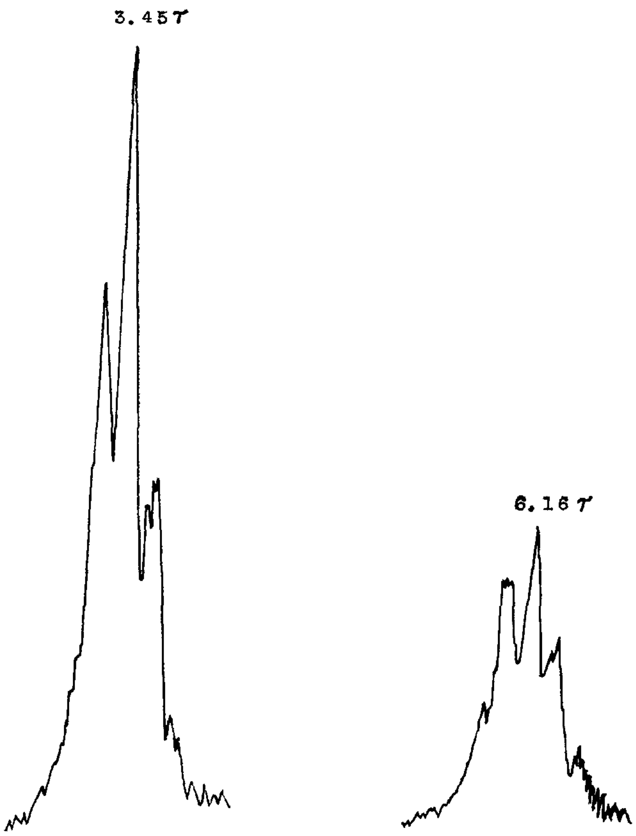
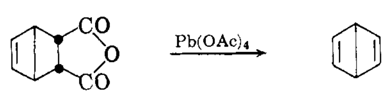


Fig. 1.—N.m.r. spectrum of bicyclo[2.2.0]hexa-2,5-diene at 60 Mc., pyridine solution with tetramethylsilane as an internal standard (τ = 10.0).

hydrogen, and there was produced a saturated dihydro product, m.p. 98–100°, which did not possess a C–CH_3 group (n.m.r.). The n.m.r. spectrum of anhydride III, possessing three peaks of equal intensity at 3.51, 6.34, and 6.58 τ (CCl_4 solution),[3] corroborates the assigned structure.[4]

Direct oxidative decarboxylation of photoanhydride III to the bicyclohexadiene I was accomplished by lead tetraacetate. Under rigorously controlled conditions (*inter alia:* reaction temperature 43–45°, bath 47–48°; 20-min. reaction time, reduced pressure) the anhydride in pyridine solution was treated with the aforementioned reagent, while a minimal amount of distillate was collected in a cooled receiver. Under



these conditions a pyridine solution containing an amount of "Dewar benzene" representing an approximately 20% yield could be obtained.

Assignment of structure rests on the following observations. On being heated at 90° for 30 min., the new hydrocarbon in pyridine solution was converted quantitatively to benzene (analytical v.p.c.); at room temperature the hydrocarbon in pyridine exhibits a half-life of about 2 days, again forming benzene. The benzene precursor itself can be successfully chromatographed in the vapor phase (Ucon polar column at 45°); its retention time (2.7 min.) is of the order expected for a hydrocarbon in the C_6-range (cyclohexene 3.3 min., bicyclo[2.2.0]hexane 3.7 min., benzene 5.7 min.). Small amounts of material trapped from the v.p.c. column exhibited only end absorption in the ultraviolet. The n.m.r. spectrum, measured on a pyridine solution of hydrocarbon I, is reproduced herewith. The olefinic and methine protons, appearing in the ratio of 2:1, exhibit splitting with apparent J = 0.7 c.p.s. for each interaction (see Fig. 1). Olefinic hydrogen (3.45 τ) is split by the nearer as well as the farther methine hydrogen and, thus, appears as a triplet; in turn, methine hydrogen is acted upon by the four olefinic hydrogens, and, thus, reveals itself as a quintuplet (6.16 τ). Thus, the n.m.r. data are consistent with structure I and moreover constitute powerful support for the assignment.

Substantiation by way of chemical behavior was found during the course of reduction experiments. Diimide (generated by decarboxylation of azodicarboxylic acid in the manner previously described[5]) hydrogenation of hydrocarbon I in pyridine–water–acetic acid solution was carried out. The product was identified as bicyclo[2.2.0]hexane, by comparison with an authentic sample,[6a,b] as well as by pyrolysis to biallyl, known to be formed when bicyclo[2.2.0] is heated.[6a]

In view of the fact that 1,2,5-tri-*t*-butylbicyclo[2.2.0]-hexa-2,5-diene was recently made in this Laboratory[7] by photolysis of the isomeric benzenoid, the chemistry reported herein represents preparation of the second known "Dewar benzene" as well as the second type of synthetic route to a member of this class.

Acknowledgment.—For financial support, the authors are indebted to the Petroleum Research Fund (Grant 589-C) and to the National Institutes of Health for a graduate fellowship (1960–1962). Thanks are due also to Mr. G. Zimmerman and Dr. H. Budzikiewicz (Stanford University) for technical contributions.

(3) Measured by means of a Varian A-60 instrument, chemical shifts expressed relative to internal tetramethylsilane at τ = 10.0.

(4) For previous photochemical conversions of 1,3-dienes to cyclobutenes, see (a) W. G. Dauben and G. J. Fonken, *J. Am. Chem. Soc.*, **81**, 4060 (1959); (b) O. L. Chapman and D. J. Pasto, *Chem. Ind.* (London), 53 (1961).

(5) E. E. van Tamelen, R. S. Dewey, and R. J. Timmons, *J. Am. Chem. Soc.*, **83**, 3725 (1961). See also E. J. Corey, W. L. Mock, and D. J. Pasto, *Tetrahedron Letters*, **No. 11**, 347 (1961); S. Hünig, H. R. Müller, and W. Thien, *ibid.*, **No. 11**, 353 (1961).

(6) (a) S. Cremer and R. Srinivasan, *ibid.*, **No. 21**, 24 (1960); (b) R. Srinivasan, *J. Am. Chem. Soc.*, **83**, 4923 (1961).

(7) E. E. van Tamelen and S. P. Pappas, *ibid.*, **84**, 3789 (1962).

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RECEIVED AUGUST 5, 1963

Optical Activity and the Conformation of Polynucleotides

Sir:

Comparatively few studies have been devoted to optical rotatory properties of polynucleotides and nucleic acids,[1–3] in contrast to relatively well developed experimental and theoretical studies on polypeptides and proteins.[4] In order to find a basis for an empirical relation between helical conformation and optical rotatory power, circular dichroism (c.d.) measurements were applied to the studies of homopolyribonucleotide model compounds of relative structural simplicity. Several polyribonucleotides have been shown to exist in a helical conformation in the solid state, and there is indirect evidence which suggests that in solution these compounds retain the same conformation under certain conditions.[5,6]

(1) J. R. Fresco, *Tetrahedron*, **13**, 185 (1961).

(2) J. R. Fresco, A. M. Lesk, R. Gorn, and P. Doty, *J. Am. Chem. Soc.*, **83**, 3155 (1961).

(3) P. O. P. Ts'o, G. K. Helmkamp, and C. Sander, *Biochem. Biophys. Acta*, **55**, 584 (1962); G. K. Helmkamp and P. O. P. Ts'o, *ibid.*, **55**, 601 (1961).

(4) Summarized in P. Urnes and P. Doty, *Advan. Protein Chem.*, **16**, 401 (1961); E. Blout in "Optical Rotatory Dispersion," C. Djerassi, Ed., McGraw-Hill Book Co., New York, N. Y., 1960; J. A. Schellman and P. Oriel, *J. Chem. Phys.*, **37**, 2114 (1962).

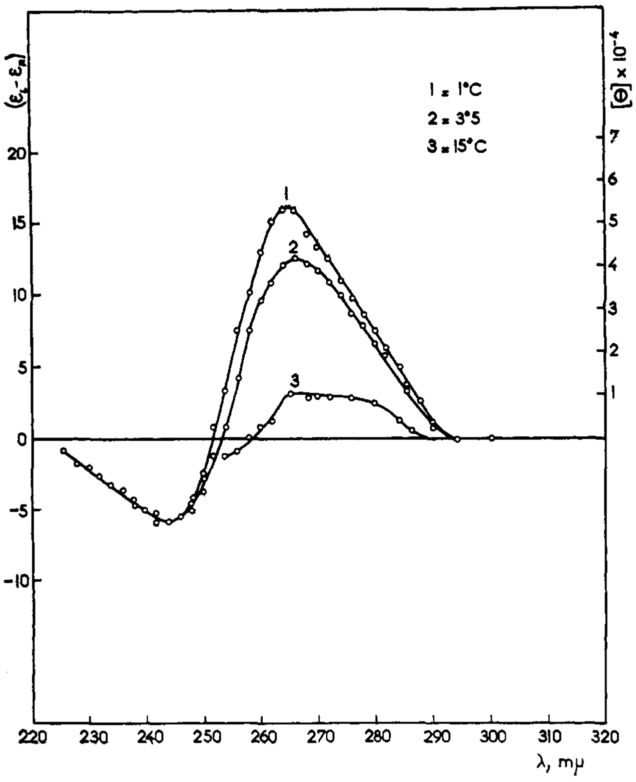

Fig. 1.—Circular dichroism curves of polyuridylic acid in 0.01 M $MgCl_2$, pH 6.8 at different temperatures: concentrations ranged from 0.0008 to 0.0013%. $[\theta]$-molar ellipticity is expressed in degrees. cm.²/mole.

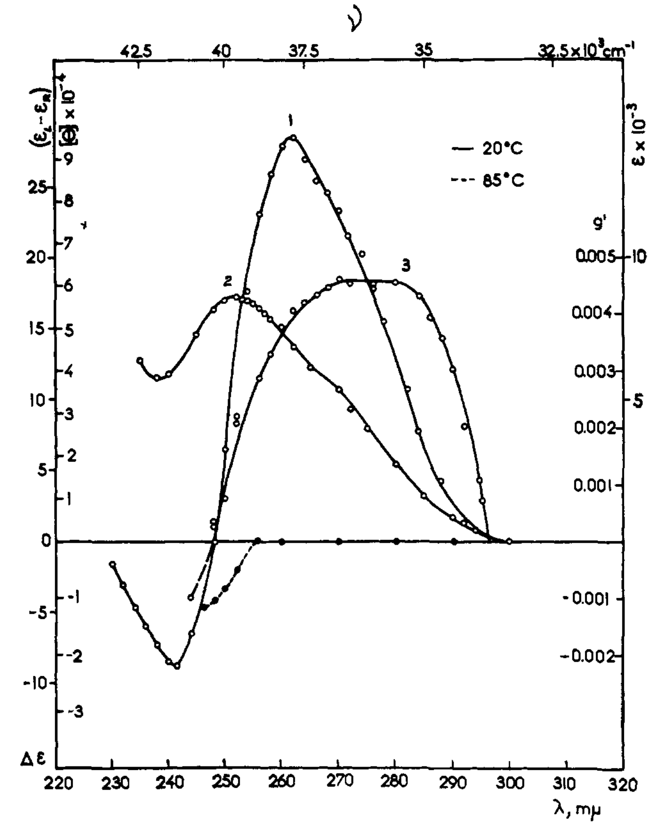

Fig. 2.—Circular dichroism (1), ultraviolet absorption (2), and dissymmetry factor g' (3) of polyadenylic acid at pH 4.86 in 0.1 M NaCl, 0.1 M acetate buffer at 20°, circular dichroism curve at 85° (- - - -). Concentrations ranged from 0.0027 to 0.0048%. For explanations see the text.

All the polyribonucleotides examined in the helical or partially helical form, polyadenylic acid (poly A), polycytidylic acid (poly C), and polyuridylic acid (poly U), exhibit circular dichroism[7] (Fig. 1–3) of positive sign (region of 260–280 mμ). At higher temperatures, where these polynucleotides are disordered, the circular dichroism disappears (Fig. 1, 2) or there is a pronounced decrease of its intensity to almost the level observed for corresponding mononucleotides. This effect is reversible, *i.e.*, on cooling, circular dichroism reappears. Below 250 mμ a negative c.d. band is observed for poly A and poly U (Fig. 1 and 2) but is not observed for poly C (Fig. 3) nor in S-RNA; its relation to changes in conformation is not well defined at present. The circular dichroism maxima and rotational strength[8] values are presented in Table I. Qualitatively similar c.d. curves, but of smaller intensity, were observed for S-RNA.

TABLE I[a]

	Absorption λ_{max}, mμ	c.d. λ_{max}, mμ	$\Delta\nu$ (cm.⁻¹) ($\nu^{abs}_{max} - \nu^{c.d.}_{max}$)	Rot. strength, 10^{-40} c.g.s.	g'
Poly A, 20°	252	262	1515	+61	≃0.05
Poly C, 20°	268	277	1212	+37	≃ .04
Poly U, 1°	258	265	1024	+30	. .

[a] Conditions described in Fig. 1–3.

(5) Reviewed in R. F. Steiner and R. F. Beers, Jr., "Polynucleotides," Elsevier Publ. Co., Amsterdam, 1961.

(6) M. Lipsett, *Proc. Natl. Acad. Sci. U.S.*, **46**, 445 (1960).

(7) Circular dichroism measurements were conducted using a Roussel-Jouan dichrograph, equipped with 4 sensitivity settings (0.4, 1.5, 2, and 3). In the conditions of our experiments the spectral band width is 0.5–1 mμ. The accuracy of wave length determination is about 1 mμ.

(8) The rotational strengths (R_{ba}) were estimated from the areas of the circular dichroism absorption bands

$$R_{ba} = \frac{3hc \times 10^3 \ln 10}{32\pi^3 N} \int \left[\frac{(\epsilon_L - \epsilon_R)}{\gamma}\right] d\nu$$

where ϵ_L and ϵ_R refer, respectively, to the decadic molar extinction coefficients for left- and right-handed circularly polarized light at the frequency ν.

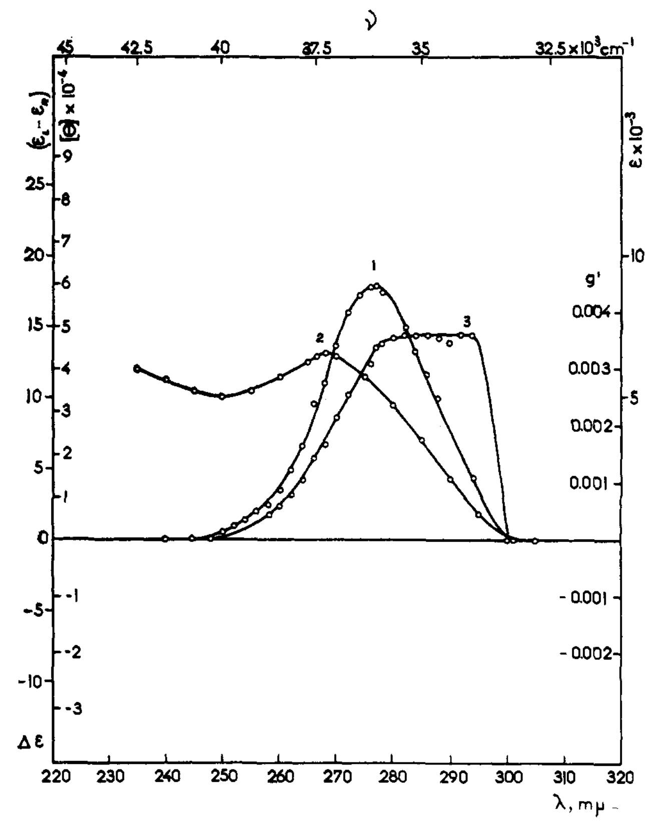

Fig. 3.—Circular dichroism (1), ultraviolet absorption (2), and dissymmetry factor g' (3) of polycytidylic acid at 20°, pH 6.8 in 0.1 M NaCl, 0.01 M phosphate buffer. Concentrations ranged from 0.0032 to 0.0048%.

Comparison of c.d. curves with corresponding ultraviolet absorption spectra (Fig. 2 and 3) shows that c.d. maxima are located at slightly longer wave lengths than the corresponding ultraviolet absorption maxima, Table I. This comparison of c.d. and absorption spectra permits the uncovering of hidden or overlapping weak absorption bands not detectable by standard ultraviolet spectral technique. Also, it can be observed that the absorption spectrum of poly A contains a shoulder near 270 mμ in agreement with a previous observation.[1]

Additional information about the nature of electronic transitions related to polymer conformation are provided by the apparent partial dissymmetry factor g'[9] (Fig. 2, 3) of poly A and poly C. It appears that the maximum values of the dissymmetry factor g' are located on the long wave-length side of the strong ultraviolet absorption band. Thus, the regions of weak absorption for poly A and poly C, 265–285 and 277–295 mμ, respectively, are strongly optically active. In agreement with previous studies on the nature of electronic transitions in purines and pyrimidines[10] and with dichroic absorption studies on oriented polynucleotide, films[11] and nucleic acids,[2] the present study suggests that the "allowedness" of the $n \rightarrow \pi^*$ transition is related to the helical structure of these polynucleotides.[12] Further support for this suggestion is provided by the apparent value of the g' factor indicated in Fig. 2 and 3; these values probably represent an *underestimate*[13] at least by a factor of ten. More realistic values of the g' factor would be about 0.05 for poly A and 0.04 for poly C, indicative of a magnetic dipole transition.[14]

The present c.d. data are qualitatively consistent with the previous optical rotatory dispersion results on nucleic acids,[2] which contain complex, not readily resolved dispersion curves in the ultraviolet region. These observations of the circular dichroism of homopolynucleotides indicate that it is a sensitive method for defining the optical rotatory contribution of individual optically active transitions and can be used as a useful tool for the studies of macromolecular conformation.[15,16]

(9) Partial dissymmetry factor introduced by Kuhn g' is given by the ratio $(\epsilon_L - \epsilon_R)/\epsilon$ at a given wavelength. W. Kuhn, *Trans. Faraday Soc.*, **46**, 293 (1930); S. F. Mason, *Mol. Phys.*, **5**, 343 (1962).

(10) S. F. Mason in Special Publications, No. 3, The Chemical Society, (London), 1955, p. 139.

(11) A. Rich and M. Kasha, *J. Am. Chem. Soc.*, **82**, 6196 (1960).

(12) This explanation cannot exclude definitely the attribution of these dichroic absorption bands to a $\pi \rightarrow \pi^*$ transition (see Gellert M., *ibid.*, **83**, 4661, 1961, and ref. 2).

(13) The $n \rightarrow \pi^*$ absorption bands are of intrinsically low intensity being at most one-tenth as intense as the $\pi \rightarrow \pi^*$ bands (M. Kasha in "Light and Life," Johns Hopkins University Press, Baltimore, Md., 1960).

(14) S. F. Mason, *Quart. Rev.* (London), **17**, 20 (1963).

(15) J. Brahms and G. Spach, *Nature*, in press.

(16) G. Holzworth, W. B. Gratzer, and P. Doty, *J. Am. Chem. Soc.*, **84**, 3194 (1962).

(17) The author is indebted to Professor Ch. Sadron, in whose laboratory this work was done, and M. Daune for valuable advice and stimulating discussions. The author is very grateful to Prof. G. Ourisson, Mr. P. Witz, and Miss H. Hermann, whose generosity and guidance made possible the circular dichroism measurements. Financial support from the Canadian Muscular Dystrophy Association is gratefully acknowledged.

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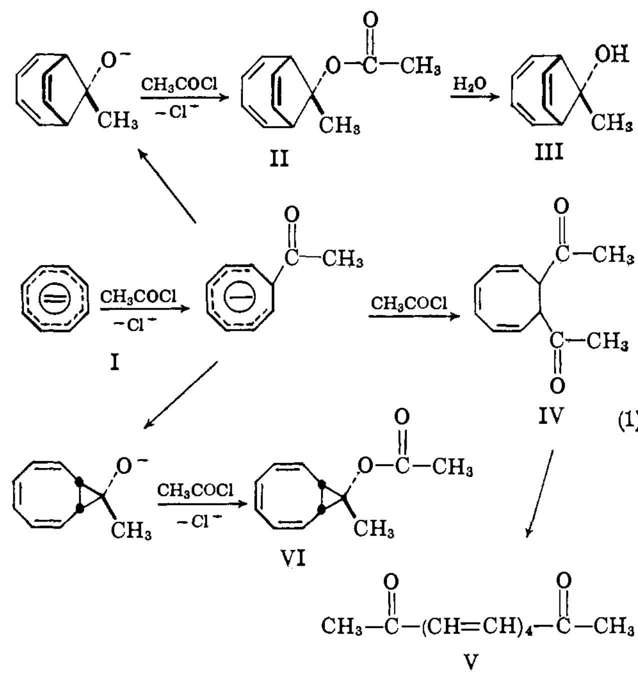
Intramolecular Reactions in Acylation of the Cyclooctatetraene Dianion

Sir:

One of the important developments of modern structural theory has been the demonstration of the existence[1a,b] and aromatic character[1b] of the cyclooctatetraene dianion (I). The utility and chemistry of I have not been described other than its acylation[2a–c] and alkylation[2b] to give unspecified isomers of diacyl- and dialkylcyclooctatrienes, its carboxylation to 2,5,7-cyclooctatriene-1,4-dicarboxylic acid,[1a] and its condensation with aldehydes and ketones[2b,d] to yield 7,8-bis(α-hydroxyalkyl)cyclooctatrienes.[2e] The acylation of I has been presently reinvestigated and acylcyclooctatrienes were not obtained; a series of novel condensation products was formed, however, which illustrate the varied chemistry of I and its potential as an intermediate in synthesis.

Addition of an ether solution of I[1b] to excess acetyl chloride (eq. 1) at 0° and isolation of products gave 9-acetoxy-9-methylbicyclo[4.2.1]nonatriene (II, 13%), 9-methylbicyclo[4.2.1]nonatrien-9-ol (III, 19%), 1,8-diacetyl-1,3,5,7-octatetraene (V, 1%), 9-acetoxy-9-methylbicyclo[6.1.0]nonatriene (VI, 22%), polymer, and amorphous hygroscopic material (15%).[3]



(1)

Hydrogenation of II,[3–5] m.p. 48–48.5°, over palladium-charcoal followed by reduction with lithium aluminum hydride (eq. 2) gave 9-methylbicyclo[4.2.1]nonan-9-ol[3] (VII, m.p. 54–55°). Catalytic hydrogenation of III,[3,6] b.p. 36–37° (0.6 mm.), also yielded VII; II is, thus, the acetate of III. The structure of VII[3] was established by its identity with 9-methylbicyclo[4.2.1]nonan-9-ol (VII) prepared from bicyclo[4.2.1]nonan-9-one[7] (VIII) and methylmagnesium iodide (eq. 2). The stereochemistry at C-9 in VII (and thus in II and III) is assigned as indicated since molecular models reveal that attack of the Grignard reagent from the side of

(1) (a) W. Reppe, O. Schlichting, K. Klager, and T. Toepel, *Ann.*, **560**, 1 (1948); (b) T. J. Katz, *J. Am. Chem. Soc.*, **82**, 3784, 3785 (1960).

(2) (a) V. D. Azatyan, *Dokl. Akad. Nauk SSSR*, **98**, 403 (1954); (b) V. D. Azatyan and R. S. Gyuli-Kevkhyan, *Dokl. Akad. Nauk Armyan SSR*, **20**, 81 (1955); (c) V. D. Azatyan, R. S. Gyuli-Kevkhyan, L. K. Freidlin, and B. D. Polkovnikov, *Izvest. Akad. Nauk SSR, Ser. Khim. Nauk*, **10**, No. 1, 55 (1957); (d) G. Wittig and D. Wittenberg, *Ann.*, **606**, 1 (1957); (e) NOTE ADDED IN PROOF.—For the recent conversion of I to the cyclononatetraenyl anion see T. J. Katz and P. J. Garratt, *J. Am. Chem. Soc.*, **85**, 2852 (1963), and E. A. LaLancette and R. E. Benson, *ibid.*, **85**, 2853 (1963).

(3) (a) All new compounds indicated gave proper analyses. (b) The n.m.r. spectra of the compounds reported herein will be described completely in subsequent papers.

(4) Acidification of this intermediate will also yield III.

(5) Ultraviolet absorption: λ_{max}^{MeOH} 265 (3600), 256 (3750), and 219 mμ (3200); infrared absorption: 5.76, 8.06, and 8.19 μ (ester group).

(6) Ultraviolet absorption: λ_{max}^{MeOH} 260 mμ (ε 6300); infrared absorption: 2.80 μ (hydroxyl).

(7) (a) C. D. Gutsche and T. D. Smith, *J. Am. Chem. Soc.*, **82**, 4067 (1960); (b) we are grateful to Dr. Gutsche for the gift of VIII.