

ever, that the acylation step in the mechanism of chymotrypsin is accompanied by a number of rather remarkable changes in properties of the side chain functional groups; deacylation must restore them to their original state. It is not unreasonable to attribute these changes to conformational alterations occurring at least in the region of the active center of the enzyme. We can conclude also that at least one of the functional groups involved in the acylation step of the catalytic mechanism is in an "abnormal" state due to the influence of neighboring groups. One wonders, therefore, about the applicability to the elucidation of enzyme mechanisms of information derived from studies on simple model compounds. It is becoming apparent that enzyme mechanisms exploit the capacity of proteins, as macromolecules, to assume special conformations, not only as a means of inducing specificity of binding, but also to enhance or suppress the activities of side-chain functional groups participating in the catalytic mechanism itself.<sup>11a</sup>

(11a) NOTE ADDED IN PROOF.—Titration to pH 3.5 was recently carried out using 0.011 *N* HCl containing 0.1 *M* KCl subsequent to the inactivation of 2.4  $\mu$ moles of chymotrypsin by 2.4  $\mu$ moles of I in 10 ml. of a solution containing 0.02 *M* CaCl<sub>2</sub>, 0.1 *M* KCl and 3% isopropyl alcohol at pH 7.0, 15°, and the results compared with a control chymotrypsin solution lacking I. Between pH 6.4 and 4.8, chymotrypsin consumed approximately one mole of acid than did DPC-chymotrypsin. However, within the pH range 4.8 to 3.5, DPC-chymotrypsin required approximately one additional mole of acid. These results suggest a shift in the *pK* of a carboxyl group from ca. 5.5 to ca. 3.7 as a result of the acylation reaction, possibly because of the disruption of a hydrogen bond.

(12) The support of the Office of Naval Research (Nonr-266 (73)) and the National Institute of Health AI-01672-06 is gratefully acknowledged.

DEPARTMENT OF MICROBIOLOGY      BERNARD F. ERLANGER<sup>12</sup>  
COLLEGE OF PHYSICIANS AND SURGEONS      HARRIET CASTLEMAN  
COLUMBIA UNIVERSITY      A. G. COOPER  
NEW YORK 32, N. Y.

RECEIVED APRIL 12, 1963

## A New Organometallic Semiconductor

Sir:

Although a variety of conjugated organic molecules are known to act as semiconductors, the carrier mobilities in them usually are very low. This is due to the difficulty electrons experience in jumping from one molecule to another, and so the carrier mobility in compounds of this kind increases with increasing molecular size.<sup>1</sup>

On this basis one would expect coordination polymers to show interesting electrical properties, if prepared from a suitable transition metal and a double aromatic ligand capable of binding two metal atoms at different points. For easy conduction throughout the polymer, each metal atom must provide a conducting path for  $\pi$ -electrons from one adjacent ligand to the other; this will be the case if the ligands are coplanar, the metal forming  $d\pi:p\pi$  bonds to both ligands by the same *d*-orbital. This in turn requires that the ligands be of chelate type, and that the metal forms either square planar complexes (*e.g.*, Cu<sup>II</sup>, Ni<sup>II</sup>), or octahedral complexes in which two opposite sites are occupied by ligands of some other kind. The former alternative seems much the more attractive, the more so since such complexes are commonly linked by metal-metal bonds perpendicular to the plane (*cf.* nickel dimethylglyoxime); bonds of this kind would tend to increase the mobility of electrons between adjacent molecules.

(1) For reviews, see D. D. Eley and M. R. Willis, and H. Akamatu and H. Inokuchi, in H. Kallmann and M. Silver, Ed., "Symposium on Electrical Conductivity in Organic Solids," Interscience Publishers, New York, N. Y., 1961, pp. 257, 277; H. A. Pohl, p. 134; H. A. Pohl, J. A. Bornmann, and W. Itoh, in J. J. Brophy and J. W. Buttrely, Ed., "Organic Semiconductors," Macmillan Co., New York, N. Y., 1962, pp. 134-142.

Very few coordination polymers of this type have been prepared and little has been done on their electrical properties; an exception is the work of Kanda and Kawaguchi,<sup>2</sup> who studied the copper derivatives of 1,6-dihydroxyphenazine, 2,5-dihydroxy-*p*-benzoquinone and rubeanic acid. It is also known that copper polyphthalocyanin is a semiconductor, but this is not a true coordination polymer; in it the monomer units are linked by carbon-carbon bonds rather than by metal coordinate links. Most of the true coordination polymers that have been prepared have been made either from "insulating" double ligands (where there can be no through-conjugation between the metal atoms) or from metals of unsuitable types (*e.g.*, ones forming tetrahedral complexes). The object of these investigations has been to prepare thermally stable polymers rather than semiconductors.

We became interested in this problem while studying electron transfer processes in aromatic compounds, our idea being that polymers of this kind might act as catalysts for electron transfer processes. We now wish to report the synthesis of a new organometallic semiconductor of this kind, the cupric derivative of the dioxime of 1,5-diacetyl-2,6-dihydroxynaphthalene. The dioxime, prepared in the usual way from 1,5-diacetyl-2,6-dihydroxynaphthalene, had m.p. 247-248° (*Anal.* Calcd. for C<sub>14</sub>H<sub>14</sub>N<sub>2</sub>O<sub>4</sub>: N, 10.2. Found: N, 10.0). It reacted with cupric acetate in the presence of acetic acid to form a dark brown solid, m.p. >300°, insoluble in all the usual solvents (*Anal.* Calcd. for C<sub>14</sub>H<sub>12</sub>N<sub>2</sub>O<sub>4</sub>Cu)<sub>n</sub>: C, 50.1; H, 3.58; N, 8.35; Cu, 18.9. Found: C, 50.1; H, 4.15; N, 8.15; Cu, 17.4). The copper content indicates a degree of polymerization of about ten. The conductivity of the polymer was measured in compressed disks (prepared at about 9 × 10<sup>4</sup> p.s.i.) at room temperature. Three samples of the polymer, prepared in different experiments, had resistivities of 8.6 × 10<sup>7</sup>, 7.4 × 10<sup>7</sup> and 8.0 × 10<sup>7</sup> ohm-cm. We have not yet been able to measure the resistivity as a function of temperature, but an indication of the energy gap seems to be given by the spectrum of the compound in potassium bromide or iodide disks. In each case absorption began at 2.2  $\mu$  and increased steadily with decreasing wave length. An absorption edge at 2.2  $\mu$  would correspond to an energy gap of 0.56 e.v.; this would give a value of  $\rho_0 = 1.8 \times 10^3$  ohm-cm., comparable with the values reported by Akamatu and Inokuchi<sup>1</sup> for very large aromatic systems. We are extending our studies to other polymers of this type.

**Acknowledgment.**—This work was supported by a grant (AF 62-104) from the Air Force Office of Scientific Research.

(2) S. Kanda and S. Kawaguchi, *J. Chem. Phys.*, **34**, 1070 (1961).

GEORGE HERBERT JONES LABORATORY      MICHAEL J. S. DEWAR  
UNIVERSITY OF CHICAGO      AMBALAL M. TALATI  
CHICAGO 37, ILLINOIS

RECEIVED MARCH 20, 1963

## Cyclic Phosphate Esters from the Hydrolysis of Cyclic Oxyphosphoranes. Evidence for Pentavalent Phosphorus in the Oxyphosphoranes<sup>1</sup>

Sir:

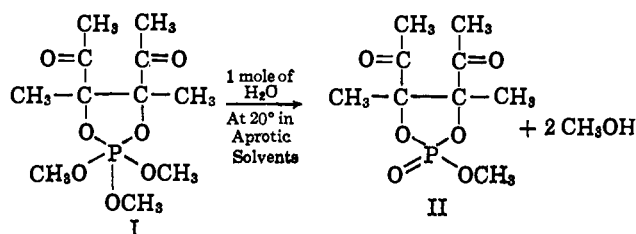
We have proposed<sup>2</sup> a cyclic *oxyphosphorane* structure (I) with pentavalent phosphorus, for the crystalline 2:1 *adduct* derived from biacetyl and trimethyl phosphite. This structural hypothesis (I) was based on

(1) Work supported by the Cancer Institute of the National Institutes of Health (CY-4769); the National Science Foundation (G19509) and the Petroleum Research Fund of the American Chemical Society (286-A).

(2) F. Ramirez, N. Ramanathan and N. B. Desai, *J. Am. Chem. Soc.*, **84**, 1317 (1962).

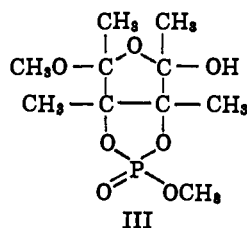
physical data; we now wish to present chemical evidence to substantiate it.

The crystalline 2:1 biacetyl-trimethyl phosphite adduct<sup>2</sup> (I) underwent a very rapid and exothermic reaction with one mole equivalent of water at 20° in aprotic solvents. The course of the hydrolysis was followed in carbon tetrachloride solution by means of quantitative infrared spectrometry: the first detectable products were the diketol cyclic phosphate (II) and two mole equivalents of methanol. Very little open phosphate ester was produced. The crystalline cyclic phosphate (II) was isolated in about 85% yield after 5 min. when the hydrolysis was performed in ether or benzene.

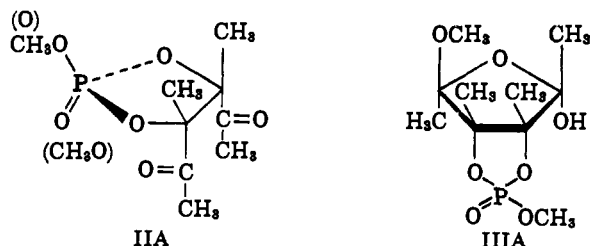


If the adduct I had an open dipolar structure, with tetravalent phosphorus, the product of the hydrolysis would have been an open phosphate ester; the latter should not undergo an instantaneous cyclization under the conditions of these experiments.

The methanol formed in the hydrolysis of the adduct I adds slowly to the carbonyl function of the diketol cyclic phosphate (II). Thus, a crystalline cyclic hemiketal phosphate (III) was isolated in about 70% yield when the original ether or benzene solution was kept several hours at 20°.



The ready formation of the hemiketal III shows that the two acetyl groups in the diketol phosphate II are *cis* to each other; the latter must then have the *meso*-configuration IIA. One of the four possible diastereomers of the hemiketal III is shown in formula IIIA, which emphasizes the furanose-cyclic phosphate character of this substance.



The H<sup>1</sup> n.m.r. spectrum of a *freshly prepared* solution of the diketol phosphate IIA is shown in Fig. 1. (upper half). The four expected lines can be seen: a doublet at 6.07  $\tau$  ( $J_{HP} = 12$  c.p.s.) due to the CH<sub>3</sub>OP group, a singlet at 7.65  $\tau$  due to the equivalent acetyls, and a singlet at 8.42  $\tau$  due to the equivalent methyls. The same solution, kept in a sealed tube, was re-examined after some time and gave the spectrum shown in Fig. 1 (lower half). The aged solution gave eight lines: one set of four as in the fresh solution, and a weaker set (*ca.* 3/4 intensity) at 6.15  $\tau$  ( $J_{HP} = 12$  c.p.s.); 7.70 and 8.35

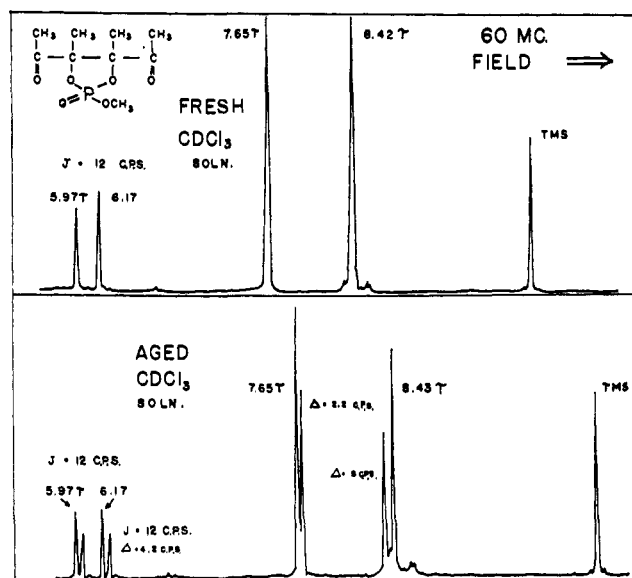
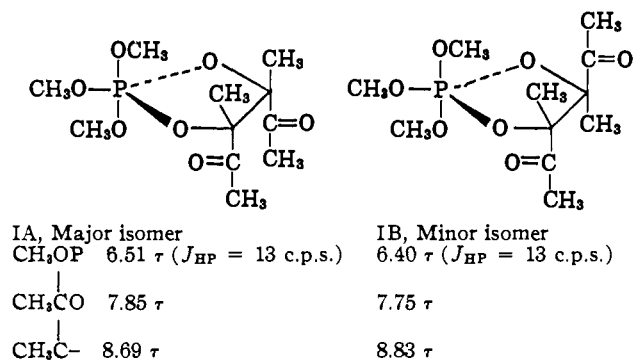


Figure 1.

$\tau$ . No major changes were detectable in the infrared spectrum of the aged solution. This behavior is consistent with a facile *stereoisomerization at phosphorus* in the cyclic phosphate IIA which alters somewhat the environment of the three different types of protons. The isomerization may be catalyzed by traces of methanol; its mechanism is being scrutinized.

The hydrolysis of the oxyphosphorane I does not affect the carbon-oxygen bonds. Therefore, the crystalline 2:1 adduct formed as the major product in the condensation of biacetyl with trimethyl phosphite<sup>2</sup> must have the *meso*-configuration, IA, since it yields the *meso*-phosphate (IIA) on hydrolysis. The liquid 2:1 adduct formed<sup>2</sup> as the minor isomer in this condensation should be the racemic form IB. The H<sup>1</sup> n.m.r. lines<sup>3</sup> for these stereoisomeric oxyphosphoranes are listed below. The formulas assume a hypothetical trigonal bipyramidal geometry.

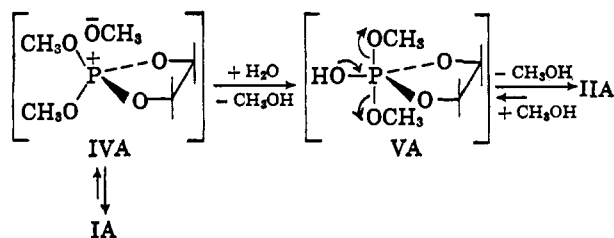


The three methoxyl groups attached to the phosphorus gave rise to one doublet only; hence they are equivalent or indistinguishable. The equivalence could mean a very rapid exchange as in IA  $\rightleftharpoons$  IVA. This suggests a replacement of methoxyl by hydroxyl (as in VA) during the hydrolysis.<sup>3a</sup> The same hypothesis (VA) would account for methanol-catalysis of the stereomutation at phosphorus in the phosphate IIA.

Certain physical properties of the 2:1 biacetyl trimethyl phosphite adduct<sup>2</sup> (I) are very similar to those of a number of related substances to which we

(3) Ten-per cent solutions in CCl<sub>4</sub> vs. internal TMS at 60 Mc.; protected against moisture.

(3a) NOTE ADDED IN PROOF.—The methoxyls could achieve equivalence without P-O fission. The replacement of methoxyl by hydroxyl may involve an increase in the coordination no. of the P from 5 to 6. These points are under investigation.



have assigned also the cyclic oxyphosphorane structure.<sup>4</sup> These assignments are, therefore, mutually strengthened by the results summarized in this communication.

**Diketol Cyclic Phosphate (IIA).**—M.p. 106–112° (slow crystallization from ether or benzene–hexane). *Anal.* Calcd. for C<sub>9</sub>H<sub>16</sub>O<sub>6</sub>P: C, 43.2; H, 6.0; P, 12.4; mol. wt., 250. Found: C, 43.2; H, 6.0; P, 12.4; mol. wt., 250 (alkaline titration at pH 7.0). Infrared in CCl<sub>4</sub> ( $\mu$ ): split CO at 5.77, 5.81 (s); PO at 7.68 (s); CH<sub>3</sub>OP at 9.52 (vs); no OH. H<sup>1</sup> n.m.r. in CDCl<sub>3</sub> vs. TMS (fresh solution) ( $\tau$ ): CH<sub>3</sub>OP at 6.07,  $J_{HP}$  = 12 c.p.s.;

CH<sub>3</sub>CO at 7.65; CH<sub>3</sub>C— at 8.42. IIA is sensitive to

moisture. Complete hydrolysis of IIA (benzene, excess water, reflux) gave 3,4-dimethyl-3,4-dihydroxy-2,5-hexanedione,<sup>2</sup> m.p. 95–96°.

**Hemiketal Cyclic-Phosphate (III).**—M.p. 114–115° (CH<sub>2</sub>Cl<sub>2</sub>–hexane). *Anal.* Calcd. for C<sub>11</sub>H<sub>19</sub>O<sub>7</sub>P: C, 42.6; H, 6.8; P, 11.0. Found: C, 42.6; H, 7.1; P, 11.0. Infrared in CHCl<sub>3</sub> ( $\mu$ ): OH at 2.83 (broad); PO at 7.70 (s); POCH<sub>3</sub> at 9.50 (vs); no CO. H<sup>1</sup> n.m.r. (freshly prepared CDCl<sub>3</sub> solution vs. TMS) ( $\tau$ ): OH at

5.77; CH<sub>3</sub>OP at 6.15,  $J_{HP}$  = 12 c.p.s.; CH<sub>3</sub>O—C— (hemiketal): 6.65; CH<sub>3</sub>C— at 8.50, 8.55 (double

intensity) and 8.58 (three of the four high-field methyl lines were resolvable). Under certain conditions, III can be recovered into IIA by removal of methanol.

**Acknowledgment.**—We are very grateful to Prof. E. Eliel (Univ. of Notre Dame) and to Mr. M. Banas (American Oil Co., Whiting, Indiana) for H<sup>1</sup>-n.m.r. facilities and instruction.

(4) (a) F. Ramirez, N. B. Desai and N. Ramanathan, *Tetrahedron Letters*, No. 5, 323 (1963); (b) F. Ramirez and N. Ramanathan, *J. Org. Chem.*, **26**, 3041 (1961); (c) F. Ramirez and N. B. Desai, *J. Am. Chem. Soc.*, **82**, 2652 (1960).

(5) Alfred P. Sloan Fellow, 1961–1963

DEPARTMENT OF CHEMISTRY  
STATE UNIVERSITY OF NEW YORK  
AT STONY BROOK  
STONY BROOK, N. Y.

FAUSTO RAMIREZ<sup>5</sup>  
N. B. DESAI  
N. RAMANATHAN

RECEIVED JULY 23, 1962

### Equalization of Electronegativity<sup>1</sup>

Sir:

Recently, Hinze, Whitehead and Jaffé<sup>2</sup> have made real progress toward the derivation of an electronegativity scale for groups and radicals, based on an extension of the definition of electronegativity for atomic orbitals originally given by Pritchard and Sumner.<sup>3</sup> However, Hinze, Whitehead and Jaffé neglect the effect of overlap between bonding orbitals, and are then led logically to the principle of equalization of the

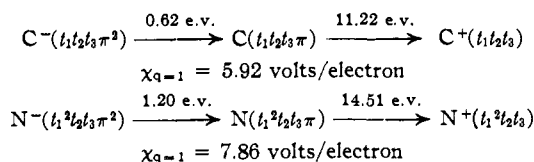
(1) Based on a lecture given at the Gordon Research Conference on Inorganic Chemistry at New Hampton, N. H., August 6–10, 1962.

(2) J. Hinze, M. A. Whitehead and H. H. Jaffé, *J. Am. Chem. Soc.*, **85**, 148 (1963).

(3) H. O. Pritchard and F. H. Sumner, *Proc. Roy. Soc. (London)*, **A235**, 136 (1956).

electronegativities of the orbitals forming the bond. In neglecting the overlap, they are in effect making a classical prediction of the electron distribution in the bond from the known (albeit quantum) properties of the constituent atoms, and the result must be in error to some extent. The order of magnitude of this error can be seen from the following calculation.

Consider an isolated  $\pi$ -bond between a carbon atom and a nitrogen atom in an extended organic system. (There is no difference in principle between  $\pi$ -bonds and  $\sigma$ -bonds.) This  $>C=N-$  bond can be treated by the self consistent electronegativity molecular orbital approximation of Pritchard and Sumner<sup>3</sup> in which the coulomb integral  $\alpha_q$  for each atom is identified with the electronegativity  $\chi_q$  of its  $\pi$ -orbital, where  $q$  is the occupation number of that orbital. The relevant valence state ionization energies for carbon and nitrogen are taken as<sup>4</sup>



In each cycle of the calculation the overlap integral and the values of  $\alpha_q$  for the two atoms are adjusted according to the values of  $q$  obtained in the previous cycle, until a self consistent set of charge densities is obtained. The results for the C=N system, with  $r_{CN} = 1.34 \text{ \AA.}$ , are<sup>5</sup>

Atom	Charge	Electronegativity
C	0.946 electron	6.50 volts/electron
N	1.054 electron	7.13 volts/electron

Clearly the difference in electronegativity is considerably reduced in bond formation, but the electronegativities are not equalized. This would have required us to get  $q_N = 1.082$ ,  $q_C = 0.918$  and thus  $\chi_q = 6.775$  volts/electron for both atoms.

This calculation suggests, therefore, that in general, the bond electronegativities of each atom will differ from the equalization value by something in excess of 10% of the original difference in electronegativity between the two constituent orbitals. This is quite a serious error and must be taken into account before a satisfactory electronegativity scale for radicals and groups can be finally established by the method of Hinze, Whitehead and Jaffé.

(4) G. Pilcher and H. A. Skinner, *J. Inorg. Nucl. Chem.*, **24**, 937 (1962).

(5) D. G. Rush, M. S. Thesis, Manchester, 1962. Apparently there was an error in the effective  $Z$  used for the overlap integrals for pyridine in ref. 3: the self consistent charge densities should be N atom 1.057, *ortho* C atoms 0.976, *meta* C atoms 0.997, *para* C atoms, 0.996; this is compatible with the strong preference of OH<sup>-</sup> and NH<sub>3</sub><sup>-</sup> for attack in the *ortho* position.

UNIVERSITY OF MANCHESTER  
MANCHESTER 13, ENGLAND

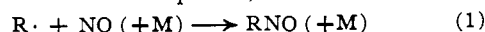
H. O. PRITCHARD

RECEIVED MAY 7, 1963

### Mechanism of the Low-Temperature Scavenging of Methyl-*d*<sub>3</sub> Radicals by Nitric Oxide

Sir:

The detailed mechanism by which nitric oxide scavenges free radicals has been a matter of considerable discussion since the discovery<sup>1</sup> of its inhibitory effect on free radical chain processes. Although it is generally agreed that the first step is one of direct addition to form a nitroso compound, *viz.*



(1) L. A. K. Staveland and C. N. Hinshelwood, *Proc. Roy. Soc. (London)*, **A154**, 335 (1936).