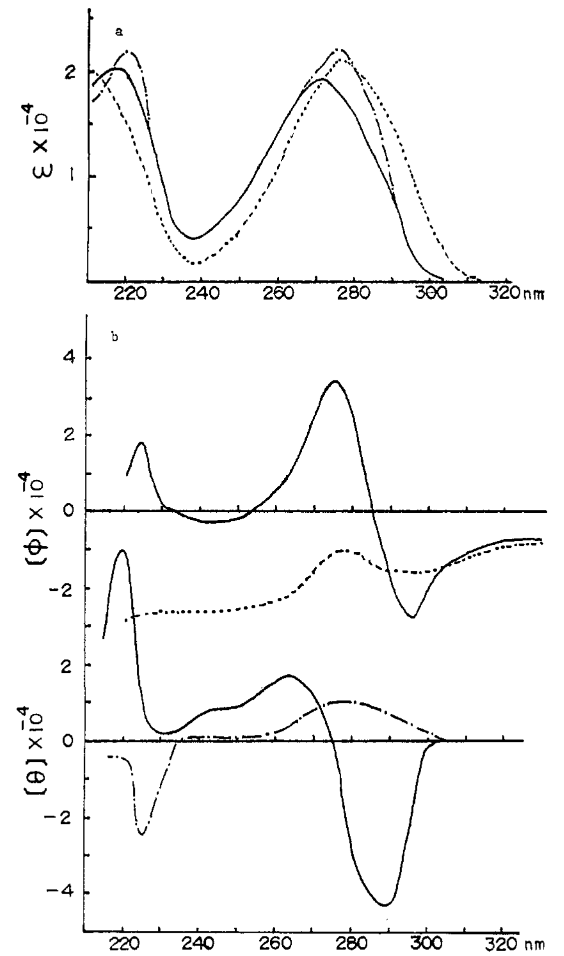

Figure 2. Uv absorption (a) and ORD and CD (b) curves of $A^{s}pA^{s}$ and pA^{s}. Solid lines are curves of $A^{s}pA^{s}$ measured at pH 6.9 (in 0.01 *M* phosphate buffer and 0.08 *M* $KClO_4$ solution) and dotted lines are at pH 1 (0.1 *M* $HClO_4$). Broken lines are curves of pA^{s} measured at pH 7 (in 0.1 *M* phosphate buffer). ϵ, $[\phi]$, and $[\theta]$ are given per nucleotide residue.

ORD and CD curves of $A^{s}pA^{s}$ are shown in Figure 2 together with uv absorption spectra. The first positive Cotton band of the monomer around 280 nm splits to a pair of a large negative (290 nm) and a positive band (264 nm). The second small positive band at 250 nm of the monomer also splits to a negative (260 nm) and a positive (245 nm) band, though the negative band may be cancelled by a large positive 264-nm band. Presumably the second positive band at 220 nm of $A^{s}pA^{s}$ is also caused by the splitting of the negative band at 225 nm of the monomer. Thus far, all Cotton bands of the monomer A^{s} split to pairs of negative and positive bands in $A^{s}pA^{s}$. This splitting may be interpreted by the exciton theory presented by Tinoco, *et al.*[9] They observed a drastic change of Cotton curves in ApA from the monomer and interpreted it by interaction of two adjacent transition moments of the base. Stacking of two adenines in $A^{s}pA^{s}$ could be thus safely deduced from the splitting bands shown here.

The base moieties of both nucleoside units in $A^{s}pA^{s}$ should be fixed at α_{CN}[10] nearly equal to $-108°$ by nucleosidic and anhydro linkages[2] and if these nucleosides are linked together with phosphodiester in 3′–5′ direction, two bases have to be in the position as shown in Figure 3 deduced from the result of nmr measurements. If we construct a model of $A^{s}pA^{s}$ fitting this requirement, a conformation having a *left-handed* screw axis seems to be the most favorable one. This conformation is unique in $A^{s}pA^{s}$, because dinucleoside phosphates from β-D-ribonucleosides give a *right-handed* screw axis.[11] Although final assignment of the left-handed screw axis must await further investigation, this model satisfactorily explained the physical properties of the $A^{s}pA^{s}$. The strong stacking tendency of $A^{s}pA^{s}$ might be due to restricted rotation of base moieties around nucleosidic linkages so that free energy of $A^{s}pA^{s}$ is minimized relative to that of ApA. An alternate explanation that sulfur atoms in position 8 attract each other and stabilize the stacked conformation may be excluded because 5′,5′-pyrophosphate synthesized from A^{s} does not stack at all, though the pyrophosphate from 5′-AMP could stack well.[13]

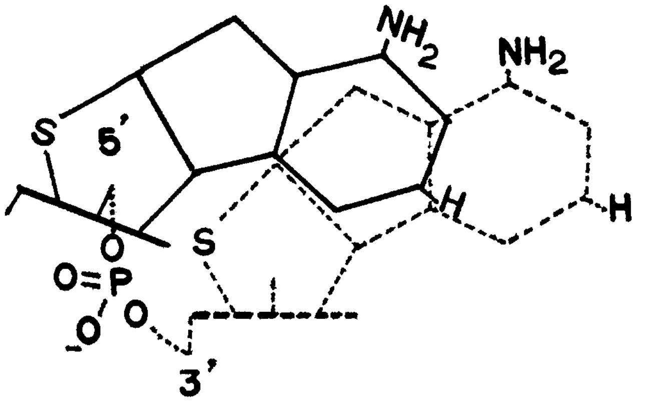

Figure 3. Schematic representation of $A^{s}pA^{s}$. Solid line is 5′-linked nucleoside and dotted line shows 3′-linked nucleoside. Furanose ring is drawn as a line, in which 3′ means 3′-OH and 5′ means 5′-OH. Note that 3′-OH's are in the left end of the furanose ring and 5′-OH's in the middle.

Further investigations of oligonucleotides involving cyclonucleosides are in progress.

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[9] I. Tinoco, Jr., *J. Amer. Chem. Soc.*, **86**, 297 (1964).

[10] J. Donohue and K. N. Trueblood, *J. Mol. Biol.*, **2**, 363 (1960).

[11] Tazawa, *et al.*,[12] synthesized dinucleoside phosphate from L-adenosine and reported its left-handed screw axis.

[12] I. Tazawa, S. Tazawa, L. M. Stempel, and P. O. P. Ts'o, Abstracts, 158th National Meeting of the American Chemical Society, New York, N. Y., Sept 1969, No. BIOL-74.

[13] Unpublished experiments by K. Yoshida.

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Aromaticity *via* Cyclopropyl Conjugation. On the Electronic Structure of Spiro[2.4]hepta-4,6-diene

Sir:

The significance of the delocalization of the electrons of the carbon–carbon bonds of suitably oriented cyclopropanes into proximate π systems has been the subject of recent interest.[1] We wish to report that for a favorably structured molecule such delocalization may result in aromatic character. The preferred geometric

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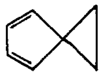
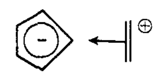
[1] For leading references see (a) S. W. Staley, *J. Amer. Chem. Soc.*, **89**, 1532 (1967); (b) A. L. Goodman and R. H. Eastman, *ibid.*, **86**, 908 (1964); (c) M. Y. Lukina, *Russ. Chem. Rev.*, 419 (1962).

orientation for such delocalization has been conclusively shown by nmr,[2] electron diffraction,[3] and kinetic studies[4] to be that conformation which possesses a "bisected geometry"[5] in which the nodal plane of the π system and the plane of the cyclopropane ring are perpendicular. This conformation allows maximum overlap of the π system with the heavily p weighted ring bonds of the cyclopropane system.[6] It has recently been estimated that this corrected empirical resonance energy amounts to approximately 1.3 kcal/mol in spiro[2.5]oct-4-ene.[1a]

In view of these results we anticipated that this electron delocalization might well assume considerable importance in a molecule in which such delocalization results in aromaticity. The delocalization of the C-1–C-2 and C-1–C-3 electrons of spiro[2.4]hepta-4,6-diene (**1a**) and partial rehybridization at C-1, C-2, and C-3 result in a contributing structure which is perhaps best represented as a π complex[7] (**1b**) of cyclopentadienylidene and ethylene. Among other changes, a contribution of **1b** to the electronic structure of the spirodiene results in (a) a decrease in the electron density at C-2 and C-3, (b) the support of a ring current in the five-membered ring, and (c) minor alterations in the already highly s weighted carbon–hydrogen bonds at C-2 and C-3. The nmr chemical shift of these cyclopropyl protons should respond to such alterations in a predictable manner. The ultraviolet spectrum of **1a** has been discussed[8] and, with the exception of the consistent bathochromic shifts attending successive alkylation of the cyclopropyl ring,[8c] appears to provide little information regarding the electronic structure of this system.



1a



1b

We have prepared spiro[2.4]hepta-4,6-diene (**1**) by the published procedure.[9] The 60-MHz nmr spectrum of **1** (CCl_4) shows two closely spaced multiplets at δ 6.77 (2 H) and 6.35 (2 H) assigned to the protons at C-5, C-6 and C-4, C-7, respectively, and a sharp singlet at δ 1.62 (3 H) assigned to the protons at C-2 and C-3. That the chemical shift of these cyclopropyl protons represents a substantial downfield shift[8c,10] from that expected on the basis of structure **1a** is evident from the following comparisons: spiro[2.4]heptane, δ 0.37;[11] spiro[2.5]oct-5-ene, δ 0.28;[1a,12] siro-[2.6]nona-4,6,8-triene, δ 0.58;[13] and spiro[2.5]oct-4-ene, δ 0.47.[1a,11] Thus the chemical shift of the cyclopropyl protons in **1** is at least 1 ppm downfield from that expected for **1a**. The essentially invariant chemical shift of the cyclopropyl protons of spiro[2.6]nona-4,6,8-triene compared with the other examples cited above appears to indicate that the downfield shift of the corresponding protons in **1** is not a result of simple conjugative effects in the 1,3-diene system. The essentially "normal" chemical shift of the cyclopropyl protons in all of the reference compounds quoted would appear to rule out substantial anisotropic effects of the carbon–carbon double bonds as has been proposed.[8c] We consider the aromatic character of a contributing structure such as the π complex to be an attractive explanation to account for the observed differences in the nmr spectrum. As a result of the high s character of the carbon–hydrogen bonds in cyclopropane, little rehybridization at C-2 and C-3 is required for π complex bonding, and we have assumed the downfield shift to be due to the effects of ring current and electron density.

The chemical shift difference expected for the protons at C-2 and C-3 as a result of the support of a six-π-electron ring current was determined from the equation derived by Johnson and Bovey.[14] From this equation it can be shown that for any aromatic system

$$\delta' = 0.2317(n/a)\delta'_{C_6H_6} \qquad (1)$$

where n is the number of π electrons, a is the radius of the aromatic system in ångström units, and $\delta'_{C_6H_6}$ is the chemical shift due to the ring current of benzene.[15] Using values of bond lengths and bond angles estimated from Dreiding models, we have estimated the downfield shift due to the support of a full six-π-electron ring current in the π complex to be 0.35 ppm. As these protons lie relatively close to the zero isoshielding line,[15] this calculated chemical shift difference is relatively insensitive to the choice of the π-complex bond distance.

The effect of the alteration in the electron density on the chemical shift was empirically evaluated by an extrapolation of the plot of the HMO π electron density *vs.* the chemical shift, δ'', due to the electron density changes for systems of varying electron density. These chemical shift differences are calculated for tropylium fluoroborate,[16] sodium cyclopentadienide,[16] dipotassium cyclooctatetraenide,[17] the proton at C-3 of di-*n*-propylcyclopropenium perchlorate,[18] and the proton at C-4 of the 2,6-dimethylheptatrienyl cation[5] by correcting the observed chemical shift for the effect of ring current determined from eq 1 with benzene (HMO π electron density 1.00, δ'' 0.00) as the arbitrary standard. Figure 1 gives the least-squares extrapolated

[2] (a) G. J. Karabatsos and N. Hsi, *J. Amer. Chem. Soc.*, **87**, 2864 (1965); (b) C. U. Pittman and G. A. Olah, *ibid.*, **87**, 2998 (1965); (c) G. L. Closs and H. B. Kluger, *ibid.*, **87**, 3265 (1965); (d) H. Gunther and D. Wendisch, *Angew. Chem., Int. Ed. Engl.*, **5**, 251 (1966); (e) W. Luttke and A. deMeijere, *ibid.*, **5**, 512 (1966); (f) G. R. DeMare and J. S. Martin, *J. Amer. Chem. Soc.*, **88**, 5033 (1966).

[3] (a) L. S. Bartell and J. P. Guillory, *J. Chem. Phys.*, **43**, 647 (1965); (b) L. S. Bartell, J. P. Guillory, and A. T. Parks, *J. Phys. Chem.*, **69**, 3043 (1965).

[4] (a) T. Sharpe and J. C. Martin, *J. Amer. Chem. Soc.*, **88**, 1815 (1966); (b) H. D. Brown and J. D. Cleveland, *ibid.*, **88**, 2051 (1966); (c) H. G. Richey, Jr., and J. M. Richey, *ibid.*, **88**, 4971 (1966).

[5] N. C. Deno, *Progr. Phys. Org. Chem.*, **2**, 129 (1964).

[6] A. D. Walsh, *Trans. Faraday Soc.*, **45**, 179 (1949).

[7] For a discussion of the role of π complexes in organic chemistry see M. J. S. Dewar and A. P. Marchand, *Annu. Rev. Phys. Chem.*, **16**, 321 (1965).

[8] (a) C. F. Wilcox, Jr., and R. R. Craig, *J. Amer. Chem. Soc.*, **83**, 4258 (1961); (b) G. Chiurdoglu and B. Tursch, *Bull. Soc. Chim. Belges*, **66**, 600 (1957); (c) R. A. Moss, *J. Org. Chem.*, **31**, 3296 (1966).

[9] K. Alder, H. J. Ache, and F. Flock, *Chem. Ber.*, **93**, 1888 (1960).

[10] K. Bangert and V. Boekelheide, *Tetrahedron Lett.*, 1119 (1963). See also ref 8c.

[11] D. E. Applequist and J. A. Landgrebe, *J. Amer. Chem. Soc.*, **86**, 1543 (1964).

[12] The corresponding data for spiro[2.6]-nona-4,8-diene, δ 0.77, and spiro[2.4]hept-4-ene, δ 0.59, further confirm this conclusion. We thank Professor S. W. Staley for providing us with these data prior to publication.

[13] C. J. Rostek and W. M. Jones, *Tetrahedron Lett.*, 3759 (1969).

[14] C. E. Johnson and F. A. Bovey, *J. Chem. Phys.*, **29**, 1012 (1958).

[15] See Figure 1, ref 13.

[16] G. Fraenkel, R. E. Carter, A. McLachlan, and J. H. Richards, *J. Amer. Chem. Soc.*, **82**, 5846 (1960).

[17] T. J. Katz, *ibid.*, **82**, 3784 (1960).

[18] R. Breslow, H. Hover, and H. W. Chang, *ibid.*, **84**, 3168 (1962).

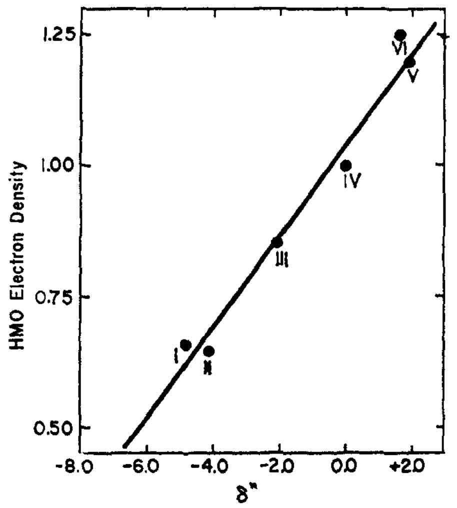


Figure 1. Plot of HMO π electron density *vs.* δ'' for I, di-*n*-cyclopropenium perchlorate; II, 2,6-dimethylhepatrienyl cation; III, tropylium fluoroborate; IV, benzene; V, sodium cyclopentadienide; and VI, dipotassium cyclooctatetraenide.

value of δ'' for the π complex (HMO π electron density 0.500) of −6.25 ppm with a probable error of 0.23 ppm. While we have not corrected the reported chemical shifts for the variation in solvent, nor for the effects of the counterion, the satisfactory linear fit of the data in Figure 1 indicates that such variations are probably not of substantial importance as compared with the molecular effects. In addition the expected changes in hybridization due to the angular distortion in the cyclopropenium and cyclooctatetraenide systems and the satisfactory fit of these data to Figure 1 appear to indicate that such effects are also minor, in part justifying our earlier assumption.

The comparison of the predicted downfield shift of approximately 6.6 ppm for the π complex and the observed shift of approximately 1.0 ppm leads to the conclusion that the π complex may contribute as much as 15% to the total electronic structure of **1**. In the absence of further information, we are of the opinion that this is the electronic structure most consistent with the facts. The apparent substantial contribution of the π complex to the electronic structure of **1** gives us confidence that this effect will be thermodynamically observable in the equilibrium studies currently in progress and that this may be but one of a series of compounds which exhibit aromatic character *via* cyclopropyl conjugation.

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[19] NSF Undergraduate Research Participant, 1968–1969.

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Interpretation of Biradical Electron Resonance Spectra

Sir:

Ferruti, *et al.*, have measured the electron resonance spectra of the nitroxide biradicals I–III as a function of pH.[1] The spectra exhibit a slight pH dependence because the polar groups may be ionized or neutralized, thus changing the nature of the chain linking the nitroxides. Their interpretation of the spectral changes is, at best, incomplete or, at worst, incorrect.

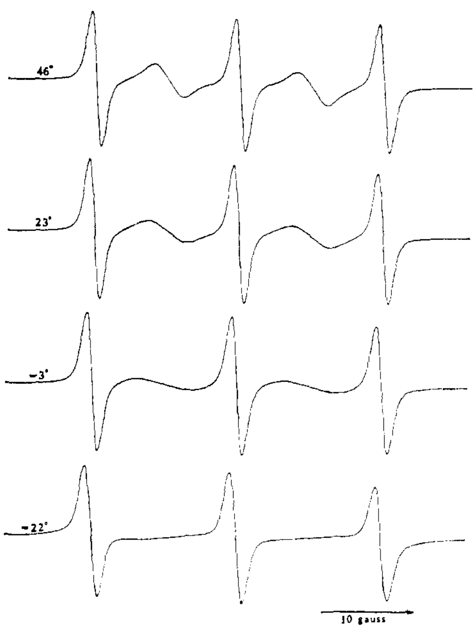
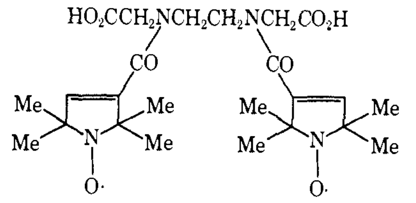
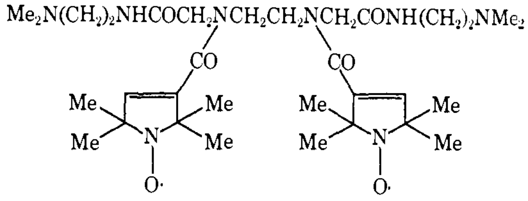


Figure 1. The electron resonance spectrum of bis(2,2,6,6-tetramethylpiperidin-4-ol) glutarate as a function of temperature.



I



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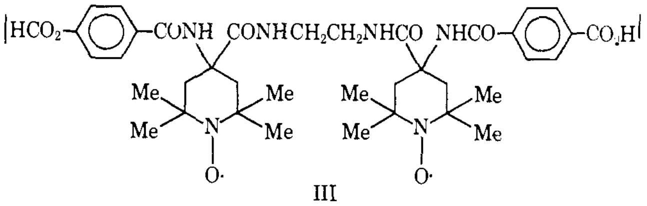

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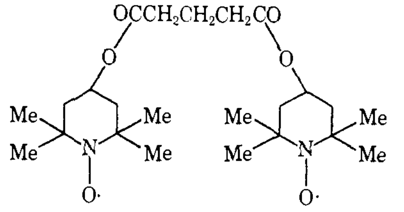

IV

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[1] P. Ferruti, D. Gill, M. P. Klein, and M. Calvin, *J. Amer. Chem. Soc.*, 91, 7765 (1969).