

spectively. The ester products were hydrolyzed directly in the reaction mixture,<sup>2b</sup> and the overall yields of 1-propanol (1-OH-<sup>14</sup>C) and 2-propanol (2-OH-<sup>14</sup>C) ranged from 92 to 95% according to isotope dilution calculations. 1-OH-<sup>14</sup>C was degraded in the usual way through conversion to propionic acid, acetic acid, and methylamine,<sup>17</sup> and 2-OH-<sup>14</sup>C was degraded by conversion to acetone, dimethylphenylcarbinol, and benzoic acid as described by Lee and Woodcock.<sup>4</sup>

**Trifluoroacetylation of 1-Butyl-*I*-<sup>14</sup>C Tosylate (6-OTs-*I*-<sup>14</sup>C).** A solution of 8.00 g (35 mmol) of 6-OTs-*I*-<sup>14</sup>C (prepared as previously described<sup>13</sup>) in 40 ml of F<sub>3</sub>CCOOH was heated under reflux for 7 days. The reflux condenser was protected by a silica gel drying tube and was cooled by refrigerated water at 6–8°. The reaction time was chosen after preliminary nmr monitoring indicated that about 7 days were needed for the complete disappearance of the C-1 proton triplet of the 6-OTs. In a third run, the reaction time was extended to 9 days and the isotopic scramblings in the recovered 2-butyl product were not significantly different (Table V).

At the completion of the period of refluxing, about 10% of the reaction mixture was removed for product analysis by isotopic dilution. Weighed quantities (about 3 g) of ordinary 1-butyl, 2-butyl, *tert*-butyl, and isobutyl trifluoroacetates were added as carriers. A sufficient amount of aqueous KOH solution was then

added to neutralize the mixture and leave a final solution containing 20% KOH. This basic solution was refluxed for 2 hr to effect the hydrolysis of the esters to the isomeric butyl alcohols. The specific activities of these alcohols, recovered by preparative vpc,<sup>13</sup> were utilized to estimate the product yields by isotopic dilution as previously described.<sup>13</sup> The total yield of the isomeric butyl alcohols was about 50%, their relative composition being given in Table III. It should be noted that control experiments using their nmr spectra as an indicator showed that 1-butyl, 2-butyl, and isobutyl trifluoroacetates were stable under the trifluoroacetylation conditions, while decomposition definitely took place with *tert*-butyl trifluoroacetate. Thus the relative yield of *tert*-butyl product as recorded in Table III represents only the surviving portion of the *tert*-butyl ester.

The remainder of the reaction mixture (about 90%) was also neutralized and then hydrolyzed in 20% KOH. 1-Butanol (6-OH) and 2-butanol (7-OH) (about 5 g each) were added as carriers and the 6-OH-<sup>14</sup>C and 7-OH-<sup>14</sup>C were recovered by preparative vpc and degraded as described by Lee and Zea Ponce<sup>13</sup> to give the <sup>14</sup>C distributions recorded in Tables IV and V.

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## A Study of the Biscyclooctatetraene and the Phenylcyclooctatetraene Anion Disproportionation Equilibria

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Contribution from the University of Puerto Rico,  
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**Abstract:** The thermodynamic parameters controlling the disproportionation equilibrium ( $\pi^{2-} + \pi \rightleftharpoons 2\pi^{\cdot-}$ ) constant for biscyclooctatetraene and phenylcyclooctatetraene have been studied in hexamethylphosphoramide. Upon comparing these thermodynamic parameters with those for cyclooctatetraene, we find that the enthalpy term increases with the degree of conjugation from the cyclooctatetraene ring system due to the decreased electron–electron repulsion in the dianion. However, the entropy term increases with extended conjugation of the ring system due to the formation of freer ions. Extended conjugation decreases ion pairing due to the dispersion of charge in the anion radical and dianion.

It is well known that solutions of cyclooctatetraene (COT) in hexamethylphosphoramide (HMPA)<sup>1</sup> or in ethereal solvents<sup>2–4</sup> will dissolve alkali metal to form the COT dianion and anion radical. The concentrations of these species are controlled by the disproportionation equilibrium (eq 1, where  $\pi = \text{COT}$ ).



The thermodynamic parameters controlling this equilibrium are more sensitive functions of ion pairing than esr parameters and possibly conductivity measurements.<sup>1</sup> Based upon the effect of the alkali metal counterion upon these thermodynamic parameters, ion pairing was observed in HMPA<sup>1</sup> where previously only free ions were thought to exist.<sup>5</sup> HMPA is still recog-

nized as one of the most powerful solvating agents for alkali metal cations.<sup>6,7</sup>

Here we wish to report the formation of the dianion and anion radical of biscyclooctatetraene (BCOT) and phenylcyclooctatetraene (PCOT) along with the thermodynamic parameters for their disproportionation equilibria in HMPA.

### Experimental Section

X-Band esr spectra were recorded using a Varian E-3 esr spectrometer. The temperature was controlled using a Varian V-4557 variable-temperature controller. The sample preparation was exactly the same as previously described.<sup>1</sup>

BCOT was synthesized by the method of Cope and Marshall<sup>8</sup> and was recrystallized twice from ether to give a constant melting point of 125–126°. The mass spectrum and nmr were consistent with the pure compound. PCOT was synthesized by the method of

(1) G. R. Stevenson and J. G. Concepción, *J. Phys. Chem.*, **76**, 2176 (1972).

(2) T. J. Katz and G. K. Fraenkel, *J. Amer. Chem. Soc.*, **82**, 3784, 3785 (1960).

(3) F. J. Smentowski and G. R. Stevenson, *ibid.*, **91**, 7401 (1969).

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(6) H. Normant, *Angew. Chem., Int. Ed. Engl.*, **6**, 1046 (1967).

(7) G. R. Stevenson, L. Echegoyen, and L. R. Lizardi, *J. Phys. Chem.*, **76**, 1439 (1972).

(8) A. C. Cope and D. J. Marshall, *J. Amer. Chem. Soc.*, **75**, 3208 (1953).

Cope and Kinter<sup>9</sup> and fractionally distilled at a pressure of 5  $\mu$  and collected from 58 to 59°.

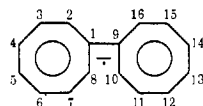
The anion radical spin concentrations were determined using the system COT-HMPA-K as a spin standard as previously described.<sup>10</sup>

## Results and Discussion

Solutions of BCOT in HMPA,  $10^{-4}$ – $10^{-3}$  M, will dissolve potassium metal to form the respective anion radical. The hyperfine pattern for the anion radical of BCOT did not show any temperature dependence upon the coupling constants between  $-10$  and  $60^\circ$ . This pattern consists of a nonet of 2.38 G due to eight equivalent protons, a triplet of 0.56 G due to two equivalent protons, and a pentet of 0.28 G due to four equivalent protons (Figure 1).

Hückel theory indicates that the three nonbonding electrons occupy a doubly degenerate molecular orbital whether or not the two rings are coplanar. From Table I it is clear that these results are not inconsistent

**Table I.** Coupling Constants and Spin Densities for the BCOT Anion Radical



Position	$a_h$ , G	Experimental electron spin density	Pariser-Parr-Pople <sup>a</sup> electron spin density	Hückel electron spin density
1, 9		0.00	0.00	0.00
2, 8, 16, 10	$2.38 \pm 0.01$	0.113	0.104	0.125
3, 7, 15, 11	$0.28 \pm 0.01$	0.013	0.00	0.00
4, 6, 14, 12	$2.38 \pm 0.01$	0.113	0.147	0.125
5, 13	$0.56 \pm 0.01$	0.027	0.00	0.00

<sup>a</sup> The bond distance between  $C_1$  and  $C_9$  was taken as 1.492 Å, all others are 1.396 Å.  $135^\circ$  was used for the bond angle within the COT rings.

with the Hückel prediction or the more sophisticated Pariser-Parr-Pople calculation.

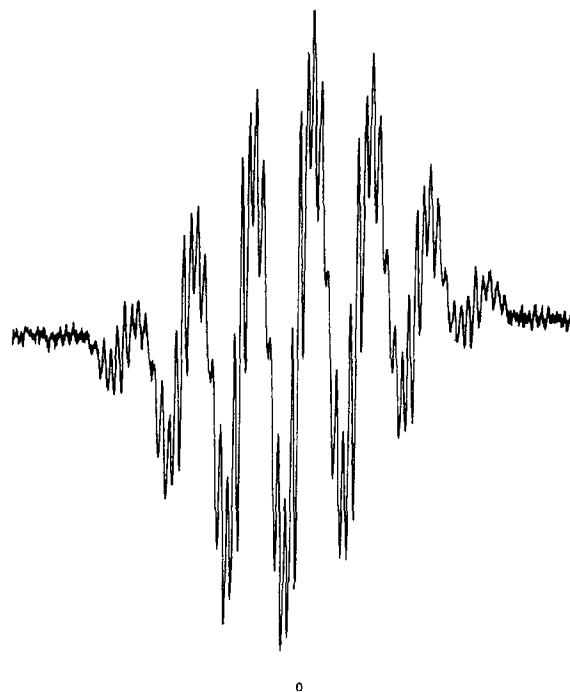
Addition of more potassium to the anion radical solution of BCOT results in a decrease in the intensity of the esr signal. The solution becomes diamagnetic upon the addition of 2 mol of potassium metal/mol of BCOT. Addition of neutral BCOT to the diamagnetic solution under high vacuum results in a return of the esr signal for the anion radical of BCOT. This confirms the formation of the dianion.

Addition of more potassium to the diamagnetic dianion solution results in the observation of the solvated electron, without evidence for the formation of the trianion radical.

The anion radical of BCOT formed in tetrahydrofuran (THF) by alkali metal reduction yields only a single line upon esr analysis from  $-110$  to  $+60^\circ$ . Even after 2 mol of metal had dissolved the single broad esr line persisted. Solutions of BCOT were reacted with a potassium mirror for 12 hr and passed through a frit under high vacuum. These filtered

(9) A. C. Cope and M. R. Kinter, *J. Amer. Chem. Soc.*, **73**, 3424 (1951).

(10) F. J. Smentowski and G. R. Stevenson, *J. Phys. Chem.*, **73**, 340 (1969).



**Figure 1.** Esr spectrum of the system BCOT-HMPA-K.

samples were then added to water and titrated with a standardized HCl solution. The titration results indicate that 2.1 mol of potassium had dissolved per mol of BCOT; thus no evidence for the formation of the trianion radical exists.

For the case of phenylcyclooctatetraene (PCOT) anion radical formed in HMPA by potassium reduction, the esr pattern is identical with that reported by Carrington, *et al.*,<sup>11</sup> in tetrahydrofuran at  $-100^\circ$ . The spectrum consists of a quintet of 3.8 G due to four equivalent protons and a quartet of 2.2 G due to three equivalent protons. This pattern is invariant with temperature.

The anion radical concentrations for the systems BCOT-HMPA-K and PCOT-HMPA-K were determined using the system COT-HMPA-K as a spin standard. The technique used has been previously described.<sup>1,10</sup> Assuming a Lorentzian line shape, the anion radical concentration is proportional to the esr peak height ( $I$ ) times the square of the extrema line width ( $\Delta W$ ). The equilibrium constant can be expressed as shown in eq 2, where  $B$  is a proportionality

$$K = (BI\Delta W^2)^2 / (\pi)(\pi^{2-}) \quad (2)$$

constant and  $(\pi)$  represents the concentration of BCOT or PCOT. A revised van't Hoff plot of  $\ln(I\Delta W^2)$  vs.  $1/RT$  yields a straight line for all systems with a slope of  $-\Delta H^\circ/2$  (Figure 2). The corresponding thermodynamic parameters are shown in Table II.

**Table II.** Thermodynamic Parameters of the Disproportionation Equilibria in HMPA at 25°. Potassium is the Reducing Agent

Subs.	$K_{eq}$	$\Delta H^\circ$ , kcal/mol	$\Delta S^\circ$ , eu
COT	$(2.3 \pm 1) \times 10^{-5}$	$-4.6 \pm 0.7$	-46
BCOT	$(2.2 \pm 1) \times 10^{-4}$	$-2.4 \pm 0.5$	-25
PCOT	$(5.6 \pm 1) \times 10^{-5}$	$-3.7 \pm 0.5$	-32

(11) A. Carrington, R. E. Moss, and P. F. Todd, *Mol. Phys.*, **12**, 95 (1966).

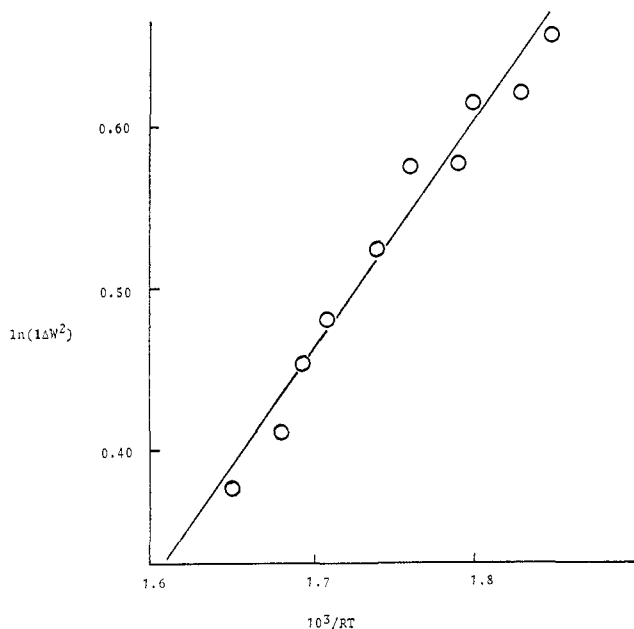


Figure 2. Modified van't Hoff plot for the system BCOT-HMPA-K.  $\Delta W$  is the line width for the overmodulated spectrum.

From Table II it is clear that the enthalpy of disproportionation increases as the degree of conjugation from the COT ring is extended. This is the expected result since extended conjugation of the COT ring system lowers the electron-electron repulsion effect in the dianion. The entropy term has been shown to be due to ion pairing.<sup>1</sup> Ion pairing decreases as the

charge of the anion and dianion is dispersed. Thus, the extension of the conjugation has the expected result of increasing the entropy of disproportionation.

From Table III it is clear that the variance of  $K_{eq}$

Table III. Thermodynamic Parameters for the PCOT and the COT Disproportionation Equilibrium in HMPA at 25°

System	$K_{eq}$	$\Delta H^\circ$	$\Delta S^\circ$
COT-HMPA-Li	$(5.0 \pm 2) \times 10^{-4}$	$-7.8 \pm 1$	$-29 \pm 2$
COT-HMPA-Na	$(2.3 \pm 1) \times 10^{-3}$	$-4.2 \pm 0.3$	$-26 \pm 1$
COT-HMPA-K	$(2.3 \pm 1) \times 10^{-5}$	$-4.6 \pm 0.7$	$-46 \pm 1$
PCOT-HMPA-Li	$(1.6 \pm 0.5) \times 10^{-4}$	$-4.9 \pm 0.2$	$-29 \pm 1$
PCOT-HMPA-Na	$(4.1 \pm 1) \times 10^{-4}$	$-4.6 \pm 0.2$	$-27 \pm 1$
PCOT-HMPA-K	$(5.6 \pm 1) \times 10^{-5}$	$-3.7 \pm 0.5$	$-32 \pm 1$

with counterion is mainly due to the entropy and not the enthalpy term. The case is more dramatic for the COT systems than it is for the PCOT systems. Comparing the system COT-HMPA-K and the system COT-HMPA-Na, we see that the enthalpies are almost identical, but the entropies differ by 20 entropy units. Since the charge on the anions of PCOT is more dispersed than it is for the COT anions, there is less ion pairing and, thus, the entropy term reflects a much smaller dependence upon the cation for the PCOT systems.

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## Hydrogen-Deuterium Exchange in Some Polymer Amides

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**Abstract:** The kinetics of hydrogen-deuterium exchange was followed for two polymers, poly(*N*-ethylacrylamide) and poly(*N*-ethylmethacrylamide), which contain side chain amide groups. Conformational information for these polymers was obtained from viscometry and nuclear magnetic resonance. Infrared spectra showed the presence of hydrogen-bonded and of free amide groups in both polymers. Single first-order exchange processes were observed, and the rate constants,  $k$ , obtained from the appearance of OH absorption bands or the disappearance of NH bands, are the same. The polymers exchange more slowly than structurally similar small amides. This behavior is interpretable in terms of steric effects, changes in local dielectric constant in the region of the amide group, and changes in the character of water in the vicinity of the polymers.

The characteristics of many simple chemical reactions may be markedly different in a protein environment than in bulk solution. Some reactions, for example enzyme-catalyzed ones, are markedly accelerated. In contrast, many are strikingly hindered, either thermodynamically or kinetically. Changes in the  $pK_a$  of tyrosine residues provide examples of the former, decreases in reactivity of sulfhydryl groups are illustrations of the latter.

The molecular basis for such gross changes in reactivity in a protein environment will be different in

details in each case. Nevertheless, some general principles may emerge from a detailed study of a single one of these modified reactions. A fairly comprehensive examination has been made, therefore, of the intrinsic and extrinsic factors that influence one of the simplest of chemical changes, the exchange of H atoms by D atoms.

Studies with small model amides<sup>1,2</sup> show that the exchange rate is very sensitive to  $H^+$  and  $OH^-$  as well

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