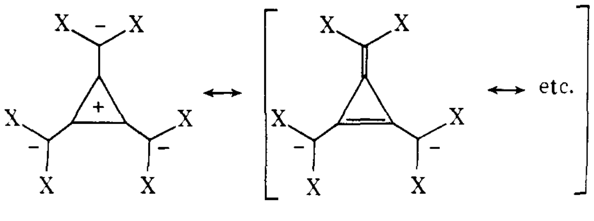
dicating strong mechanical coupling between the geminal cyano groups. The two ir-active C≡N stretches of the bis(TBA) salt of **2a** were also active in the Raman spectrum;[10] however, one was much stronger than the other. Comparison of these results with a fundamental vibrtion mode analysis indicated the expected D_{3h} symmetry for **2a.** In contrast, **2f–i** which contained more than four ester groups appeared to have nonplanar structures in which some ester groups were twisted out of the ring plane due to steric overcrowding, judging from the broadness and complexity of the carbonyl stretching bands. All the dianions showed a skeletal vibration[3a,11] in the ir spectra near 1420 cm^{-1}, that was also observed in the Raman spectra[12] of **2a** and **2i.** A Raman active and ir inactive skeletal vibration of the **2a** bis(TBA) salt appeared as a Fermi pair at 1915 and 1870 cm^{-1}. The corresponding band of the **2i** bis(TBA) salt was observed at 1880 cm^{-1}.

In the ^{13}C NMR spectrum, **2a** exhibited peaks at δ 124.5 (ring), 24.8 (methylene),[13] and 121.0 ppm (nitrile); the hexaester dianion **2i** at 138.4 (ring), 72.7 (methylene), 169.3 (carbonyl), and 49.3 ppm (methoxyl). If the ring carbon shifts are taken as a measure of π charge density,[14] the cyclopropenium **2A** contribution to the ground state may be estimated[15] as 8 and 30% for **2a** and **2i**, respectively. The estimates are consistent with the observed polar solvent effects on the electronic spectra and in qualitative agreement with the MO calculations.[4] The greater contribution of **2A** in the ground state of **2i** relative to **2a** again points to the steric overcrowding among the ester groups in **2i.**



2A **2B**

The polarographic data in Table I indicated that dianions **2** were oxidized in general by two one-electron processes to the radical anions **4** and the neutral species **5**. Although

$$\underset{\mathbf{2}}{[C_6X_6]^{2-}} \underset{+e}{\overset{-e}{\rightleftarrows}} \underset{\mathbf{4}}{[C_6X_6]\cdot^{-}} \underset{+e}{\overset{-e}{\rightleftarrows}} \underset{\mathbf{5}}{[C_6X_6]^{0}} \qquad E_1 \quad E_2$$

some oxidation waves were not reversible, it is evident that the first and second redox potentials as well as the difference between the two can be altered over a wide range by a proper choice of substituents. Thus, the hexaester **5i** is expected to be as electron deficient as TCNQ (−0.37, +0.17 V), but the radical anion **4i** would disproportionate more readily than that of TCNQ. The hexacyano compound **5a** will be one of the most potent π acids and should form a very stable radical anion.[5]

Acknowledgment. The author wishes to thank Drs. D. G. Swartzfager for the polarographic measurements, M. D. Gordon for the MO calculations, and D. W. Ovenall for the CMR studies.

References and Notes

(1) For recent articles on trimethylenecyclopropanes, see T. Bally and E. Haselbach, *Helv. Chim. Acta*, **58,** 321 (1975); E. A. Dorko, R. Sheps, and S. A. Rice, *J. Phys. Chem.*, **78,** 568 (1974).

(2) Triquinocyclopropandiides may be considered as an example of this class. R. West and D. C. Zecher, *J. Am. Chem. Soc.*, **92,** 161 (1970); R. West, D. C. Zecher, S. K. Koster and D. Eggerding, *J. Org. Chem.*, **40,** 2295 (1975).

(3) More pronounced perturbation is expected for the isoelectronic trisheterocyclopropenium ions which have been synthesized recently. (a) For a review, see Z. Yoshida, *Top. Curr. Chem.*, **40,** 48–72 (1973); (b) R. Gomper and U. Jersak, *Tetrahedron Lett.*, 3409 (1973); (c) Z. Yoshida, S. Miki, and S. Yoneda, *ibid.*, 4731 (1973).

(4) MO (PPP-CI) calculations on hexacyano-TMCP provided the following molecular parameters; π bond orders 0.362 and 0.775 for the ring and radial C–C bonds, charge densities +0.074, −0.019, +0.284, and −0.311 for the ring C, radial C, and nitrile C and N, respectively. The corresponding parameters for the dianion **2a** are 0.525, 0.506; +0.083, −0.319, +0.301, and −0.516.

(5) The oxidations of **2** to the radical anions and to the neutral species are reported in the accompanying communications: T. Fukunaga, M. D. Gordon, and P. J. Krusic, *J. Am. Chem. Soc.*, following paper in this issue.

(6) All new compounds analyzed satisfactorily.

(7) S. W. Tobey and R. West, *J. Am. Chem. Soc.*, **85,** 1179 (1963).

(8) Acetylacetone was also condensed successfully.

(9) Phenyl-, and benzoyl-, benzenesulfonylacetonitrile, and nitromethane could also be condensed with **3a.**

(10) All ir spectra were obtained as KBr pellets and Raman spectra as powder.

(11) (a) G. L. Closs, *Adv. Alicyclic Chem.*, **1,** 53 (1966); (b) B. Schrader, *Angew. Chem., Int. Ed. Engl.*, **12,** 885 (1973).

(12) Raman spectra of other dianions have not been examined.

(13) The methylene carbon signal could be unambiguously observed only by judicious addition of chromium acetylacetonate. A paramagnetic reagent can reduce ^{13}C spin–lattice relaxation times and thus increases the sensitivity.

(14) The methylene carbon shifts do not appear to correlate with charge densities, but nuclear paramagnetic shieldings seem to be the dominant term. The methylene carbon shifts of malononitrile and methyl malonate are 9.0 and 41.4 ppm, respectively.

(15) The ring carbon shifts were compared with that of the cyclopropenium ion[16] (δ 177 ppm) assuming that the ^{13}C shift dependence on π charge (167 ppm/π electron[17]) is applicable.

(16) G. A. Olah, J. M. Bollinger, and A. M. White, *J. Am. Chem. Soc.*, **91,** 3667 (1969).

(17) G. A. Olah, P. W. Westerman, and D. A. Forsyth, *J. Am. Chem. Soc.*, **97,** 3419 (1975).

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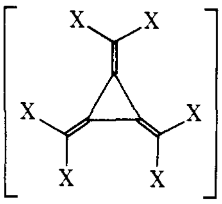
Negatively Substituted Trimethylenecyclopropanes and Their Radical Anions

Sir:

In the accompanying communication[1] we described the synthesis of trimethylenecyclopropanediides, **1**, fully substituted with cyano and/or ester groups. It was also shown that the dianions could be oxidized polarographically via radical anions, **2** to the neutral trimethylenecyclopropanes (TMCP), **3**. We wish to report here the oxidation products of these TMCP dianions.



$\equiv [C_6X_6]^{2-}$

1

$$\underset{\mathbf{1}}{[C_6X_6]^{2-}} \underset{+1e}{\overset{-1e}{\rightleftarrows}} \underset{\mathbf{2}}{[C_6X_6]\cdot^{-}} \underset{+1e}{\overset{-1e}{\rightleftarrows}} \underset{\mathbf{3}}{[C_6X_6]^{0}}$$

a, X = CN; b, X = $COOCH_3$; c, X = H

The disodium salt of **1a** is cleanly oxidized with potassium persulfate in water to maroon, crystalline $K^+[C_6(CN)_6]\cdot^-$ in 95% yield.[2] The latter could be converted by metathesis to other simple 1:1 salts such as the tris(di-

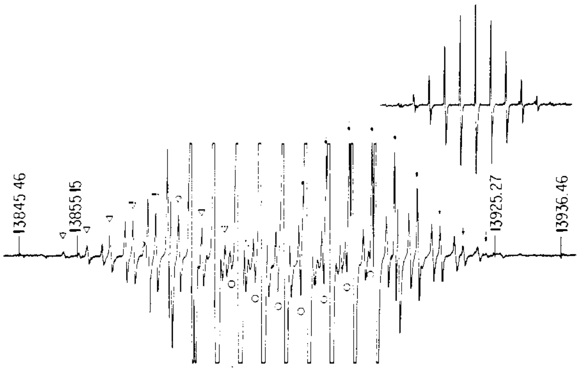


Figure 1. ESR spectrum of $K^+[C_6(CN)_6]\cdot^-$ in THF–HMPA (room temperature) at high amplification showing three sets of isotopic satellite lines (natural abundance): ^{13}C lines from a set of three equivalent carbon atoms (triangles), ^{13}C lines from a set of six equivalent carbon atoms (arrows), and ^{15}N lines (circles). Only one half of each satellite spectrum is labeled. The spectrum at low amplification is shown in the insert. The proton NMR field markers are in kilohertz.

methylamino)cyclopropenium[3] salt of **2a**. The potassium salt showed λ_{max} (in CH_3CN) at 673 nm (ϵ 19 900), 598 (12 900), and 320 (30 500).[4] The ir spectrum exhibited broad and generally featureless background absorption with only two sharp bands at 2225 and 1492 cm^{-1}. The compaction resistivity was 3×10^5 ohm cm. The ESR spectrum of the potassium salt of **2a** in THF-HMPA (2:1 v/v)[5] showed the expected 13 lines (1:6:21:50:90:126:141) due to six equivalent nitrogens (a^N = 0.906 G, g = 2.00275 ± 0.00010) and three sets of isotopic satellite lines (Figure 1). Scrutiny of the relative intensities revealed that two groups of lines are associated with a ^{13}C species containing six (a^C = 7.029 G, nitrile carbons) and three (a^C = 9.992 G) equivalent carbons, respectively, while the third set is associated with the species in which one of the six ^{14}N is replaced by ^{15}N. The ^{15}N doublets (1.277 G) are related to the ^{14}N splitting by the ratio of the respective nuclear moments.[6] The lines associated with the remaining ^{13}C species were not visible, and therefore they must nearly coincide with the major lines of the spectrum. The ^{13}C coupling for this isotopic species is then restricted to the values: 0, 1.81, and 3.62 ± 0.1 G.

INDO calculations[7] were carried out for the radical anions of the parent trimethylenecyclopropane and its hexacyano derivative (see Table I). For the hydrocarbon radical anion **2c**, most of the unpaired π-electron density resides on the three methylene carbons leading to a large positive $a(^{13}C)$ for this position. This is still true for the cyano derivative although some positive spin density is now delocalized onto the nitrogen atoms. An excellent agreement with the INDO results is obtained if the 9.992 G coupling is assigned to the methylene carbons and if the possible absolute value of 3.62 G is chosen for the ring carbons.[8] The latter assignment is also consistent with the value of −2.9 G for the ring carbon splittings calculated by the method of Hinchliffe[9] with the Rieger and Fraenkel spin polarization relationships.[10]

Potassium persulfate can also be used to prepare the radical anion salts $K^+[C_6(CN,COOCH_3)_3]\cdot^-$ and $K^+[C_6(CN)_5,COOCH_3]\cdot^-$ from the corresponding dianions.[1] ESR spectra of high resolution are obtained for both radical anions in the THF-HMPA solvent. For the former, a^N = 0.893 G (3 N) and $a_{CH_3}{}^H$ = 0.362 G (9 H); for the latter, a^N = 0.892 G (5 N) and $a_{CH_3}{}^H$ = 0.445 G (3 H). The ESR of the former radical anion is consistent with an alternating disposition of the CN and $COOCH_3$ substituents.

Table I. INDO and Experimental ESR Results for Trimethylenecyclopropane Radical Anions

Radical anion	Atom	π-Spin densities	a (Gauss) Calcd	a (Gauss) Exptl[a]
2c	C_{ring}	−0.051	−4.30	
	$C_{methylene}$	+0.385	+15.74	
	H		−8.40	
2a	C_{ring}	−0.047	−3.90	(3.62)[b]
	$C_{methylene}$	+0.259	+9.62	9.992
	C_{cyano}	−0.063	−6.19	7.029
	N_{cyano}	+0.124	+1.35 (+1.10)[c]	0.906

[a] Absolute values. [b] See text. [c] Employing ^{14}N relationship suggested by D. M. Hirst, *Theor. Chim. Acta*, 20, 409 (1971).

While the oxidation of the bis(tetrabutylammonium) (TBA) salt[1] of **1a** with bromine afforded $(TBA)[C_6(CN)_6]\cdot^-$, a similar oxidation of the disodium salt gave a purple, complex salt[2] of $Na_6[C_6(CN)_6]_5$ composition, which on recrystallization from alcohol gave a new blue complex salt,[2] $Na_2[C_6(CN)_6]_3$. Polarographic studies showed that the first oxidation-reduction wave (E = +0.35 V)[1] possessed a cathodic as well as an anodic component due to **2a** and **1a**. Assuming that the diffusion coefficients of the two species are equal, the ratio of **1a**/**2a** was calculated to be 0.24 ± 0.02 and 1.08 ± 0.1 for the first and second complex salt, confirming the structures $Na_6(\mathbf{2a})_4(\mathbf{1a})$ and $Na_3(\mathbf{2a})(\mathbf{1a})$, respectively. The tetrathiafulvalene (TTF) salt of **2a** having $(TTF)_2[C_6(CN)_6]^2$ composition was obtained by metathesis of the TBA salt of **1a** or **2a** with TTF chloride.[11] The black crystalline salt had compaction resistivity of 1 ohm cm.

It was further found that thallic trifluoroacetate could oxidize **1a** in trifluoroacetic acid by two one-electron oxidation processes to $[C_6(CN)_6]^0$. Freshly prepared samples were bright yellow, insoluble in the solvent, but turned brown on exposure to air and blue in contact with many solvents. Consequently no attempt was made to obtain elemental analyses. Nevertheless, the mass spectrum (m/e 288.0192; calcd for $C_{12}N_6$ 228.0174), the simple ir spectrum (in Nujol; ν_{max} 2225 w, 1555 s, 1220 m, 1060 s cm^{-1}), and the Raman spectrum (2225, 1765 cm^{-1}) together with the formation of **2a** and **1a** on treatment with KBr and NaI, respectively, confirmed the isolation of $[C_6(CN)_6]^0$. The deceptively simple four-line ir and two-line Raman spectra are strong evidence for the highly symmetric, planar D_{3h} structure for **3a**.

In the case of the hexaester, the conjugate diacid[1] of **1b** was found to be oxidized most cleanly by sodium periodate in water to give $[C_6(COOCH_3)_6]^0$, **3b**, as stable yellow crystals:[2] mp 137–140 °C, m/e 426.0805 (calcd for $C_{18}H_{18}O_{12}$ 426.0797); λ_{max} (in CH_3CN) 400 sh nm (ϵ 16 300), 375 (20 700), 223 (13 700); ^1H NMR (in $CDCl_3$) δ 3.90 ppm (s); ^{13}C NMR (in $CDCl_3$) δ 163.1 ppm (C=O), 122.2 (ring), 119.3 (methylene), 53.0 (OCH_3). The similar chemical shifts of the ring and methylene carbons indicate no or little polarization of the double bonds. It should also be noted that the ring carbon resonance is very similar to that of the dianions **1a** and **1b** (125 and 138 ppm, respectively), suggesting no significant contribution of the cyclopropenium structure to the dianion ground state.[1]

In contrast to the simple ir and Raman spectra of **3a**, **3b** showed complex multiline spectra. Furthermore, all the ir active bands were found, although with different intensities, in the Raman spectrum. These facts strongly suggest that the molecule does not possess D_{3h} symmetry. This distortion is undoubtedly caused by steric overcrowding among the six ester groups.

The neutral hexaester **3b** can be readily reduced to **1b** by iodide ions. In both the formation and the reduction of **3b**, the generation of **2b** was indicated by the transient appearance of a green intermediate. Although its isolation was not successful, the radical anion derived from **3b** in HMPA by the method of Sakurai[12] was detected by ESR. The spectrum consisted of 19 binomial lines appropriate for 18 equivalent protons ($a^H = 0.308$ G).

References and Notes

(1) T. Fukunaga, *J. Am. Chem. Soc.*, preceding paper in this issue.
(2) All new compounds analyzed satisfactorily unless otherwise stated.
(3) Tris(dimethylamino)cyclopropenium hexafluorophosphate[2] was used as the cationic source; for the tetrafluoroborate salt, see Z. Yoshida, *Top. Curr. Chem.*, **40,** 48 (1973).
(4) Other salts of **2a** described also showed similar absorptions.
(5) Mixtures of THF and hexamethylphosphoramide as solvents for radical anions were found to afford ESR spectra of greatly enhanced resolution compared to common solvents. Relatively concentrated solutions can be studied without appreciable line broadening allowing the easy examination of isotopic species in natural abundance.
(6) C. J. Vetee, *J. Chem. Phys.*, **43,** 1080 (1965).
(7) (a) J. A. Pople, D. L. Beveridge, and P. A. Dobosh, *J. Am. Chem. Soc.*, **90,** 4201 (1968); (b) *d*(CC ring) = 1.445 Å, *d*(CC methylene) = 1.395 Å, *d*(CC cyano) = 1.420 Å, *d*(CN) = 1.165 Å, *d*(CH) = 1.08 Å.
(8) (a) The methylene ^{13}C splittings for the related TCNE and TCNQ radical anions are not known with certainty. Our measurements on $TCNE\cdot^-K^+$ in THF–HMPA revealed that the value of 2.92 G suggested for this splitting[8b] is in error. The difficulty arises from overlapping lines. From a careful analysis of the relative intensities of the cyano-^{13}C and ^{15}N satellite lines, we conclude that a^C(methylene) = 6.27 G in this radical anion. For $TCNQ\cdot^-$, the reported value of 7.18 G[8c] must also be questioned in the light of a more recent paper;[8d] (b) P. H. Rieger, I. Bernal, W. H. Reinmuth, and G. K. Fraenkel, *J. Am. Chem. Soc.*, **85,** 683 (1963); (c) P. H. H. Fischer and C. A. McDowell, *ibid.*, **85,** 2694 (1963); (d) M. T. Jones and W. R. Hertler, *ibid.*, **86,** 1881 (1964).
(9) A. Hinchliffe and M. A. Ali, *Theor. Chim. Acta*, **5,** 271 (1966).
(10) P. H. Rieger and G. K. Fraenkel, *J. Chem. Phys.*, **37,** 2795 (1962).
(11) F. Wudl, G. M. Smith, and E. J. Hufnagel, *J. Chem. Soc., Chem. Commun.*, 1453 (1970); F. Wudl, *J. Am. Chem. Soc.*, **97,** 1962 (1975).
(12) H. Sakurai, A. Akada, H. Umino, and M. Kira, *J. Am. Chem. Soc.*, **95,** 955 (1973).
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Synthetic Models of Deoxyribonucleic Acid Complexes with Antimalarial Compounds. I. Interaction of Aminoquinoline with Adenine and Thymine

Sir:

Chloroquine (**1**) is an antimalarial drug which inhibits the DNA and RNA polymerase reactions in vitro and the DNA replication and RNA transcription in susceptible cells.[1] The existence of a strong interaction between chloroquine and nucleoproteins has been demonstrated and the complex seems to be best described in terms of at least two distinct classes of DNA binding sites: the diethylamine of the diaminoaliphatic chain interacts ionically with the anionic phosphate groups, while a more specific interaction is involved between the aromatic portion of the drug and the nucleotide bases.[2] It has been proposed that the protonated aminoquinoline ring[3] is intercalated between the base pairs of double stranded DNA.[4]

In order to study *ring–ring interactions* between the drug and the bases in the absence of complicating factors, we devised the "simplified" models "B-C_3-Q": **2** and **3**. These molecules include the aromatic part of the drug bound to a purine (adenine) or a pyrimidine (thymine), through a trimethylene chain (which is of sufficient length to allow a vertical, intramolecular stacking of the rings).[5] The spectroscopic behavior of such models in solution, compared to that of the corresponding reference compounds **4**, **5** and **6**, should reflect the stacking ability of the systems and hence should give rough information about the affinity of the aminoquinoline portion of chloroquine for a purine or pyrimidine type receptor.

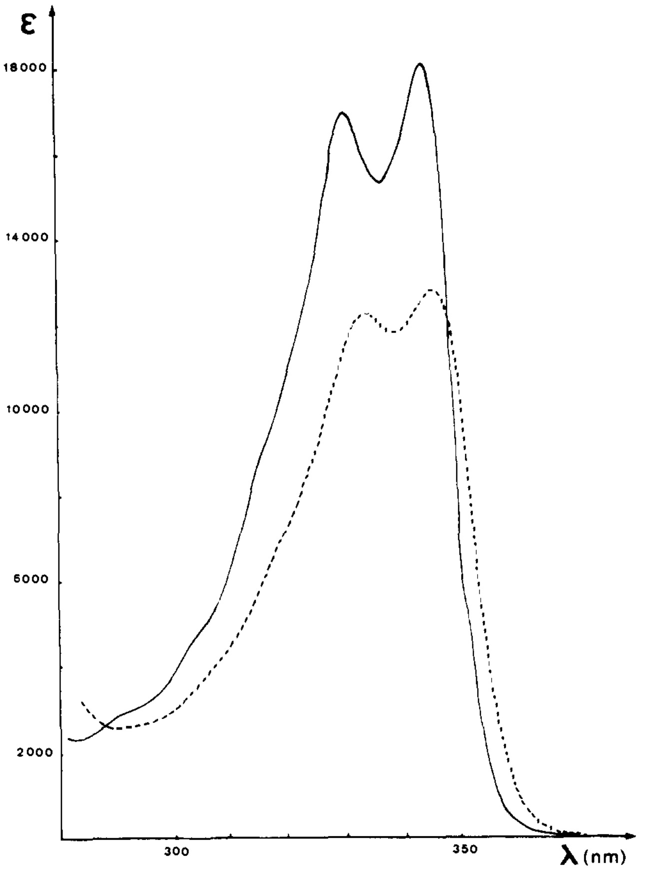
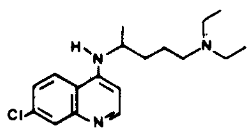
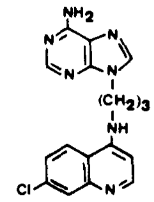
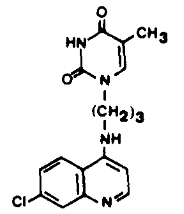
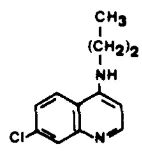


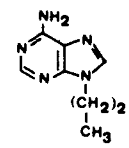
Figure 1. Comparative ultraviolet spectra of **2**, Ade-C_3-Q (- - -), and **4**, Q-C_3 (—), in water, pH 6.9, 5×10^{-5} M, 25 °C.

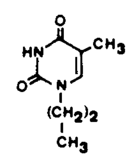

1


2 : Ade-C_3-Q


3 : Thy-C_3-Q


4 : Q-C_3


5 : Ade-C_3


6 : Thy-C_3

Model compounds **2** (Ade-C_3-Q) and **3** (Thy-C_3-Q)[6] were obtained from 4,7-dichloroquinoline through a nucleophilic substitution reaction by the primary amino function of the appropriate aminopropylnucleotide base. Thus, 9-(3-aminopropyl)adenine (Ade-C_3-NH_2)[7] was treated with 4,7-dichloroquinoline in DMSO at 120°, to afford **2** (Ade-C_3-Q) (mp 255–256°, yield 60%). Reaction of 1-(3-aminopropyl)thymine formate (Thy-C_3-NH_3^+, $HCOO^-$)[8] with the same dichloroquinoline in DMSO in the presence of