in ether with ethylphosphonic dichloride (59 g., 0.4 mole) gave after 12 hr. under reflux, followed by the usual aqueous treatment, only 2 g. of an oil from evaporation of the ethereal layer. The aqueous layer, after removal of magnesium as the hydroxide, was acidified with hydrochloric acid and evaporated to dryness, then distilled in vacuum to yield a liquid fraction, b. p. 53-111°/0.35 mm. Redistillation through a packed column gave 17 g. of ethyl-t-butylphosphine oxide, a colourless liquid, b. p. 116—116.5°/26 mm., $n_{\rm D}^{27\cdot5}$ 1.4510, $d_4^{27\cdot5}$ 0.9267 (Found: P, 23.1. Calc. for C₆H₁₅OP: P, 23.1%). The distillation residue left from the isolation of the above oxide was extracted for 2 days with ether and yielded 7 g. of ethyl-t-butylphosphinic acid, m. p. 101-103° (from hexane) (Found: P, 20.5%; Equiv. 151. Calc. for C₆H₁₅O₂P: P, 20.65%; Equiv. 150.2). The same acid was formed by oxidation of ethyl-t-butylphosphine oxide with 15% hydrogen peroxide at room temperature for 2 days.

Similar peroxide oxidation of isopropylphenylphosphine oxide gave isopropylphenylphosphinic acid, m. p. 88-89° (from benzene-hexane) (Found: P, 16.85%; Equiv. 184. Calc. for C₉H₁₃O₂P: P, 16.8%; Equiv. 184.2). A very low yield of this acid was isolated from an ethereal extract of the distillation residues left after the isolation of di-isopropylphenylphosphine oxide, described above.

The results showed that while two isopropyl groups may be introduced by the Grignard reaction into a phosphonic dichloride, only one t-butyl group may be so introduced. That this is not caused purely by steric hindrance can be deduced by assembling scale models of such t-butylated tertiary phosphine oxides. The impossibility of producing such oxides in actual reactions may well be attributed to the rather complex and bulky reaction intermediates formed in the attack by a Grignard reagent on the chlorine atoms in phosphonic dichlorides.

Reaction of a large excess of isopropylmagnesium bromide in ether with pure tetramethylene-1,4-diphosphonic tetrachloride gave after 2 days under reflux, followed by the usual hydrolytic treatment and removal of magnesium, a yellowish oily acidic material. Extraction of this with much hexane gave a low yield of PP'-di-isopropyltetramethylene-1,4-diphosphinic acid, HOP(O)(Prⁱ)CH₂CH₂CH₂CH₂P(O)(Prⁱ)OH, m. p. 155-157° (from benzene-ethanol). Potentiometric titration of the acid gave a curve with a single break, thus confirming the above structure. Recrystallisation from water gave the pure acid, m. p. 156-158° (Found: P, 22.8%; Equiv. 272.0. Calc. for $C_{10}H_{24}P_4O_2$: P, 22.95%; Equiv. 270.2). Evidently this acid was formed by airoxidation of the presumed bis-secondary phosphine oxide formed in the reaction with the Grignard reagent. The reaction mixture failed to yield any volatile fractions and attempts to find some satisfactory solvents for solvent extraction of the mixture were unsuccessful.

[6/819 Received, June 28th, 1966]

⁴ G. M. Kosolapoff and R. F. Struck, J. Chem. Soc., 1961, 2423. ⁵ K. Isslieb and D. W. Muller, Chem. Ber., 1959, **92**, 3175.