

tion at 57–60° (0.05 mm.) afforded 5.07 g. of XLI: infrared spectrum 5.97 μ (s); mass spectrum (*m/e* values) 162 (d_0 , 5.5%), 163 (d_1 , 92.5%), and 164 (d_2 , 2%).

trans-2-Keto-10-methyl- Δ^6 -octahydronaphthalene-4 β - d_1 (XLII). To a solution of 2.0 g. of lithium in approximately 200 ml. of liquid ammonia was added dropwise a solution of 4.00 g. of the hexalone XLI in 100 ml. of anhydrous diethyl ether.³⁸ A Dry Ice-acetone condenser was used to maintain the liquid ammonia, but no external cooling was applied to the reaction flask. After addition was completed, the reaction was stirred for 2 additional hr., more ammonia being liquified during this time. Anhydrous diethyl ether was added and the condenser was removed. After most of the ammonia had evaporated, water was added and the two-phase system was separated. The aqueous phase was extracted with diethyl ether and the combined ethereal solution was washed with dilute hydrochloric acid and water. After drying over anhydrous magnesium sulfate, the solvent was evaporated under reduced pressure and the cloudy oil which remained showed two spots on thin layer chromatography and hydroxyl absorption in the infrared spectrum (2.92 μ). The crude product was subjected to chromic acid oxidation²³ to afford a yellow oil, which was distilled at 60–73° (0.15–0.25 mm.) to provide 2.85 g. of a colorless oil (XLII), higher boiling material being rejected. Thin layer chromatography showed only a single spot: infrared spectrum 5.85 (s) and 4.62 μ (w); mass spectrum (*m/e* values) 164 (d_0 , 4%), 165 (d_1 , 92.5%), and 166 (d_2 , 3.5%).

trans-3-Bromo-10-methyldecal-2-one-4 α - d_1 (XLIII) was synthesized from 128 mg. of the octalone XLII, as

(38) C. Djerassi, D. Marshall, and T. Nakano, *J. Am. Chem. Soc.*, **80**, 4853 (1958).

described in the preparation of the C-4 epimer X, to afford 110 mg. of crystalline material (XLIII), which was recrystallized from aqueous acetone: m.p. 136.5–139.5°; n.m.r., doublet centered at δ 4.67 and 4.90, $J = 14$ c.p.s.

Anal. Calcd. for $C_{11}H_{16}BrDO$: C, 53.66; H + D, 7.32. Found: C, 53.64; H + D, 7.14.

trans-9-Methyl- Δ^2 -octahydronaphthalene-8 β - d_1 (XLIV) was prepared from 2.40 g. of octalone XLII as reported for the synthesis of the epimer VI, to furnish a crude product which when distilled at 0.25 mm. below 55° afforded 1.26 g. of a colorless oil (XLIV): infrared spectrum 4.63 μ (w); mass spectrum (*m/e* values) 150 (d_0 , 4%), 151 (d_1 , 93%), and 152 (d_2 , 3%).

trans-1-Methylcyclohexane-1,2-diacetic-6 β - d_1 acid (XLV) was prepared from 1.19 g. of XLIV, as described for the synthesis of the isomer VII, to afford a solid, which when recrystallized from acetone provided 1.02 g. of XLV, m.p. 194–197°.

trans-8-Methylhydrindan-2-one-7 β - d_1 (XLVI). Catalytic pyrolysis of the diacid¹⁵ XLV (980 mg.), as described in the preparation of *trans*-8-methylhydrindan-2-one-7 α - d_1 (VIII), afforded a crude oil which was distilled at 35–50° (0.10 mm.) to furnish 431 mg. of a yellow oil. Redistillation at 40–50° (0.10 mm.) provided an oil (XLVI) which was shown to be homogeneous by vapor phase chromatography on a 5% diethylene glycol succinate on 60/80 firebrick column at 140°: mass spectrum (*m/e* values) 152 (d_0 , 4%), 153 (d_1 , 94%), and 154 (d_2 , 2%).

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The Structure of the So-Called "Ethyl Metaphosphate" (Langheld Ester)

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Phosphorus pentoxide reacts with diethyl ether to form mixtures of polyphosphate esters consisting of bicyclopolyphosphate ester (II), cyclotetrapolyphosphate ester (III), isocyclotetrapolyphosphate ester (IV), and tetrapolyphosphate ester (V). While the presence of reorganization products, especially tripoly- and pentapolyphosphate esters, cannot be unequivocally excluded, the consistency of all the measurements, including the absence of pyrophosphates, would be difficult to maintain if this had occurred to any large extent. The content of the tetrapolyphosphate esters in the mixtures

was calculated from ³¹P n.m.r. measurements with this assumption. The so-called ethyl metaphosphate (Langheld ester) is a mixture of III (45 to 50%), IV (25 to 36%), and V (14 to 30%). From the selective reaction rates one might expect that the effective reaction sites for dehydration polymerization would be the branched phosphorus atoms (P_b) found only in compounds II and IV. These particular compounds are the very ones most difficult to produce.

The product of the reaction of diethyl ether and phosphorus pentoxide,³ which is usually called ethyl meta-

(1) Postdoctoral fellow from Giessen University, Germany.

(2) The work described in this paper was sponsored in part by the U. S. Atomic Energy Commission.

(3) K. Langheld, *Ber.*, **43**, 1857 (1910); **44**, 2076 (1911).

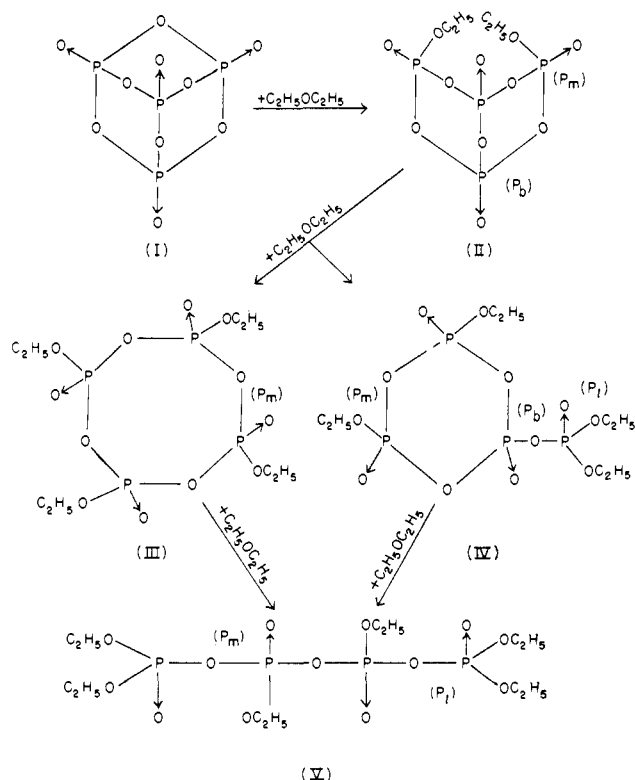


Figure 1. Reaction of P_4O_{10} with diethyl ether.

phosphate, has recently become interesting as a reagent for the synthesis of polysaccharides, polypeptides, and polynucleotides.⁴ However, several other attempts to synthesize the biologically important substances in that way gave inconsistent results.⁵⁻⁷ It is desirable that this controversy be clarified. To achieve the greatest applicability as a polymerizing reagent, the ethyl metaphosphate must be uniform and highly reproducible. Unfortunately, this has not been possible until now because of incomplete understanding of the nature of ethyl metaphosphate. Heretofore, the proposal of Rätz and Thilo⁸ that the ester is a mixture of cyclotetrapolyphosphate ester (Figure 1, structure III) and isocyclotetrapolyphosphate ester (Figure 1, structure IV) has been accepted, but the phosphorus n.m.r. spectrum of the product obtained by several groups does not conform to that assignment.^{9,10} In this paper, studies are described which were made to determine the actual composition of the so-called ethyl metaphosphate.

Langheld³ first prepared ethyl metaphosphate by refluxing phosphorus pentoxide with diethyl ether. This synthesis was improved by Steinkopf and Schubart¹¹ using chloroform as a solvent. Since then,

(4) G. Schramm, H. Grötsch, and W. Pollmann, *Angew. Chem.*, **74**, 53 (1962).

(5) G. Weill, University of California, Lawrence Radiation Laboratory, Bio-Organic Chemistry Quarterly Report, UCRL-10934, July 29, 1963, p. 79.

(6) N. K. Kochetkov, E. I. Budowsky, V. D. Domkin, and N. N. Khromov-Borissov, *Biochim. Biophys. Acta*, **80**, 145 (1964).

(7) T. M. Jacob and H. G. Khorana, *J. Am. Chem. Soc.*, **86**, 1630 (1964).

(8) R. Rätz and E. Thilo, *Ann.*, **572**, 173 (1951).

(9) J. R. Van Wazer, C. F. Callis, J. N. Shoolery, and R. C. Jones, *J. Am. Chem. Soc.*, **78**, 5715 (1956).

(10) G. Weill, M. P. Klein, and M. Calvin, *Nature*, **200**, 1005 (1963).

(11) W. Steinkopf and I. Schubart, *Ann.*, **424**, 1 (1921); see especially p. 19.

several additional methods have been described in the literature.^{4,8,12} They differ mainly in the time of heating and in the ratio of diethyl ether and chloroform in the reaction mixture.

However, in our experiments various products were obtained by heating diethyl ether and phosphorus pentoxide in chloroform, depending on the time of heating and on the amount of ether which was used. They ranged from a rubber-like material (B) through a very heavy oil (C) to an oil of lower viscosity (D) (Table I).

Table I. Properties and Phosphorus N.m.r. Peaks of the Materials Which Were Obtained by Reaction of P_4O_{10} with Diethyl Ether

Material	Description ^a	n_D^{20}	Density (20°)	Viscosity (20°), poise	% Phosphorus		
					P_m	P_b	P_t
A	Plastic-like	...	...	...	71.9	22.9	5.2
B	Rubber-like	...	...	...	78.7	9.8	11.5
C	Heavy oil	1.441	1.462	237.44	75.2	8.9	15.9
D	Viscous oil	1.438	1.413	19.45	73.4	6.2	20.4
E	Light oil	1.437	1.408	9.76	69.8	4.0	26.2
F	Oil	1.434	...	...	62.7	3.1	34.2
G	Oil	1.433	...	...	55.8	1.8	42.4

^a All soluble in $CHCl_3$, colorless to lightly brown.

The refractive index of the liquids varied from 1.441 (C) to 1.438 (D) (20°), and the viscosity from 237.44 (C) to 19.45 poises (D) (20°). Therefore, the description of ethyl metaphosphate as a mixture of *ca.* 10% compound III and *ca.* 90% compound IV⁸ cannot be entirely correct. This does not describe the different properties of our materials prepared by various methods. Furthermore, for the preparation of ethyl metaphosphate, 2 equiv. of diethyl ether are necessary. If only 1 equiv. or less of ether was used, a plastic-like material (A) was obtained, which was soluble in $CHCl_3$. Refluxing the solid material A with an excess of ether gave an oil with the refractive index 1.438 and with a viscosity of 25.23 poise. Thus, the solid product A could be an intermediate in the preparation of ethyl metaphosphate.

An insight into this problem is possible by means of phosphorus n.m.r. measurements. A phosphorus atom which is bonded to another phosphorus atom *via* an oxygen atom shows a different chemical shift in the n.m.r. spectrum than an atom which is bonded to zero, two, or three phosphorus atoms *via* oxygen. Thus each type of phosphorus should show a separate line, and the compounds with structures II to V can be expected to show three different peaks corresponding to the branched-bonded (P_b), the middle-bonded (P_m), and the terminal-bonded phosphorus (P_t).⁹

If the Langheld ester were a mixture of III and IV,⁸ the n.m.r. spectrum would show a large peak of middle-bonded phosphorus (P_m), and two smaller, but equal, peaks of terminal- (P_t) and branched-bonded phosphorus (P_b). But the spectrum obtained by Van Wazer⁹ showed only 3% P_b compared with 25% P_t . However, while Weill, Klein, and Calvin¹⁰ get a similar result from one preparation (with 6% P_b and 32% P_t), from another sample a value of 13% P_b and 15% P_t was obtained. It was thought that hydrolysis had taken place in those samples where a difference in the

(12) W. Pollmann and G. Schramm, *Biochim. Biophys. Acta*, **80**, 1 (1964).

sizes of the P_b and P_t was found. In our experiments, all materials showed a very small proton peak of an OH group at 12.1 p.p.m. in the proton n.m.r. spectra. This peak did not increase during the experiments. On the other hand, the relative amounts of OH and C_2H_5 groups, calculated from the areas under the n.m.r. peaks, changed in the series from A to G. It ranged from 1:8.3 (OH: C_2H_5) for material A through 1:13.7 for material D to 1:17.7 for material G. These values are not constant for each material; they changed slightly for each actual preparation. The contamination of the ethyl metaphosphate with a small amount of OH groups (which probably replace some of the ethyl groups of compounds II to V to a slight extent) must result from impurities in the phosphorus pentoxide.

Therefore, no hydrolysis could have taken place during the experiments (see also the Experimental section), but the phosphorus n.m.r. spectra generally showed different sizes of the P_b and P_t peaks, as can be seen from Table I and Figure 2.

Heretofore inconsistent molecular weight determinations of the ethyl metaphosphate have been reported. They ranged from two¹³ to six times¹⁴ the molecular weight of the monomeric ethyl metaphosphate.

Recently, one determination by an ebullioscopic method using chloroform as a solvent was published, giving a molecular weight of four times that of the monomeric form.¹² Our ebullioscopic measurements in chloroform (see Experimental) did not agree with this, but showed around six times that of the monomeric form. However, by using methyl acetate or acetonitrile as a solvent in which association is minimized,¹⁵ it could be clearly established that materials B to E have a molecular weight of approximately four times that of the monomeric form. Thus in chloroform associations occur which lead to apparent molecular weights higher than the actual. No suitable solvent was found for material A (see Experimental) and, therefore, no accurate determination could be achieved. But, since the molecular weight determinations of material A in chloroform gave the same results as those of materials B to E in chloroform and since all these similar materials should show the same tendency for association, there is good reason to assume that material A also has a molecular weight of four times that of the monomeric form. Consequently, the following can be concluded from the preparative, the analytical, and the n.m.r. results.

1. The material A, resulting from 1 equiv. of diethyl ether or less, is a mixture of compounds II¹⁶ (35.4%), III (43.8%), and IV (20.8%). The mixture can contain only a very small amount of compound V (if it does contain any at all) since the P_b peak is much larger than the P_t peak. This means that P_4O_{10} (I) reacts with diethyl ether to form compound II. At the same time, a further reaction of II to III and IV takes place. Compound II, therefore, is highly sen-

(13) E. Wertyporoch and H. Kiekenberg, *Biochem. Z.*, **268**, 8 (1934).
 (14) P. Pascal, *Bull. soc. chim. France*, [4] **33**, 1611 (1923); *Compt. rend.*, **176**, 1398 (1923).

(15) K. Rast in Houben-Weyl's "Methoden der organischen Chemie," 3/1, Georg Thieme Verlag, Stuttgart, 1955, p. 327.

(16) The possible formation of a compound with the structure II as a result of the reaction of P_4O_{10} with diethyl ether has already been suggested: M. Calvin, *Am. Inst. Biol. Sci. Publ.*, **12**, 29 (1962); see Figure 8 therein.

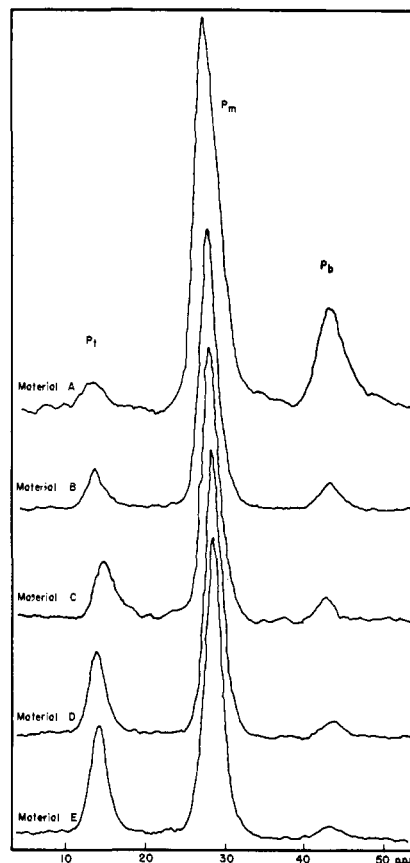


Figure 2. Phosphorus n.m.r. spectra of different samples of "ethyl metaphosphate." The abscissa is the chemical shift in p.p.m. from 85% H_3PO_4 .

sitive to an attack by diethyl ether. The content of the compounds II, III, IV, or V in the mixture, as given in the parenthesis and in Table II, can be easily

Table II. Composition of the Materials A-G

Material	Compd., %			
	II	III	IV	V
A	35.4	43.8	20.8	...
B	...	57.4	39.2	3.4
C	...	50.4	35.6	14.0
D	...	46.8	24.8	28.4
E	...	39.6	16.0	44.4
F	...	25.4	12.4	62.2
G	...	11.6	7.2	81.2

calculated from the n.m.r. results as explained in the Experimental section.

2. Material B, which was obtained with 2 equiv. of diethyl ether, is a mixture of III (57.4%) and IV (39.2%), with a small amount of V (3.4%). The observation that the reaction of P_4O_{10} with a single equivalent of diethyl ether to produce material A implies that a further reaction of II with ether occurred, leading to the formation of III and IV. Thus, no appreciable amount of II can be expected to remain in material B. The rings of compounds III and IV are opened by diethyl ether to form the chain compound V to some extent, giving rise to a larger amount of terminal phosphorus (P_t) than branched phosphorus (P_b). Compounds III and IV must be very sensitive

to nucleophilic substances, since they were even attacked slowly by such a very weak nucleophile as diethyl ether. This is confirmed by hydrolytic studies.^{10,17}

3. With an excess of diethyl ether we get a mixture, mainly III with smaller amounts of V and IV. This is the material which has been observed most often, and is called ethyl metaphosphate (in our experiments, materials C and D).

4. Refluxing of the ester with diethyl ether converts more of the compounds III and IV into V. The material E obtained by refluxing for 65 hr. consists of III (39.6%) and V (44.4%) with a smaller amount of IV (16.0%). After a longer time of refluxing, materials were obtained which consist mainly of V (materials F and G). There can be no considerable attack by diethyl ether of compound V leading to 2 moles of tetraethyl pyrophosphate. Extraction of material E with carbon tetrachloride gave a liquid (n_{20}^D 1.431) which showed 44.0% P_t , 55.5% P_m , and 0.5% P_b in the phosphorus n.m.r. spectrum. Tetraethyl pyrophosphate (100% P_t) is easily soluble in carbon tetrachloride but compounds III (100% P_m) and IV (50% P_m , 25% P_t , and 25% P_b), as contained in material B, are nearly insoluble in this solvent. Thus, the CCl_4 extract, which was small, cannot be a mixture of tetraethyl pyrophosphate and compound III and a trace of IV, but can consist of compound V (50% P_t , 50% P_m) contaminated with a small amount of III and a trace of IV. This indicates that no considerable amount of tetraethyl pyrophosphate is present in the mixture and shows that hexaethyl tetrapolyphosphate is soluble to some extent in CCl_4 . Further investigations of this separation are in progress.

The results of Schwarzmann and Van Wazer¹⁸ demonstrating slow structural reorganization in mixtures of triethyl phosphate and P_4O_{10} suggest that similar processes might have occurred in our materials. Thus the initial cyclic and linear tetrapolyphosphate esters conceivably could have undergone some rearrangements to pyro-, tripoly-, pentapoly-, and hexapolyphosphate esters. However, no tetraethyl pyrophosphate was found in mixture E where it should have been present if any rearrangement had occurred. No single type of measurement permits us to determine if these processes could occur at very low rates. However, no changes in n.m.r. spectra were observed over a period of several weeks. The entire complex of measurements (n.m.r., molecular weights, elemental analysis, and reaction rates) suggests, therefore, that if reorganization has occurred at all it can be only to a very limited extent. The absence of significant quantities of tetraethyl pyrophosphate suggests that the rate of rearrangement of the linear tetrapolyphosphate under our conditions cannot be very high. It also makes it unlikely that significant amounts of tripoly- and pentapolyphosphate esters are hidden in the calculations of the amount of compound V. Therefore, all the quantitative statements, as given in Table II, are based on the presumption of the absence of such processes at a significant rate.

5. P_4O_{10} does not readily react with V, IV, and III to form II. Only decomposition of the esters takes place on prolonged heating.

(17) Unpublished results from this laboratory.

(18) E. Schwarzmann and J. R. Van Wazer, *J. Am. Chem. Soc.*, **83**, 365 (1961).

In earlier papers,^{8,12} the composition of ethyl metaphosphate was studied by using hydrolytic destruction of the ester.^{18a} By this method, an amount of isocyclo-tetrapolyphosphate ester (IV) is estimated higher than is actually present, *i.e.*, total hydrolysis of compound III gives 4 moles of ethyl dihydrogen phosphate, or four primary and four secondary acid groups; compound IV gives 2 moles of ethyl dihydrogen phosphate, 1 mole of diethyl hydrogen phosphate, and 1 mole of phosphoric acid, or four primary, three secondary, and one tertiary acid groups; and compound V gives 2 moles of ethyl dihydrogen phosphate and 2 moles of diethyl hydrogen phosphate, or four primary and two secondary acid groups. If the amounts of compounds III and IV are calculated from the amount of diethyl hydrogen phosphate⁸ or from the amount of secondary acid groups,¹² total hydrolysis of pure compound V would appear to have more of compound IV in the mixture than is actually present. Thus, in previous measurements, 85¹² and 90%⁸ of compound IV for two actual preparations were inferred. Actually, the content of compound IV probably never exceeds about 40%.

Although the methods used in ref. 3, 8, and 11 for the preparation of mixtures of tetrapolyphosphate esters (or Langheld ester) give up to 70% yield, they are unsatisfactory because they often lead to a rubber-like material, as we have found. This may result from a loss of diethyl ether during refluxing. The method used in ref. 4 requires an excess of diethyl ether and a very long refluxing time. We found that at 25 hr. the reaction is far from complete. The reason for this is that ethyl metaphosphate is soluble in chloroform but insoluble in the excess diethyl ether solvent mixture here employed. Ethyl metaphosphate covers the surface of the P_4O_{10} and prevents further reaction of P_4O_{10} with diethyl ether. A more satisfactory procedure, as described below, leading to a nearly 100% yield of tetrapolyphosphate esters, results from treating most of the P_4O_{10} with a small amount of diethyl ether in chloroform to form first compound II, and then allowing compound II to react with additional diethyl ether to form III, IV, and V.

It is to be expected that compounds II, III, IV, and V will differ in their capabilities and effectiveness in producing the dehydration polymerization reaction. From the relative reaction rates, one might expect that the effective reaction sites would be the branched phosphorus atoms (P_b) found only in compounds II and IV. These particular compounds are the very ones most difficult to produce. The compounds and polymers produced by the use of ethyl metaphosphate may therefore be expected to depend sharply upon the methods used in preparing and handling the ethyl metaphosphate, a suggestion which would account for the variable results reported.⁴⁻⁷ We are currently attempting to separate each of the compounds from the mixture and will study the susceptibility of each of the separate polyphosphate esters, as well as their mixtures, to nucleophilic reactions with ethers, alcohols, amines, esters, sulfides, etc.

(18a) NOTE ADDED IN PROOF. New hydrolytic studies of ethyl metaphosphate recently have been published by W. Winkler, H.-P. Walter, and E. Thilo (*Ber.*, **97**, 2385 (1965)). The presence of OH groups in their original materials, which are probably distributed statistically in structures II to V, must lead to a variety of hydrolytic products which were actually found by these workers.

Experimental

All experiments were carried out under nitrogen which had been dried over P_4O_{10} in an apparatus which had previously been dried by heating under vacuum and which then was closed with a $CaCl_2$ tube.^{19,20} The n.m.r. tubes were dried by heating and were sealed as soon as filled. The viscosity was measured with a falling-ball viscometer (Hoeppler viscosimeter HV 303), the density was measured by weighing 25 ml. of the ester, and the refractive index was obtained with an Abbe refractometer (Spencer refractometer). The chloroform was purified from ethanol by shaking with water, then dried by shaking and by refluxing with P_4O_{10} ; after distillation phosgene was removed by refluxing with diphenylamine, and HCl was removed by the addition of aniline and distillation through a column. The diethyl ether was dried with sodium and then distilled over lithium aluminum hydride. Phosphorus pentoxide (Baker and Adamson) was used.

Material A. P_4O_{10} (124 g., 0.437 mole), 150 ml. of $CHCl_3$, and 32.4 g. (45.4 ml., 0.437 mole) of diethyl ether were refluxed for 15 hr. The mixture was filtered, and from the filtrate the solvent was evaporated under vacuum to a final pressure of 0.5 mm. A slightly yellow plastic resulted which was soluble in $CHCl_3$, yielding 62 g. (39.6%, calculated for $C_4H_{10}O_{11}P_4$).

Anal. Calcd. for $C_8H_{20}O_{12}P_4$ (432.16): C, 22.24; H, 4.66; P, 28.67. Calcd. for $C_4H_{10}O_{11}P_4$ (358.04): C, 13.42; H, 2.81; P, 34.61. Found: C, 16.1; H, 3.9; P, 32.0.

Material B. P_4O_{10} (55 g., 0.194 mole), 100 ml. of chloroform, and 28.5 g. (40 ml., 0.385 mole) of diethyl ether were refluxed for 15 hr. Filtration and evaporation of the solvent from the filtrate gave a heavy oil. Removal of the rest of the solvent at a pressure of 0.5 mm. gave a rubber-like material, soluble in $CHCl_3$, which yielded 54.6 g. (65.2%, calculated for $C_8H_{20}O_{12}P_4$).

Anal. Calcd. for $C_8H_{20}O_{12}P_4$ (432.16): C, 22.24; H, 4.66; P, 28.67. Found: C, 20.0; H, 5.0; P, 29.9; mol. wt., 429.6, 443.1 (in methyl acetate).

Material C. P_4O_{10} (114 g., 0.4 mole), 148 g. (208 ml., 2.0 mole) of diethyl ether, and 100 ml. of chloroform were refluxed with vigorous stirring for 25 hr. The mixture was filtered from the undissolved P_4O_{10} and the diethyl ether and chloroform were removed from the filtrate by evaporation (at least at a pressure of 0.5 mm.). A highly viscous oil was obtained which yielded 120 g. (69.4%, calculated for $C_8H_{20}O_{12}P_4$).

Anal. Calcd. for $C_8H_{20}O_{12}P_4$ (432.16): C, 22.24; H, 4.66; P, 28.67. Calcd. for $C_{12}H_{30}O_{13}P_4$ (506.27): C, 28.47; H, 5.97; P, 24.47. Found: C, 21.5; H, 5.5; P, 28.4; mol. wt., 435.0, 452.0 (in methyl acetate).

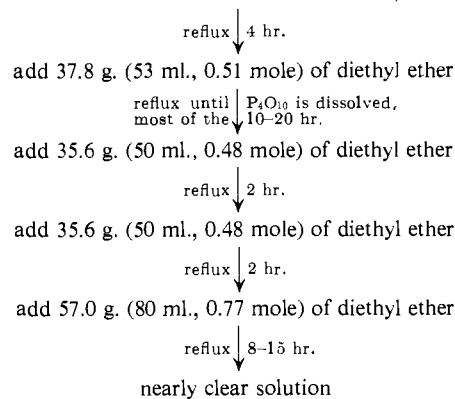
Material D. Material A (156.8 g.) was dissolved in 120 ml. of $CHCl_3$ and 142.7 g. (200 ml., 1.93 mole) of diethyl ether was added. After 10 hr. of refluxing, the chloroform and excess ether were evaporated. An oil was obtained which had the same refractive index, viscosity, and phosphorus n.m.r. spectrum as the material prepared as described in the next section, and yielded 175 g.

(19) H. Metzger and E. Müller in Houben-Weyl's "Methoden der Organischen Chemie," 1/2, Georg Thieme Verlag, Stuttgart, 1959, p. 321.

(20) K. Ziegler and co-workers, *Ann.*, **629**, 1 (1960).

Material D. (New method for the preparation of ethyl metaphosphate). We summarize the procedure in the following flow diagram.

145 g. (0.51 mole) of P_4O_{10} + 300 ml. of $CHCl_3$ + 37.8 g. (53 ml., 0.51 mole) of diethyl ether



(We suppose that the small undissolved residue contains compounds resulting from impurities in the phosphorus pentoxide, such as highly polymeric polyphosphoric acids.)

After filtration, the $CHCl_3$ and excess diethyl ether were removed by evaporation under vacuum and the oil which resulted was freed of the solvent at 0.2 mm., yielding 218.0 g. (99%, calculated for $C_8H_{20}O_{12}P_4$). The $CHCl_3$ and excess diethyl ether can be reused after fractional distillation. If the polyphosphate ester is dissolved in $CHCl_3$ and precipitated by adding diethyl ether, the oil then obtained shows the same phosphorus n.m.r. spectrum as the original ester. On exposure to moisture, a small amount of a material could be observed which was insoluble in chloroform and contained a larger quantity of OH groups and of P_t phosphorus.

Anal. Calcd. for $C_8H_{20}O_{12}P_4$ (432.16): C, 22.24; H, 4.66; P, 28.67. Calcd. for $C_{12}H_{30}O_{13}P_4$ (506.27): C, 28.47; H, 5.97; P, 24.47. Found: C, 22.2; H, 4.7; P, 28.3; mol. wt., 459.2, 474.7 (in methyl acetate); 445.3, 448.9, 457.3, 480.4 (in acetonitrile).

Material E. Material D (15 g., 0.035 mole) was dissolved in 15 ml. of $CHCl_3$. Diethyl ether (20.6 g., 29 ml., 0.28 mole) was added and the mixture was refluxed for 65 hr. After filtration and the removal of the ether and $CHCl_3$ under vacuum (final pressure at 0.5 mm.) a light fluid oil was obtained, which yielded 15 g.

Anal. Calcd. for $C_8H_{20}O_{12}P_4$ (432.16): C, 22.24; H, 4.66; P, 28.67. Calcd. for $C_{12}H_{30}O_{13}P_4$ (506.27): C, 28.47; H, 5.97; P, 24.47. Found: C, 23.5; H, 5.2; P, 27.7; mol. wt., 461.3, 499.5 (in methyl acetate); 456.6, 483.3, 495.2, 530.8 (in acetonitrile).

The same procedure, but with refluxing for 145 hr. or 220 hr., respectively, to materials F and G.

Molecular weight determinations were carried out by an ebullioscopic method using the apparatus of Sucharda and Bobranski.¹⁵ Measurements in chloroform gave the values found in Table III.

The molecular weights of materials B to E obtained in methyl acetate, and of materials D and E obtained in acetonitrile, are listed together with the other analytical data for these materials. Approximately 0.7 to 1.2 g. of substance dissolved in 14 g. of methyl acetate or 1.5 to

Table III

Material	Mol. wt. found	Concentration of solution, g. substance in g. CHCl ₃
A	613.0	1.1759-22.0973
	768.8	1.7813-22.0090
D	601.6	1.0264-24.3599
	727.7	2.4065-21.1223
E	665.2	2.2251-21.9102
	683.3	1.3468-24.1594

5.0 g. dissolved in 14 g. of acetonitrile was used. No reaction between the solvents and materials B to E occurred during the determinations, as evidenced by ³¹P n.m.r. measurements. Material A was decomposed partly in methyl acetate as well as in acetonitrile. No other suitable solvents for material A could be found.

Determinations by means of an osmometer failed; entirely unsatisfactory data were obtained, probably resulting from some hydrolysis of the very small amount of substance which is used during the determinations.

N.m.r. Measurements. All the phosphorus n.m.r. measurements were made with the Varian V-4300-C spectrometer operating at 24.6 Mc./sec., in conjunction with an apparatus for "continuous averaging."²¹

The curves were cut out and weighed for quantitative analysis. The chemical shifts 16, 29, and 42 for

(21) M. P. Klein and G. W. Barton, Jr., *Rev. Sci. Instr.*, **34**, 754 (1963).

P_t, P_m, and P_b are identical with those published in earlier papers^{9,10} (compared to 85% phosphoric acid as external standard). The proton n.m.r. measurements were made with the Varian A-60 spectrometer.

Calculation of the Ratio of the Compounds II, III, IV or III, IV, V in the Products from the Ratio of the N.m.r. Peaks of P_b, P_m, P_t. To illustrate the manner by which the relative amounts of the various components, in mole per cent, were determined from the n.m.r. spectra, we give a sample calculation. In mixture B, for example

$$P_m + P_t + P_b = \Sigma P_B$$

where P_i refers to the area under the *i*th peak and is proportional to the number of P_i atoms; material B is composed of compounds II, IV, and V; P_m occurs in II, IV, and V; P_t occurs in IV and V; P_b occurs in IV only; in IV, P_b = P_{tIV} and P_{mIV} = P_{tIV} + P_b; in V, P_{tV} = P_{mV} and P_{tV} = ΣP_t - P_{tIV}.

Experimentally P_b/ΣP_B = 9.8%; P_m/ΣP_B = 78.7%, and P_t/ΣP_B = 11.5%. Therefore

$$IV = P_b + P_{tIV} + P_{mIV} = 9.8 + 9.8 + 19.6 = 39.2\%$$

$$V = 2(\Sigma P_t - P_{tIV}) = 2(11.5 - 9.8) = 3.4\%$$

$$III = \Sigma P_m - P_{mIV} - P_{mV} = 78.7 - 19.6 - 1.7 = 57.4\%$$

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The Structure of Sugar Osazones¹

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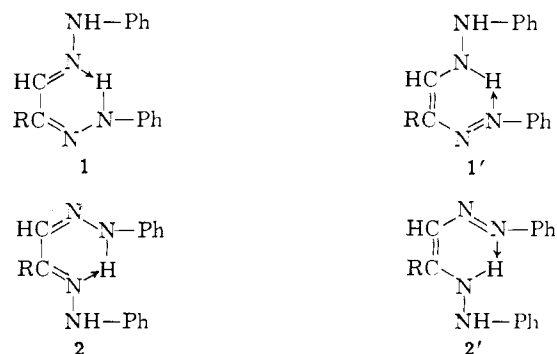
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The open-chain chelate structure of sugar osazones, first proposed by Fieser and Fieser, is confirmed now by n.m.r. spectral data. A long-range, spin-spin coupling between the C-1 proton and the nonchelated NH proton was observed, which is a decisive proof in favor of the **1** and **1'** chelate structures. Additional support came from deuteration and high-resolution n.m.r. spectroscopy (100 Mc.) using the double resonance method. A quasi-aromatic structural formula is advanced.

The structure of sugar osazones and related compounds was controversial for a long time. On theoretical grounds Fieser and Fieser² proposed two alternate chelate structures **1** and **2**, these being stabilized by their ability to exist in the tautomeric forms **1'** and **2'**.

(1) Paper presented at the International Carbohydrate Symposium, July 13-17, 1964, Münster (Westfalen), Germany.

(2) L. F. Fieser and M. Fieser, "Organic Chemistry," D. C. Heath and Co., Boston, Mass., 1944, p. 353.



The first chemical evidence supporting the open-chain chelate structure was advanced by Mester,^{3a} who also favored³⁻⁵ structure **1**. Additional support

(3) (a) L. Mester, *J. Am. Chem. Soc.*, **77**, 4301 (1955); (b) L. Mester and A. Major, *ibid.*, **79**, 3232 (1957).

(4) B. Jambor and L. Mester, *Acta Chim. Acad. Sci. Hung.*, **9**, 485 (1956).

(5) L. Mester and F. Weygand, *Bull. soc. chim. France*, 350 (1960).