

Infra-Red Absorption Spectra of Some Organic Phosphoryl Compounds

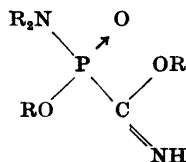
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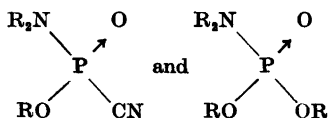
During the last fifteen years organo-phosphorus compounds have more and more attracted the interest of chemists. From 1934 and onwards G. Schrader¹ is said to have synthesized over 2000 new compounds submitted to bioassay. Some of these were so toxic that they were intended to be used as war-gases during World War II. Many of them have superseded the valuable nicotine as insecticides. Lately they have been used therapeutically in some diseases *e.g.* myasthenia gravis and glaucoma.

The phosphorus compounds of this type are potent enzyme inhibitors. The enzyme cholinesterase, vital to the transmission of nerve impulses in the body, is completely inhibited even by very minute amounts².

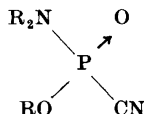
One of the most active substances is dimethylamido-ethoxy-phosphoryl cyanide (TABUN), the method of synthesis of which can be traced back to Schall³. However, he never seems to have recognized the true, chemical constitution of his compound. According to him the compound was an imino-ether with the following structure:



Michaelis⁴ in 1903 suggested that Schall had obtained a mixture of



Further work on the synthesis of this compound has been done by Schrader who adopted the formula



published in Protar (1948)⁵. Because the method of synthesis of dimethyl-amido-ethoxy-phosphoryl cyanide still leaves some doubt to its chemical structure, we have made an infra-red spectroscopical examination of this compound and some related derivatives. This method is a very suitable way to elucidate problems of this kind. In addition the purpose of the present study has been to determine the characteristic frequencies of the P-N linkage. Similar measurements of alkyl esters of phosphorus oxy-acids have recently been made for the P→O and P-O linkages by Meyrick and Thompson⁶.

EXPERIMENTAL

The absorption spectra of the phosphoryl compounds between 2.5 and 15.0 μ were recorded on a Beckman Infrared Spectrophotometer. It was equipped with rock salt optics and rock salt prism. The absorption cell sealed with an amalgam gasket had a thickness of the liquid sample of 0.10 mm. The compounds were dissolved in carbon tetrachloride which is a very good solvent owing to its weak absorption in this spectral region except between 12 and 14 μ where instead benzene solutions were used. The concentration of the solutions was 10 % except in the range 9–11 μ where 4 % solutions were used to get a better resolution of the very strong absorption bands in this part of the spectrum.

The compounds studied were synthesized at the Medical Section of the Research Institute of National Defence²:

	n_D^{20}	B. p.
Diethoxy-phosphoryl chloride	1.4177	68–70°/3 mm
Diethoxy-phosphoryl cyanide	1.4015	91.5–94°/11 mm
Diethoxy-phosphoryl amide	—	140°/3 mm
Dimethylamido-phosphoryl dichloride	1.4080	58–60°/4–5 mm
Dimethylamido-ethoxy-phosphoryl chloride	1.4380	70–74°/4–6 mm
Dimethylamido-ethoxy-phosphoryl cyanide (TABUN)	1.4250	100–108°/9 mm
Tetraethyl pyrophosphate (TEPP)	1.4184	132°/1.3
<i>sym</i> -Bis-(dimethylamido)-diethylpyrophosphate	1.4392	130°/1.5 mm

RESULTS AND DISCUSSION

Figs. 1 and 2 show the infra-red absorption spectra of the compounds examined. From these spectra one can observe some absorption frequencies which can be correlated with specific atomic configurations.

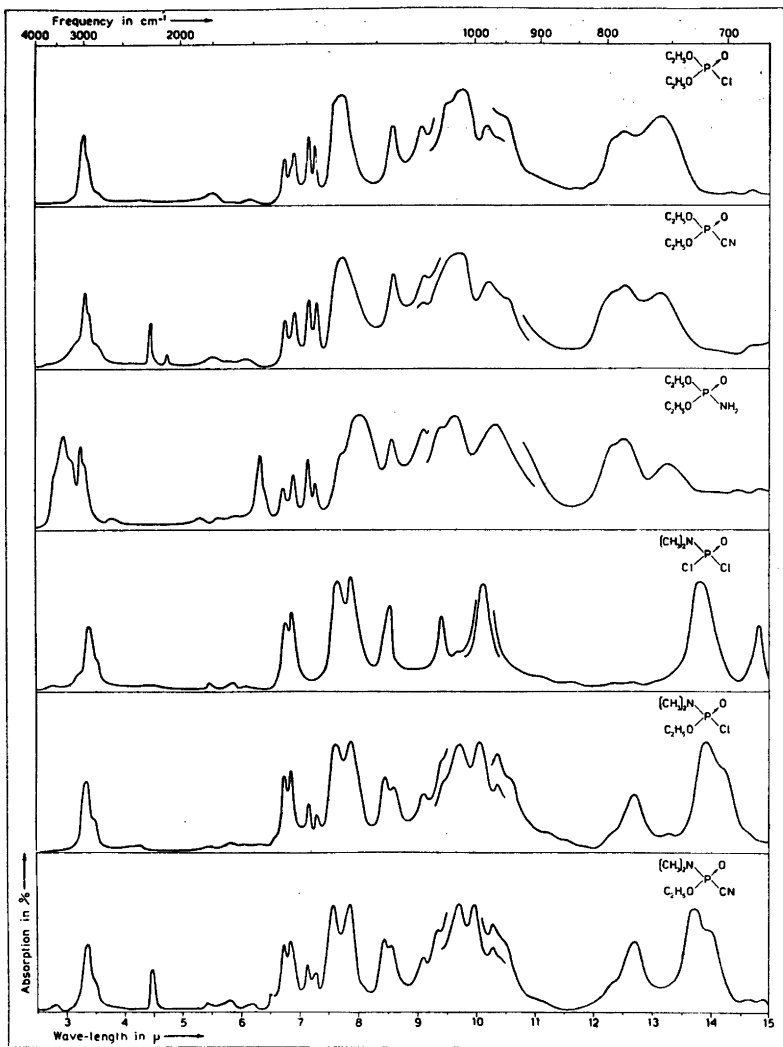


Fig. 1. Absorption curves of the phosphoryl compounds.

The absorption bands caused by the vibrations in the $>\text{CH}_2$ and $-\text{CH}_3$ groups occur in the normal positions: bondstretching vibrations in $>\text{CH}_2$ and $-\text{CH}_3$ at $3.27\text{--}3.55\ \mu$ ($3058\text{--}2817\ \text{cm}^{-1}$), bondbending vibrations in $-\text{CH}_3$ at $6.72\text{--}6.94\ \mu$ ($1488\text{--}1440\ \text{cm}^{-1}$) and bondbending vibrations in $>\text{CH}_2$ at $7.14\text{--}7.31\ \mu$ ($1400\text{--}1368\ \text{cm}^{-1}$).

The absorption band at $4.48\ \mu$ ($2232\ \text{cm}^{-1}$), occurring only in the spectrum of the two cyanogen compounds, can be assigned to the bondstretching vib-

Table 1. Absorption bands of the phosphoryl compounds.

λ = Wavelength in μ
 ν = Frequency in cm^{-1}
 s = strong, m = medium, w = weak

Diethoxy-phosphoryl chloride		Diethoxy-phosphoryl cyanide		Diethoxy-phosphoryl amide	
λ	ν	λ	ν	λ	ν
3.33	3 003 m	3.20	3 125 w	2.98	3 356 s
3.40	2 941 m	3.35	2 985 m	3.10	3 226 m
5.54	1 805 w	3.42	2 924 m	3.27	3 058 s
6.77	1 477 m	3.55	2 817 w	3.35	2 985 m
6.87	1 456 m	4.48	2 232 m	3.80	2 632 w
6.93	1 443 m	4.76	2 101 w	5.32	1 880 w
7.18	1 393 m	5.55	1 802 w	5.65	1 770 w
7.29	1 372 m	6.10	1 639 w	6.34	1 577 m
7.62	1 312 s	6.77	1 477 m	6.73	1 486 m
7.74	1 292 s	6.94	1 441 m	6.91	1 447 m
8.60	1 163 m	7.19	1 391 m	7.16	1 397 m
9.09	1 100 m	7.31	1 368 m	7.28	1 374 m
9.54	1 048 s	7.75	1 290 s	7.73	1 294 m
9.78	1 022 s	8.61	1 161 s	8.04	1 244 s
10.20	980 s	9.11	1 098 s	8.57	1 167 s
10.45	957 s	9.70	1 031 s	9.10	1 099 s
12.35	810 m	10.22	978 s	9.40	1 064 s
12.53	798 m	10.55	947 s	9.64	1 037 s
13.15	761 s	12.35	810 m	10.34	967 s
		12.55	797 s	12.35	810 s
		13.14	761 m	12.52	799 s
				13.26	754 m

rations in the $-\text{C}\equiv\text{N}$ linkage. The diethoxy-phosphoryl cyanide shows a band at 4.76μ (2101 cm^{-1}) also, which may be interpreted either as vibrations in the isocyanide group $-\text{N}=\text{C}$ obtained as a by-product in the synthesis or as vibrations in HCN formed by a partial hydrolysis of the compound. Both these groups may be surmised to cause absorption in this region.

All the phosphoryl derivatives show an absorption band in the region $7.57-8.04 \mu$ ($1321-1244 \text{ cm}^{-1}$). Most of them cause a doubling of the band. This absorption can be correlated with the stretching of the $\text{P}\rightarrow\text{O}$ bond, which has previously been established by Meyrick and Thompson. They also have attributed the double band at $12.20-12.70 \mu$ ($820-788 \text{ cm}^{-1}$) to the stretching vibrations of the $\text{P}-\text{O}$ linkage in the skeleton $\text{P}-\text{O}-\text{C}$.

Dimethylamido-phosphoryl dichloride		Dimethylamido-ethoxy-phosphoryl chloride		Dimethylamido-ethoxy-phosphoryl cyanide	
λ	ν	λ	ν	λ	ν
3.23	3 096 w	3.35	2 985 m	2.83	3 534 w
3.40	2 941 m	3.49	2 865 w	3.37	2 967 m
3.55	2 817 w	5.48	1 825 w	3.50	2 857 w
5.48	1 825 w	5.86	1 706 w	4.48	2 232 m
5.88	1 701 w	6.56	1 524 w	5.44	1 838 w
6.77	1 477 m	6.75	1 481 m	5.82	1 718 w
6.88	1 453 m	6.86	1 458 m	6.18	1 618 w
7.65	1 307 s	7.17	1 395 m	6.52	1 534 w
7.88	1 269 s	7.30	1 370 m	6.74	1 484 m
8.54	1 170 s	7.61	1 314 s	6.85	1 460 m
9.41	1 062 m	7.88	1 269 s	7.15	1 399 m
9.68	1 033 m	8.46	1 182 m	7.29	1 372 m
10.11	989 s	8.60	1 163 m	7.57	1 321 s
13.82	723 s	9.11	1 098 m	7.86	1 272 s
14.81	675 m	9.40	1 064 s	8.44	1 185 m
		9.70	1 030 s	8.57	1 167 m
		10.05	994 s	9.10	1 099 m
		10.36	966 s	9.34	1 071 s
		10.60	944 m	9.70	1 031 s
		12.35	810 w	9.96	1 004 s
		12.70	788 m	10.28	973 s
		13.30	752 w	10.45	956 m
		13.92	718 s	12.32	811 w
		14.25	702 s	12.70	788 m
				13.70	730 s
				13.95	716 s

In all the spectra of the dimethylamido compounds two absorption bands appear, which are absent from the spectra of all other derivatives. One occurs at 9.94—10.11 μ (1006—989 cm^{-1}) and the other, which in more complex compounds is split, at 13.70—14.25 μ (730—702 cm^{-1}). The latter absorption may be a result of the stretching vibrations of the P-N bond in the combination $\text{P-N} \begin{matrix} \diagup \text{C} \\ \diagdown \text{C} \end{matrix}$ analogously to the absorption of the P-O linkage mentioned above. The origin of the former absorption is still more difficult to derive, because the spectrum in this region is so complex. This absorption may possibly depend on the vibrations in the C-N bond. If the two methyl radicals in the amido group are exchanged for hydrogen, both the absorption bands disappear,

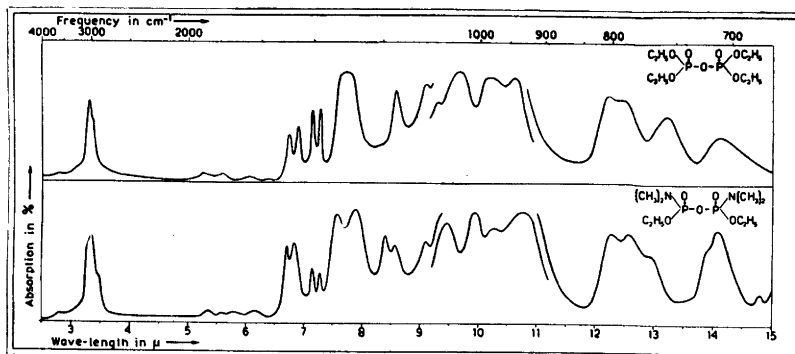


Fig. 2. Absorption curves of the derivatives of pyrophosphoric acid.

and instead the normal absorption bands of the —NH_2 bond are obtained at 2.98μ (3356 cm^{-1}) and 3.10μ (3226 cm^{-1}) caused by bondstretching vibrations and a band at 6.34μ (1577 cm^{-1}) attributed to the bondbending vibrations. To some extent this argument supports the hypothesis of the correlation between the P-N resp. C-N linkages and the stated absorption bands.

The absorption spectra of the two derivatives of pyrophosphoric acid show a close resemblance to the other spectra. However, an obvious difference is present at about 14.10μ (710 cm^{-1}). In order to verify whether this absorption may be associated with the stretching in the P-O linkage in the skeleton P-O-P, too few spectra have been recorded.

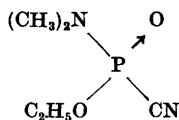
A rough computation by the aid of Hooke's law indicates that the absorption band arising from the stretching in the P-Cl bond can be expected to appear at about 14μ . An absorption referring to this vibration seems to be found only in the spectrum of dimethylamido-phosphoryl dichloride at 14.81μ (675 cm^{-1}). Analogously to the absorption of the C-Cl bond a displacement of the absorption of the P-Cl linkage to longer wavelengths is expected, and for that reason this absorption of the other chlorine compounds probably lies above 15μ .

From these results one can conclude, that the formula given by Schall is incorrect, because no absorption band assigning the imino group has been detected, while on the other hand the existence of the $\text{—C}\equiv\text{N}$ bond is evident. Neither can it be a question of a mixture, which was proposed by Michaelis. This is obvious on comparison between the spectra of dimethylamido-ethoxy-phosphoryl cyanide and of dimethylamido-ethoxy-phosphoryl chloride. These compounds are synthesized by two quite different methods, but their absorption spectra coincide perfectly with the exception of the absorption of the $\text{—C}\equiv\text{N}$ linkage. If the first mentioned compound should

Table 2. Absorption bands of the derivatives of pyrophosphoric acid.

Tetraethyl pyrophosphate				<i>sym</i> -Bis-(dimethylamido)-diethyl pyrophosphate			
λ	ν	λ	ν	λ	ν	λ	ν
3.10	3 226 w	8.56	1 168 s	2.80	3 571 w	8.57	1 167 m
3.30	3 030 s	9.07	1 103 s	3.28	3 049 m	9.10	1 096 m
3.37	2 967 m	9.29	1 076 s	3.35	2 985 s	9.46	1 057 s
5.25	1 905 w	9.65	1 036 s	3.46	2 890 m	9.94	1 006 s
5.60	1 786 w	10.18	982 s	5.36	1 866 w	10.26	975 s
6.74	1 484 m	10.60	943 s	6.16	1 623 w	10.74	931 s
6.90	1 449 m	12.20	820 s	6.72	1 488 m	12.27	815 s
7.14	1 401 m	12.40	806 s	6.85	1 459 m	12.56	796 s
7.27	1 376 m	13.18	759 m	7.15	1 399 m	12.92	774 m
7.70	1 299 s	14.10	709 m	7.28	1 373 m	13.90	719 m
				7.57	1 321 s	14.08	710 s
				7.90	1 266 s	14.80	675 w
				8.40	1 190 m		

be composed of a mixture of dimethylamido-ethoxy-phosphoryl cyanide and diethoxy-phosphoryl dimethylamide, this would be apparent by a stronger absorption of the $>\text{CH}_2$ group at 7.14—7.31 μ . However, this is not the case and the structure of dimethylamido-ethoxy-phosphoryl cyanide can be written:



The results obtained indicate the possibility of following the complete course of the hydrolysis, the knowledge of which is of great toxicological interest. By means of determination of liberated cyanide and simultaneous toxicity tests it has been possible to get a rough view of the inactivation of the described compounds by hydrolysis. Recently performed investigations in infrared made by us have confirmed that besides the splitting off of the cyanide group the P-N bond is split. More detailed examinations in this field are now in progress.

SUMMARY

The infra-red absorption spectra of six phosphoryl compounds and two derivatives of pyrophosphoric acid have been recorded and correlated with the molecular structure. Further the characteristic bands for the C-N and P-N linkages in the skeleton $\text{P-N} \begin{matrix} \diagup \text{C} \\ \diagdown \text{C} \end{matrix}$ at about 10.0μ resp. 14.0μ have been discussed and an absorption at about 14.1μ has been surmised to be characteristic for the P-O bond in the combination P-O-P.

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