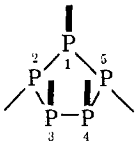
Table I. Phosphorus Chemical Shift and Phosphorus–Phosphorus Coupling Constants in Pentamethylcyclopentaphosphine[a]



| $\delta(P_1)$ | $\delta(P_2)$<br>$\delta(P_5)$ | $\delta(P_4)$<br>$\delta(P_3)$ | $J_{12}$<br>$J_{15}$ | $J_{14}$<br>$J_{13}$ | $J_{25}$ | $J_{24}$<br>$J_{53}$ | $J_{23}$<br>$J_{54}$ | $J_{43}$ |
|---|---|---|---|---|---|---|---|---|
| −49.8 | −49.2 | −47.5 | −248.6 | +23.3 | −3.6 | −8.1 | −236.4 | −310.3 |

[a] The $\delta(P)$ values are in parts per million downfield from external 85% $H_3PO_4$; the $J$ values are in hertz; a negative sign of $^1J(PP)$ is assumed (see text).

of the phosphorus spectral lines and the results of these triple resonance experiments were used to sketch an experimental energy level diagram (eld). This experimental eld was then compared to the eld of "trial and error" AA'BB'C calculated systems in order to perform iterative calculations with the LAOCOON III program. The best parameters from the analysis are presented in Table I. The error in the coupling constant values is less than 1.2 Hz.

In the molecule under study, $(CH_3P)_5$, the relative orientations of the methyl substituents are unknown. However, X-ray diffraction studies have shown that $(CF_3P)_5$[18] and $(C_6H_5P)_5$[19] exist with two substituents attached to adjacent phosphorus atoms which lie on the same side of the ring. Such a stereochemical relationship which affords the best possible cis–trans alternation of the methyl groups is consistent with the nmr data (the AA'BB'C system and the coupling constant values; see later) and will be assumed here.[20] The assignments of the chemical shifts of phosphorus atoms 2,3 and 4,5 could be reversed (Table I). However, such a labeling would involve two small $^1J(PP)$ values (±23.3 and ∓3.6). Since all the previously reported $^1J(P^{III}P^{III})$ values are larger than 100 Hz, excluding the $^1J(PP) = 55$ Hz found in the highly strained 1,2,3,4-tetrakis(trifluoromethyl)-3,4-diphosphacyclobutene,[21] this alternate labeling appears to be highly unlikely.

From the spectral analysis only the relative signs of the coupling constants are determined. However, the known directly bonded $^1J(P^{III}P^{III})$ coupling constants range from 100 to 400 Hz in magnitude, excluding the above-mentioned low value. In all this class of coupling constants, those signs which have been determined are negative despite large degrees of variance in the P substituents.[22] As a consequence it seems reasonable to assume that the $^1J(PP)$ values obtained in the phosphorus nmr spectral analysis of the pentamethylcyclopentaphosphine (which are experimentally shown to be of the same sign) are all negative.

The most striking feature of the data in Table I is the large difference observed in the $^1J(PP)$ values (∓248.6, ∓236.4, and ∓310.3 Hz). Small differences in the PPP angles and thus in the hybridization state of the three different kinds of phosphorus atom of $(CH_3P)_5$ in solution are not unexpected,[23] but such small differences cannot be responsible for the large difference here observed in the $^1J(PP)$ values. We suggest that most of this difference is due to the difference in the stereochemical orientation around the coupled nuclei. The largest absolute value (310.3 Hz) would correspond to an approximate cis relationship between the lone pair of the bonded phosphorus atoms.

In assuming negative values of $^1J(PP)$, the experimental order here observed in the $^1J(PP)$ couplings is consistent with the calculation carried out previously.[14]

It must be pointed out that the couplings between nondirectly bonded phosphorus nuclei are different in magnitude and sign. This result is difficult to rationalize in terms of $^2J(PP)$ or $^3J(PP)$ since the observed couplings are simultaneously $^2J(PP)$ and $^3J(PP)$. To our knowledge these are the first $^2J(PPP)$ values reported in the literature.[24]

Clearly a comprehensive understanding of the large stereochemical dependence observed here for the $^1J(PP)$ spin–spin coupling would be of great value for stereochemical study of diphosphines and polyphosphines. Further studies are now in progress on both the experimental and theoretical aspects in order to get more information on this problem.

**Acknowledgments.** We thank Mr. R. Nardin for his skillful assistance in running the nmr spectra. We are also grateful to Messrs. Taieb and Csakvary for adapting the computer programs to our computer facilities.

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(18) C. J. Spencer and W. N. Lipscomb, *Acta Crystallogr.*, **14**, 250 (1961); **15**, 509 (1962).

(19) (a) J. J. Daly, *J. Chem. Soc. A*, 428 (1966); (b) J. J. Daly, "Perspectives in Structural Chemistry," Vol. 3, J. D. Dunitz and J. A. Ibers, Ed., Wiley, New York, N. Y., 1970.

(20) It must be pointed out that such an alternate orientation of the methyl groups is observed in the solid state for $(CH_3As)_5$ (J. H. Burns and J. Waser, *J. Amer. Chem. Soc.*, **79**, 859 (1957); J. Donohue, *Acta Crystallogr.*, **15**, 708 (1962)).

(21) W. Mahler, *J. Amer. Chem. Soc.*, **86**, 2306 (1964).

(22) R. K. Harris, *Progr. Nucl. Magn. Resonance Spectrosc.*, **6**, 61 (1971).

(23) The small differences observed in the $^{31}P$ chemical shifts suggest that the hybridization state is quite similar in the three different phosphorus atoms.

(24) F. G. Mann and A. J. H. Mercer, *J. Chem. Soc., Perkin Trans. 1*, 1631 (1972).

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*Received May 29, 1973*

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## $^{13}C$ CIDNP Effects Associated with the Thermal 1,3 Rearrangement of Oxime Thionocarbamates

*Sir:*

We have recently reported[1] CIDNP effects in the proton nmr spectra of products **2** and **3** of thermal 1,3

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(1) W. B. Ankers, C. Brown, R. F. Hudson, and A. J. Lawson, *J. Chem. Soc., Chem. Commun.*, 935 (1972).

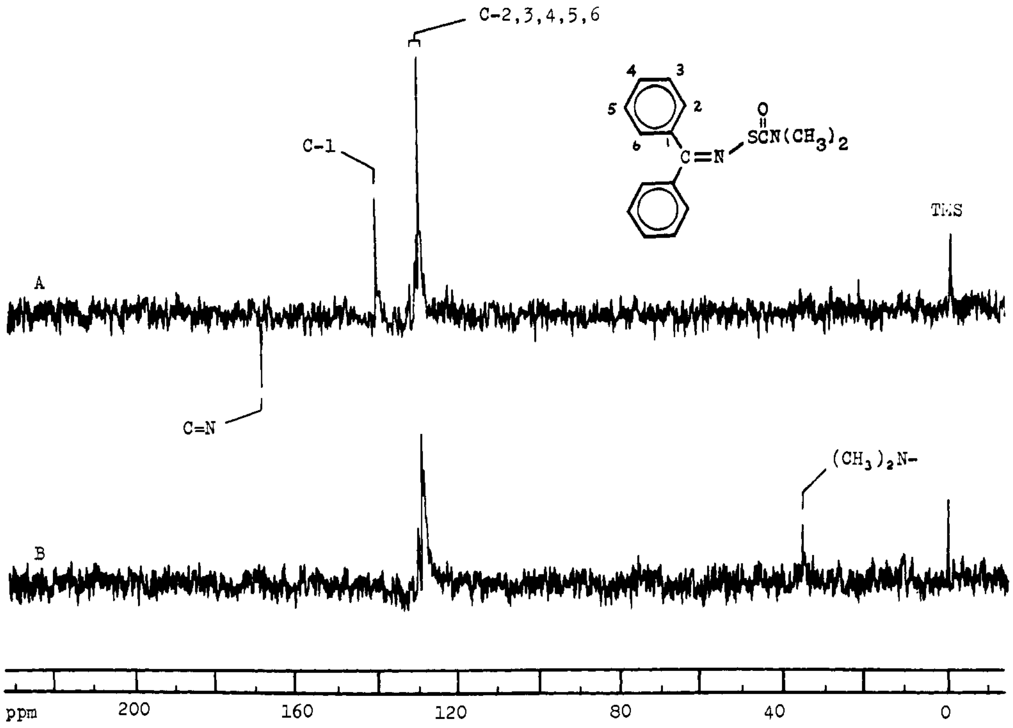
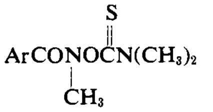


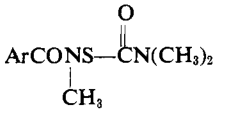
Figure 1. Proton noise-decoupled $^{13}C$ spectra of **5a** (400 transients each) recorded: A, *ca.* 1.5 min after insertion of sample in the spectrometer probe at 85°; B, *ca.* 3 min later.

rearrangement of the hydroxamic acid derivatives **1**.



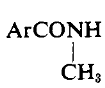
$\mathrm{ArCO\underset{\displaystyle CH_3}{N}O\overset{\displaystyle S}{\overset{\|}{C}}N(CH_3)_2}$

**1**



$\mathrm{ArCO\underset{\displaystyle CH_3}{N}S{-}\overset{\displaystyle O}{\overset{\|}{C}}N(CH_3)_2}$

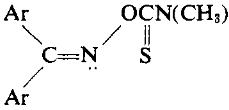
**2**



$\mathrm{ArCO\underset{\displaystyle CH_3}{N}H}$

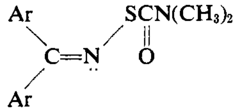
**3**

The observed polarizations (A for **2**, E for **3**) were in accord[2] with a reaction pathway involving homolysis of the N–O bond to give a radical pair which either recombined within the solvent cage to give the thiolo derivative **2** or parted to give rise to, *inter alia*, the amide **3**. However, although the related thermal rearrangement[3] of the oxime **4** to the thiooxime **5** was accompanied by the production of iminyl radicals, **6**,



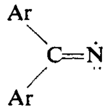
**4**

**4a**, Ar = $C_6H_5$
**4b**, Ar = 3,F-$C_6H_4$



**5**

**5a**, Ar = $C_6H_5$
**5b**, Ar = 3,F-$C_6H_4$



**6**

detected by esr[4,5] and exhibited kinetic behavior[4] characteristic of a radical reaction, no CIDNP effects could be detected in the $^1H$ nmr spectrum of the products. We were anxious to confirm that the radical species observed were responsible for product formation, and although no $^{13}C$ CIDNP effects have been reported for 1,3 rearrangements, sufficient success has been achieved with the well-known decomposition of acyl peroxides[6] and more recently in the reduction of diazonium salts[7] to encourage us to employ this for our purpose.

We therefore decided to examine the $^{13}C$ spectra of the products, in the expectation of observing polarization of (carbon) nuclei nearer to the reaction site. Reasonable signal-to-noise ratios were obtained by using Fourier transform techniques and proton noise decoupling. Samples of **4** were dissolved in $CDCl_3$ ($^2H$ lock) and sealed into 8-mm nmr tubes. The tubes were then placed in the probe of the spectrometer (previously preheated to 85°), and spectra were recorded after allowing *ca.* 30 sec for thermal equilibration. By using a small pulse width (4 $\mu$sec, *ca.* 25° pulse), and a repetition time of 0.41 sec, three sets of 400 transients could be accumulated and stored on a magnetic drum within *ca.* 9 min. Typical spectra so obtained for rearrangement of **4a** are shown in Figure 1. It can be seen that during the first few minutes after insertion of the sample, strong polarization of product lines at 166.9 ppm (E) and 138.9 ppm (A) occurs. Similar results were obtained for **4b** (E at 163.9 ppm and A at 140.4 ppm). These lines were assigned[8] to the C=N and C-1 carbon atoms, respectively, of the products **5** (Figure 1). Perhaps surprisingly no positive evidence of polarization of the C=O carbons in **5a** or **5b** was obtained.[9,10]

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[2] These polarizations were precisely those expected on the basis of *g* values and coupling constants for the radicals involved, applying the rules formulated by Kaptein (R. Kaptein, *J. Amer. Chem. Soc.*, **94**, 6251 (1972)) and will be discussed in detail later.

[3] R. Cross, R. J. E. Searle, and R. E. Woodall, *J. Chem. Soc. C*, 1873 (1971).

[4] R. F. Hudson, A. J. Lawson, and E. A. C. Lucken, *Chem. Commun.*, 807 (1971).

[5] R. F. Hudson, A. J. Lawson, and E. A. C. Lucken, *J. Chem. Soc., Chem. Commun.*, 721 (1972).

[6] E. Lippmaa, T. Pehk, and T. Saluvere, *Ind. Chim. Belg.*, **36**, 1070 (1971).

[7] S. Berger, S. Hauff, P. Niederer, and A. Rieker, *Tetrahedron Lett.*, 2581 (1972).

[8] The C=N and C=O resonances in these compounds were at similar frequencies, but analysis of the spectra of a series of compounds allowed unambiguous assignments.

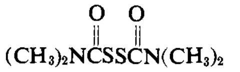
[9] It is also clear from the spectra that there is polarization of some (or all) of the other aromatic carbons and possibly of the $N(CH_3)_2$ carbons, but we have not attempted to analyze this.

[10] A referee has pointed out that this could be due to fortuitous chemical shift equivalence of the C=N and C=O carbons, with the re-

Under the conditions used for the CIDNP studies **4a** is converted to **5a** in *ca.* 90% yield and the azine **7** (Ar = $C_6H_5$) is among the products. However, control experiments with authentic samples showed that none

$Ar_2C{=}NN{=}CAr_2$

**7**



$(CH_3)_2N\overset{O}{\overset{\|}{C}}SS\overset{O}{\overset{\|}{C}}N(CH_3)_2$

**8**

of the polarized lines corresponded to any of the $^{13}C$ resonances of **7** (Ar = $C_6H_5$) or of the possible additional products, carbon oxysulfide and the disulfide **8**.

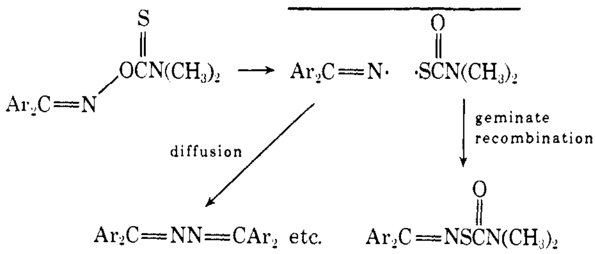
The *g* values for the iminyls[5] **6** are *ca.* 2.003 and for the radical $(CH_3)_2NCOS\cdot$,[11] 2.05. Furthermore the distribution of spin density in iminyls is governed by hyperconjugation,[12] and thus the signs of the hyperfine coupling constants for the C=N and C-1 carbons in **6** will be negative and positive, respectively.

Knowledge of these parameters allows application of Kaptein's rules[2] for net polarization

$$\Gamma_{ne} = \mu\epsilon\Delta g A_i \tag{1}$$

where $\mu$, $\epsilon$, $\Delta g$, and $A_i$ have their usual significance. Since the net effects for the C=N and C-1 carbons are respectively E(−) and A(+), it is clear from eq 2 and 3 that $\epsilon$ is positive and that polarized **5** therefore arises from cage recombination of the iminyl and $(CH_3)_2NCOS\cdot$ radicals (Scheme I), providing overwhelming support for our proposed pathway.[4]

**Scheme I**



$$\text{C=N:}\quad \text{sign product} = -+--\equiv -\ (\text{E}) \tag{2}$$

$$\text{C-1:}\quad \text{sign product} = -+-+\equiv +\ (\text{A}) \tag{3}$$

Azine **7** must arise from iminyls which escape from the cage, and so should show polarization of the C=N and C-1 carbons of the opposite sense to those observed for the rearrangement product **5**. No such polarization could be detected in our spectra. A possible explanation for this lies in the relatively long life[12] of the iminyl radical **6** (in keeping with its ready detection by esr[4,5]). This would allow nuclear relaxation[13] to occur before product formation. We are currently investigating this interesting aspect of the problem.

sult that the C=O signal is masked by that of the C=N. However, these lines are clearly distinguished in the spectrum of authentic product recorded at the reaction temperature.

(11) A. J. Lawson, unpublished work.

(12) J. A. Brivati, K. D. J. Root, M. C. R. Symons, and D. J. A. Tingling, *J. Chem. Soc. A*, 1942 (1969); M. C. R. Symons, *Tetrahedron*, 615 (1973).

(13) This situation was anticipated by Closs and Trifunac as early as 1970: G. L. Closs and A. D. Trifunac, *J. Amer. Chem. Soc.*, **92**, 2186 (1970).

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*Received April 14, 1973*

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## Possible Sequential Analysis of Small Oligopeptides (Penta to Hepta) with $^1H$ Nuclear Magnetic Resonance Spectroscopy at 300 MHz

*Sir:*

In 1966 Sheinblatt[1] in Israel succeeded in determining the amino acid sequences of di- and tripeptides by comparing $\alpha$-H shift values in their nmr spectra obtained in $D_2O$ at different pH values. The addition of base transforms their zwitterion forms into the corresponding anionic species, whereas acid creates the cationic forms. Therefore, during titration, the H atoms nearest the carboxyl (head side) eventually become either shielded (NaOD added) or deshielded (DCl added) relative to those in the zwitterionic form, and the opposite behavior is found for the $\alpha$-H atoms nearest the tail. With conventional magnets, the resulting chemical shift change is small; only in the case of the amino acid residues adjacent to the head and the tail positions are these shifts large enough to permit assignment in the nmr spectrum. Since the nmr absorption owing to the penultimate residue in tripeptides are relatively insensitive to pH changes in the surrounding solvent medium, the sequence designation of tripeptides is easily established by this simple nmr procedure.

Sheinblatt's original studies were performed at 100 MHz. With a gain of a factor of three in field strength (300 MHz), we found that the second residue (and sometimes also the penultimate residue) shows demonstrable shift changes in its $\alpha$-H atom absorption. This suggested to us the possibility of sequence determination by nmr spectroscopy of tetra- and (in favorable cases) of pentapeptides.

We have found now the addition of shift-inducing lanthanide *salts* ($Eu^{3+}$, $Pr^{3+}$, $Tb^{3+}$, $Yb^{3+}$, $Ho^{3+}$) to be extremely helpful in increasing the shift variation by an additional factor of *ca.* 10–30. In $D_2O$, *free* carboxylate anions, but not the undissociated $CO_2H$ groups are good ligands.[2] We have found that free amino functions also show definitive capability to compete favorably with the solvent for ligand formation with the added lanthanide shift reagent (LSR). Shifts of both $\alpha$-H atoms and $\beta$-H atoms can easily be followed, thus facilitating identification of each amino acid residue (Figure 1). Further, the homonuclear indor technique allows the complete identification of that residue together with an assignment of its relative position in the peptide chain.

Figure 2 shows observed shift changes for the $\alpha$-H atoms in tetraalanine which result upon addition of increasing amounts of the $La^{3+}$. $Pr^{3+}$ causes downfield shifts whereas $Eu^{3+}$ affords upfield shifts; these results are in the opposite direction from what is found in nonprotic solvents.[2] The effect is presumed[3] to be largest for the head (no. 4) residue (*e.g.*, the residue situated adjacent to the carboxylate group). This

(1) M. Sheinblatt, *J. Amer. Chem. Soc.*, **88**, 2845 (1966).

(2) K. G. Morallee, E. Nieboer, F. J. Rossotti, R. J. Williams, A. Xavier, and R. A. Dwek, *Chem. Commun.*, 1132 (1970); F. A. Hart, G. P. Moss, and M. L. Staniforth, *Tetrahedron Lett.*, 3389 (1971); G. P. Moss, private communication.

(3) The regularity of maximum shift change, *e.g.* for $Pr^{3+}$ being 800–1000 Hz for $\alpha$(H-4), 60 Hz for $\alpha$(H-3), and 3–6 Hz for $\alpha$(H-2), etc., led us to suppose that the peptide chain is almost unfolded and that there is a regular increase in distance of these $\alpha$-H atoms from the site of coordination. This may not necessarily be true for other (longer) peptides which may contain additional acidic and/or basic functions.