Stereochemistry of the Reaction of O-Ethyl Ethylphosphonothioic Acid with Phosphorus Pentachloride

By J. MICHALSKI and M. MIKOŁAJCZYK

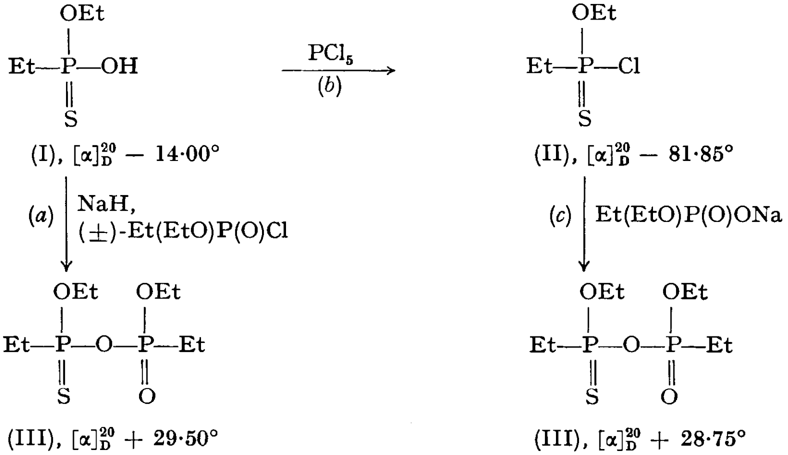
(*Institute of Organic Chemistry, Polish Academy of Sciences, Lodz, Poland*)

THE preparation and preliminary characterisation of the optically active *O*-ethyl ethylphosphonochloridothionates, Et(EtO)P(S)Cl (II), was reported recently.[1] In contrast with their oxygen analogues, Et(EtO)P(O)Cl,[2,3] the chlorides (II) are optically stable and present excellent intermediates for the synthesis of a wide range of optically active organophosphorus derivatives. The preparation of the chlorides (II) provides a convenient model for the mechanistic study of the reaction of phosphorus pentachloride with phosphorus thioacids. We now report on some stereochemical features of the mechanism of the model reaction.

The more detailed study of the reaction conditions shows that (−)-chloride (II) of the highest rotation value is obtained in ether solution at −5°. The following specimens of the chloride (II), isolated as described earlier,[1] $[\alpha]_D^{20}$ − 82·80°,* −81·85°, and −63·00°, were prepared from the (−)-acid (I), having the corresponding rotation values, $[\alpha]_D^{20}$ − 14·15°, −14·00°, and −11·00°.

The degree of optical purity of the (−)-chloride (II) can be deduced from its reaction with sodium *O*-ethyl ethylphosphonate. The properties of (+)-diethyl ethylphosphothionate (III) formed, are compared with those of compound (III) prepared by condensation of (−)-sodium *O*-ethyl ethylphosphonothioate with racemic *O*-ethyl ethylphosphonochloridate.

The formation of the pyrophosphonothionate



(I), $[\alpha]_D^{20}$ − 14·00°

(II), $[\alpha]_D^{20}$ − 81·85°

(III), $[\alpha]_D^{20}$ + 29·50°

(III), $[\alpha]_D^{20}$ + 28·75°

$$\mathrm{Et(EtO)P(S)OH} \xrightarrow[(b)]{\mathrm{PCl_5}} \mathrm{Et(EtO)P(S)Cl}$$

$$\mathrm{Et(EtO)P(S){-}O{-}P(O)(OEt)Et}$$

---

* Neat compounds were used for all specific rotation determinations mentioned in the paper.

[1] J. Michalski and M. Mikołajczyk, *Chem. and Ind.*, 1964, 661.

[2] J. Michalski and A. Ratajczak, *Chem. and Ind.*, 1960, 1241; *Roczniki Chem.*, 1963, **37**, 1185.

[3] H. S. Aaron *et al.*, *J. Amer. Chem. Soc.*, 1962, **84**, 617.

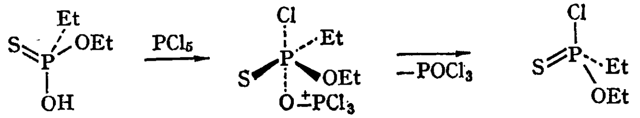
(III) in reaction (*a*) does not affect the asymmetric centre in acid (I). This conclusion is based on the well-established mechanism of condensation of this type.[4,5] The attack of the electrophilic phosphorus atom of (±)-*O*-ethyl ethylphosphonochloridate is directed on oxygen of the ambident anion derived from acid (I) and not on sulphur. The asymmetric centre P(S) in the resulting (+)-pyrophosphonothionate (III) has, therefore, the same configuration as the starting (−)-acid (I) and is assumed to have the same optical purity.

$$(\mathrm{IV}) \xleftarrow[(a')]{(\pm)\mathrm{Et(EtO)P(S)Cl}} (\mathrm{I}) \xrightarrow[(b)]{\mathrm{PCl_5}} (\mathrm{II}) \xrightarrow[(c')]{(+)\mathrm{Et(EtO)P(S)ONa}} (\mathrm{IV})$$

$$[\alpha]_{\mathrm{D}}^{20}\ +33{\cdot}90^\circ \qquad -14{\cdot}15^\circ \qquad -82{\cdot}80^\circ \qquad +32{\cdot}60^\circ$$

The comparison of the rotation value of pyrophosphonothionate (III) from reaction (*a*) with that of (III) prepared by the reaction sequence (*b–c*) indicates at least 97·5% optical purity of the chloride (II). Thus, the conversion of the (−)-acid (I) into (−)-chloride (II) should be 98·5% stereospecific if full stereospecificity of the reaction (*c*) can be assumed. However, some racemisation due to the chloride anion exchange is to be expected in this reaction. Reaction (*b*) seems, therefore, even more stereospecific than indicated above.

A similar reaction sequence has been studied with diethyl ethylpyrophosphonodithionate, (IV), Et(EtO)P(S)OP(S)(OEt)Et. The results indicate that the minimal stereospecificity of reaction (*b*) is 98%.



Since the (+)-pyrophosphonothionate (III) and (+)-pyrophosphonodithionate (IV) prepared by routes (*b–c*) and (*b–c′*) are equal in rotation sign to those obtained from reactions (*a*) and (*a′*), they must have a configuration identical to that of (−)-acid (I). This may be explained by assuming either subsequent inversions or retentions during the reactions (*b–c*) and (*b–c′*). The former possibility seems to be valid in this case. By making the very probable assumption that the reactions (*c*) and (*c′*) proceed with inversion,[6,7] the reaction of phosphorus pentachloride with acid (I) should follow the same stereochemical course. This is consistent with the result of alkaline hydrolysis of (−)-chloride (II) described before.[1]

As proved by thin-layer chromatography *O*-ethyl ethylphosphonochloridate is not formed in the reaction considered.[1] This is supporting evidence that the attack of phosphorus pentachloride is directed entirely on the oxygen atom, resembling the phosphorylation of thio-acids by means of acyl halides.[4,5,8] The possible phosphonium-type intermediate is then decomposed by the nucleophilic attack of the chloride anion co-linear with the leaving group.

The probable transition state of this displacement is that with bipyramidal structure similar to an S_N2 transition state with axial bonds *pd* weaker than sp^2 bonds in the basal plane.[9]

(*Received, December 29th,* **1964**.)

---

[4] R. A. McIvor, G. A. Grant, and C. E. Hubley, *Canad. J. Chem.*, 1956, **34**, 1611.

[5] J. Michalski, M. Mikołajczyk, and A. Ratajczak, *Chem. and Ind.*, 1962, 819.

[6] M. Green and R. F. Hudson, *Proc. Chem. Soc.*, 1959, 227; *J.*, 1963, 540, 3883.

[7] A. Ratajczak, *Bull. Acad. Polon. Sci., Sér. Sci. chim.*, 1964, **12**, 139, 145.

[8] M. I. Kabachnik *et al.*, *Zhur. obshchei Khim.*, 1956, **26**, 120, 2228.

[9] M. Green and R. F. Hudson, *Angew. Chem.*, 1963, **75**, 47.