0.2H_2O: C, 60.13; H, 4.71; N, 15.57. Found: C, 60.38; H, 4.64; N, 15.23. UV-vis spectrum (pH 7.00 buffer) 252 (1.42×10^4), [290] (2200), 400 nm (1100).

Detection and Isolation of 3_{ox} and 7 during the Solvolysis of 3 in pH 7.00 0.2 M Phosphate Buffer. A solution of 50 mg (0.148 mmol) of 3·HBr in 60 mL of pH 7.00 0.20 M phosphate buffer (μ = 1.0, KCl) was prepared under strictly anaerobic conditions and then stirred for 1.5 h at 30 °C. Opening of the reaction to the air was followed by extraction 5x with 50-mL portions of chloroform. These extracts were dried over $MgSO_4$, filtered, and concentrated to afford a green-yellow solid, 6.6-mg yield. TLC in 10% ethanol in chloroform indicated 7 as the major product with a trace amount of 3_{ox}. Thus, the crude product represents ~25% yield based on 3·HBr. Separation of the two quinones was carried out by using a 25-g silica gel column prepared with chloroform. Elution with chloroform removed 3_{ox} followed by 7. The identity of 7 was determined by ^1H NMR and mass spectral comparison with those of authentic material. The identity of 2-(bromomethyl)-1-methylbenzimidazole-4,7-dione (3_{ox}) was established by spectral means: ^1H NMR ($CDCl_3$) δ 6.69 and 6.68 (2 H, d, 5-H and 6-H), 4.58 (2 H, s, CH_2Br), 4.04 (3 H, s, N-(1)-methyl); mass spectrum; m/z 254 ($M^+ - H$), 256 ($M^+ + 2H$), 175 ($M^+ - Br$).

Isolation of 6 from the Reaction of 3 and 2-Mercaptoethanol in pH 7.00 Phosphate Buffer. A solution consisting of 50 mg (0.174 mmol) of 3-HBr in 2 mL of methanol was combined with 5 mL of pH 7.00 0.2 M phosphate buffer (μ = 1.0, KCl) and 135 μL (1.74 mmol) of 2-mercaptoethanol under strictly anaerobic conditions. After a 5-min reaction time the reaction mixture was opened to the air and immediately acidified by addition of concentrated HCl. Evaporation in vacuo afforded a mixture of buffer salts and the product. To remove the latter, solids were extracted with ethanol, and the insoluble material was discarded. Crystallization of the product from the filtrate was facilitated by concentration to ~1 mL and then dilution to ~5 mL with ethyl acetate: yield; 33.8 mg (67%) of 6·HCl; ^1H NMR (Me_2SO-d_6) δ 6.78 (2 H, s, Ar), 4.30 (2 H, s, 2-methyl), 4.14 (3 H, s, N(1)-methyl), 3.52 and 2.70 (4 H, 2 t, J = 6 Hz, SCH_2CH_2O). Anal. Calcd for $C_{11}H_{14}N_2O_3S$·HCl·$2H_2O$: C, 40.42; H, 5.86; N, 8.56. Anal. Found: C, 40.26; H, 4.65; N, 8.26.

Acknowledgment. This research was supported by the Chemistry Department at Arizona State University, a Faculty Grant-in-aid from Arizona State University, a Cottrell Research Grant from Research Corporation, the donors of the Petroleum Research Fund, administered by the American Chemical Society, and by an award from the National Cancer Institute, DHHS (PHS #1 R01 CA 36876-01).

Registry No. 3, 99922-37-9; 3·HBr, 99922-30-2; 3_{ox}, 99922-35-7; 5·HCl, 99922-31-3; 6·HCl, 99922-36-8; 7, 97042-58-5; 8·HBr, 99922-34-6; 9, 26002-57-3; 9 trifluoroacetate, 99922-26-6; 10, 56741-28-7; 11, 99922-27-7; 12, 99922-28-8; 13, 99922-29-9; 14, 99922-32-4; 15, 99922-33-5; $(CF_3C(O))_2O$, 407-25-0; $HS(CH_2)_2OH$, 60-24-2; glycolic acid, 79-14-1.

Deprotonation/Alkylation Reactions of Monoalkyl 9,10-Dihydroanthracenes and 7,12-Dihydropleiadenes. Stereochemical Outcome and Anion Models

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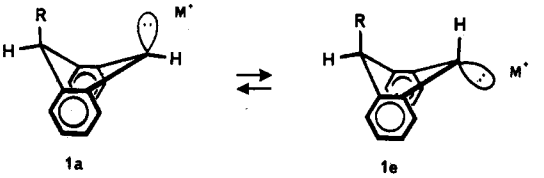
Received August 2, 1985

The alkylation stereochemistry of 9-alkyl-10-lithio-9,10-dihydroanthracene has often been explained on the basis of inverting, boat-shaped anion models. Recent carbon-13 NMR data for these anions has led to the suggestion of a flattened, sp^2-hybridized model, and alkylation studies herein are presented in support of this model. Since recent molecular mechanics calculations have indicated a wide range of central ring folding for 9,10-dihydroanthracenes (DHA's), alkylation studies with a system of known, reliable geometry were desirable. Hence, results are presented for a series of 7-alkyl-12-lithio-7,12-dihydropleiadenes (DHP's), and it is concluded that the neutral precursor geometries do not serve as good models for the anions. Substituent preferences in DHP's are examined by molecular mechanics calculations.

The alkylation of 9-alkyl-10-metallo-9,10-dihydroanthracene has attracted a considerable amount of attention.[1] From NMR studies, the neutral precursors (9,10-dihydroanthracenes) have been regarded as rapidly inverting boat structures with substituents preferentially located at the pseudoaxial position.[2] This concept, together with the stereochemical outcome of early alkylation studies, led to the model shown as **1a** ⇌ **1e**. An alkylation



1a **1e**

with small alkyl halides (R′X) was considered to give cis products via **1a**, whereas larger R′X (and R) produced trans products presumably via faster alkylation of **1e**. In the latter case, reaction was expected to be slower with **1a** due to a transannular steric effect between the substituent R and the alkylating agent R′X.[3]

(1) (a) Harvey, R. G.; Arzadon, L.; Grant, J.; Urberg, K. *J. Am. Chem. Soc.* **1969**, *91*, 4545. (b) Harvey, R. G.; Arzadon, L. *Tetrahedron* **1969**, *25*, 4887. (c) Harvey, R. G.; Davis, C. C. *J. Org. Chem.* **1969**, *34*, 3607. (d) Harvey, R. G. *Synthesis* **1970**, 161. (e) Zieger, H. E.; Schaeffer, D. J.; Padronnagio, R. M. *Tetrahedron Lett.* **1969**, 5027. (f) Schaeffer, D. J.; Zieger, H. E. *J. Org. Chem.* **1969**, *34*, 3958. (g) Schaeffer, D. J.; Litman, R.; Zieger, H. E. *J. Chem. Soc., Chem. Commun.* **1971**, 483. (h) Zieger, H. E.; Gelbaum, L. T. *J. Org. Chem.* **1972**, *37*, 1012. (i) Panek, E. J.; Rodgers, T. J. *J. Am. Chem. Soc.* **1974**, *96*, 6921. See also: Panek, E. J. *Ibid.* **1974**, *96*, 7961. (j) Daney, M.; Lapouyade, R.; Mary, M.; Bouas-Laurent, H. *J. Organomet. Chem.* **1975**, *92*, 267. (k) Fabre, C.; Salem, M. H. A.; Mazaleyrat, J. P.; Tchaplo, A.; Welvart, Z. *Ibid.* **1975**, *87*, 9. (l) Fu, P. P.; Harvey, R. G.; Paschal, J. W.; Rabideau, P. W. *J. Am. Chem. Soc.* **1975**, *97*, 1145. (m) Bank, S.; Bank, J.; Daney, M.; Labrande, B.; Bouas-Laurent, H. *J. Org. Chem.* **1977**, *42*, 4058. (n) Daney, M.; Lapouyade, R.; Bouas-Laurent, H. *Tetrahedron Lett.* **1978**, 783. (o) Rabideau, P. W.; Burkholder, E. G. *J. Org. Chem.* **1978**, *43*, 4283. (p) Daney, M.; Lapouyade, R. *J. Organomet. Chem.* **1979**, *172*, 385. (q) Rabideau, P. W.; Burkholder, E. G. *J. Org. Chem.* **1979**, *44*, 2354. (r) Daney, M.; Bouas-Laurent, H.; Calas, B.; Giral, L.; Platzer, N. *J. Organomet. Chem.* **1980**, *188*, 277. (s) Daney, M.; Lapouyade, R.; Bouas-Laurent, H. *J. Org. Chem.* **1983**, *48*, 5055.

(2) (a) For a review: Rabideau, P. W. *Acc. Chem. Res.* **1978**, *11*, 141. (b) Dalling, D. K.; Zilm, K. W.; Grant, D. M.; Heeschen, W. A.; Horton, W. J.; Pugmire, R. J. *J. Am. Chem. Soc.* **1981**, *103*, 4817.

0022-3263/86/1951-0527$01.50/0

Table I. Deprotonation/Alkylation Reactions of 9-Alkyl-9,10-dihydroanthracenes and 7-Alkyl-7,12-dihydropleiadenes[a,b]

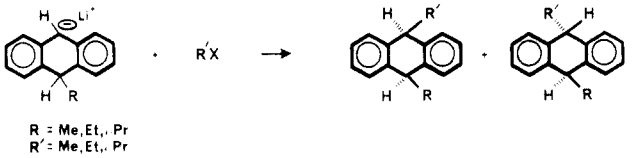
substrate	cis:trans ratio for reaction with R′X		
	CH_3I	CH_3CH_2Br	$(CH_3)_2CHBr$
MeDHA[c]	91:9	88:12	34:66
	(89:11)[d]	(87:13)[d]	(35:65)[d]
EtDHA[c]	100:0	95:5	62:38
i-PrDHA[c]	100:0	72:28	25:75
7-MeDHP[e]	57:43	40:60	10:90
7-EtDHP[e]	78:22	41:59	10:90
7-*i*-PrDHP[e]	8:92	5:95	0:100

[a] Ratios from GLPC on an OV-1 column. [b] Isomer assignment by NMR. [c] Deprotonated by *n*-BuLi and alkylated in THF at −78 °C. [d] Anhydrous NH_3 added before alkylation. [e] Alkylation in THF at 0 °C (data from ref 9); see ref 12.

More recently, molecular mechanics calculations have suggested a wide range of folding angles for 9,10-dihydroanthracenes (DHA's) and have even predicted planar minima in some cases.[4] This is especially interesting since the presumed boat-to-boat ring inversion has never been observed by NMR even at low temperatures.[5] These results, together with a proton NMR study[1i] of some DHA anions suggesting sp^2 hybridization at the anionic center, prompted us to examine the carbon-13 NMR spectra of DHA–Li and 9-*t*-Bu-10-LiDHA[6] since this technique has proven to be a useful tool for the determination of electron delocalization and conformational preference in charged species.[7] Indeed this study suggested sp^2 hybridization as well as flattened geometries even with a large substituent. Herein we attempt to rationalize the alkylation stereochemistry of 9-R-10-LiDHA in terms of this model and also test the general usefulness of neutral precursor geometry in predicting anion conformations.

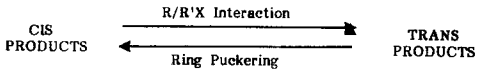
Results and Discussion

We wished to examine the stereochemical outcome of the alkylation of 9-R-10-LiDHA (**2**) with variation in both R and R′ (Me, Et, *i*-Pr). We have already considered the R = *i*-Pr case,[1i] and so we extended these conditions (*n*-BuLi/THF/−78 °C) to include Me and Et.[8] The data are summarized in Table I. These results, together with the previous carbon-13 NMR study, lead to a general model for the anion as follows: *an anion with sp^2 hybridization*

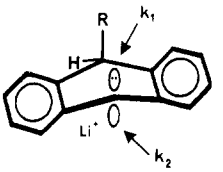


at the anionic center and a "flattened" geometry for the central ring. Hence rather than the ring-to-ring inversion this involves a broad potential well with wide amplitude vibration around a single minimum. We envision a planar minimum for DHA–Li itself and slightly puckered minima for 9-R-10-LiDHA. In the latter case, the degree of puckering is expected to be related to the size of R.

Scheme I



From this model, two major effects emerge. If we first consider the effect of puckering on the rate of axial vs. equatorial alkylation (i.e., k_1 vs. k_2 in **3**), it can be easily seen from models that the axial side of the p-orbital is more accessible since "peri" interactions from the ortho hydrogens partially block the equatorial side (albeit "extreme" puckering could cause the bottom lobe of the p-orbital to protrude resulting in an increase of k_2). This predicts cis



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products (i.e., $k_1 > k_2$). However, as R and R′X increase in size, the transannular steric interaction becomes important and k_1 decreases relative to k_2. This would, of course, predict a reversal to trans products (see Scheme I). Application of this proposal follows below.

With MeI as the alkylating agent (R′X), the transannular steric effect is expected to be minimal in each case, and this predicts cis products. The results (Table I) indicate 91%, 100%, and 100% cis in the series R = Me, Et, and *i*-Pr. It is interesting to note that R = Me provides some trans (9%). This is consistent with our scheme since we expect less (average) ring puckering in this case. Alkylation with larger R′X provides some fascinating results that clearly demonstrate the validity of our approach. Ethylation produces a decrease in trans products going from R = Me to R = Et but then increases again with R = *i*-Pr (12% to 5% to 28%). This is very instructive and quite consistent with the above model. We argue that in going from Me to Et, the DHA ring-puckering effect is increasing more than the transannular steric effect. That is, the average rotational state of the ethyl group (i.e., greatest population) is to "flag out" away from the central ring.[4b] Thus an Et group in this position is expected to exert a greater steric effect on the "peri" hydrogens (ring puckering) than it does on the group across the ring (transannular effect). Hence (see Scheme I) the slight decrease in trans products. However, with ethylation of 9-*i*-Pr-10-LiDHA, the relatively large size of the *i*-Pr group retards k_1. With R′ = *i*-Pr, transannular effects are important in all cases with appreciable amounts of trans products, 66%, 38%, and 75% in the series R = Me, Et, and *i*-Pr. However, once again a decrease in trans products is observed in going from R = Me, which then increases with R = *i*-Pr. We believe this to be caused by the same effects outlined above for R′ = EtBr. It should also be noted that data are available for the alkylation of 9-*t*-Bu-10-LiDHA,[1i] although it is not included in Table I since it was done at a different temperature. Nonetheless the results are quite consistent with the results (and interpretation) herein.

Since some ambiguity exists concerning the solution conformation of DHA and its derivatives, the question of whether or not the geometries of the neutral precursors

(3) Completely planar anions were suggested in an earlier study,[1i] but this appeared rather inconsistent with alkylation results.[1n]

(4) (a) Lipkowitz, K. B.; Rabideau, P. W.; Raber, D. J.; Hardee, L. E.; Schleyer, P. v. R.; Kos, A. J.; Kahn, R. A. *J. Org. Chem.* **1982**, *47*, 1002. (b) Raber, D. J.; Hardee, L. E.; Rabideau, P. W.; Lipkowitz, K. B. *J. Am. Chem. Soc.* **1982**, *104*, 2843.

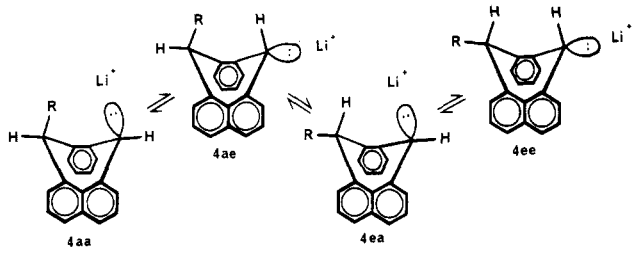
(5) DHA itself and many of its derivatives are folded in the solid state.[2]

(6) Rabideau, P. W.; Wetzel, D. M.; Husted, C. A.; Lawrence, J. R. *Tetrahedron Lett.* **1984**, 31.

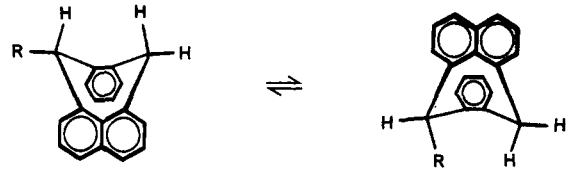
(7) (a) Young, R. N. *Prog. NMR Spectrosc.* **1979**, *12*, 261. (b) Hallden-Abberton, M.; Fraenkel, G. *Tetrahedron* **1982**, *38*, 71.

(8) (a) The case of R = Me, R′ = *i*-Pr was examined previously by Zieger and Gelbaum[1h] although with slightly different results (66% vs. 59% trans). However reaction conditions are not identical. (b) The carbon-13 NMR spectra were recorded with NH_3/THF as solvent. To justify application to the experiments herein, we also carried out selected alkylations under the conditions. The results (Table I) are almost identical. This is not unexpected, see ref 1i.

Scheme II



serve as a useful model for the anions cannot be answered. This led us to seek a cyclic, diarylmethane system wherein the geometry is well established.[9] Such an example is provided by the 7,12-dihydropleiadenes (DHP). Inversion barriers are relatively high ($\Delta G^{\ddagger}$ = 13–16 kcal/mol[10]), and moreover, DHP's exhibit an interesting variation in group preference. A single methyl substituent shows preference (88%) for the pseudoequatorial position whereas ethyl is nearly 50:50 and isopropyl is pseudoaxial (95%).



R		
Me	88%	12%
Et	48%	52%
iPr	< 5%	>95%

It is interesting to consider a scheme for 7-R-12-LiDHP (Scheme II) similar to the earlier proposals for the DHA anions.[1] In fact, a folded (boat conformation) model is more appropriate for DHP than DHA due to the requirements for the interior angles of a seven- vs. six-membered ring. This point is supported by a considerably higher inversion barrier for DHP's.

It must be realized that precursor geometries could only be important in determining product ratios if alkylation rates were of the same order of magnitude as interconversion rates. This is, of course, the Curtin–Hammett Principle.[11] With DHP's, the interconversion rates are relatively slow with values for the first-order rate constants ranging from 35 to 150 s^{-1} over a temperature range of 6–42 °C.[10] Alkylation rates for DHP anions are not known, but Bank, et al.[1m] have carried out kinetic studies with a variety of DHA anions as well as diphenylmethyl anion. With hexyl bromide and isopropyl iodide, rates were generally greater than 2×10^3 M^{-1} s^{-1}, although slower rates were found with isopropyl bromide. It should also be noted, however, that in contrast to the kinetic study, the present work involves reverse quenching into a large excess of alkyl halide.

In evaluating potential geometries, we realize that an axial anion orbital (**4aa** and **4ea**) will overlap with the adjacent aromatic rings, but the equatorial configuration (**4ae** and **4ee**) will not. Hence in the absence of serious transannular steric effects, we would expect axial alkylation. However, in the presence of transannular effects, alkylation would occur at the back lobe of an axial anionic center or with the (unlikely) equatorial anion. In any event, a slower reaction rate would be expected. This means that structure **4ea** would be the most likely candidate in the 7-methyl case (since methyl prefers the equatorial site), and this predicts trans products. In fact (Table I), although isopropylation does afford 90% trans, ethylation shows only a slight (60%) trans preference, and methylation provides 57% cis.[12] In the 7-ethyl case **4aa** and **4ea** would seem to be likely precursors with **4ea** reacting fastest due to the presence of a transannular steric effect in **4aa**. This again predicts trans. However, the ethyl system shows even greater cis tendencies than the methyl case.

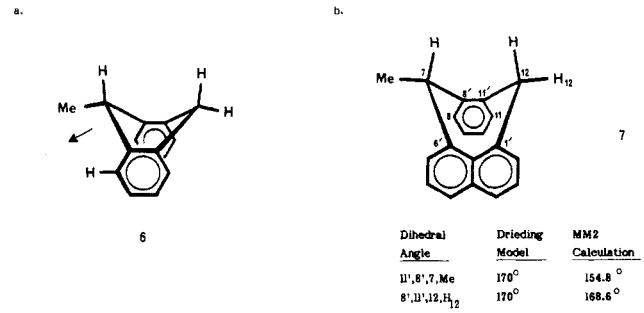
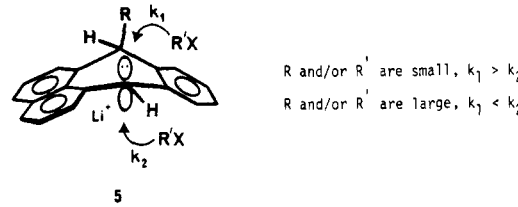


Figure 1. (a) Pseudoequatorial conformation of 9-methyl-9,10-dihydroanthracene. (b) Pseudoequatorial conformation of 7-methyl-7,12-dihydropleiadene.

Unexpectedly, the results with DHP's reveal a striking similarity with the DHA's including the anomolous, high cis preference with the ethyl substituent. The major difference is a faster progression toward trans products with larger R and/or R′ in the DHP case. However, one recognizes that transannular effects will be more important in DHP since the pseudoaxial bond is directed across the ring whereas it is slightly "outward" in the DHA case. These considerations suggest a model for DHP similar to that for DHA. That is, sp^2 hybridization with a somewhat flattened central ring (**5**). In this particular conformation, we predict *that all substituents (including methyl) will have pseudoaxial preference.*



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To consider the likelihood of this hypothesis, we must consider the factors behind substituent locations in DHP's. Lansbury[10] has pointed out that the range of conformational energies in DHP's for the series Me, Et, and *i*-Pr (2.5 kcal/mol) is much greater than cyclohexane (0.3 kcal/mol) which has served as a reference system. He attributed this to the β-atoms present in ethyl and isopropyl and their interferences with the aryl "ortho" protons. It is interesting to contrast the DHP and DHA systems. The equatorial methyl in 9-MeDHA is directed toward the ortho hydrogen (**6** in Figure 1), but in 7-MeDHP, the methyl is angled up a bit (i.e., **7**). In fact, we suspected that the methyl group might be lifted up even more by an angle distortion, and so decided to test this possibility with force field (MM2) calculations.[13] As shown

(9) For a preliminary account, see: Rabideau, P. W.; Marcinow, Z. *Tetrahedron Lett.* **1984**, 5463.
(10) For a review, see: Lansbury, P. T. *Trans. N. Y. Acad. Sci.* **1967**, *29*, 357. Also: Lansbury, P. T.; Lacher, A. J.; Saeva, F. D. *J. Am. Chem. Soc.* **1967**, *89*, 4361.
(11) Seeman, J. I. *Chem. Rev.* **1983**, *83*, 83.
(12) The deprotonation/alkylation reactions for DHP were run at 0 °C, instead of −78 °C as with DHA, since poor results were obtained at the lower temperature. This may have been a solubility problem. However, a change in temperature from 0 to −78 °C produces little difference in stereochemical results for DHA's.[11]
(13) (a) Burkert, U.; Allinger, N. L. "Molecular Mechanisms"; American Chemical Society: Washington, D.C., 1982; ACS Monogr. No. 177. (b) Allinger, N. L.; Yuh, Y. H. *QCPE* **1980**, *12*, 395.

Table II. Molecular Mechanics (MM2) Calculations for 7-R-7,12-Dihydropleiadenes

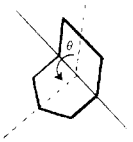
R	dihedral angles,[a] deg 11′,8′,7,6′	dihedral angles,[a] deg 8′,11′,12,1′	folding angle,[b] deg	substituent location[c]	total steric energy, kcal/mol
H[c]	68	68	120		-3.0
Me[c]	73	70	117	E	2.0
Me[c,d]	63	66	125	A	2.8
Et[c,d]	73	68	116	E	3.5
Et[c]	61	65	125	A	3.4
i-Pr[c,d]	72	68	95	E	11.7
i-Pr[c]	58	66	126	A	9.0
Me[e]	61	60		E	5.1
Me[e]	51	50		E	10.9
Me[e]	41	40		E	17.5
Me[e]	31	30		E	23.5
Me[e]	21	20		E	28.8
Me[e]	10	10		E	22.9
Me[e]	0.5	0.1	180		20.4
Me[e]	10	10		A	18.1
Me[e]	20	20		A	15.8
Me[e]	30	30		A	13.2
Me[e]	40	40		A	9.7
Me[e]	50	50		A	5.9
Me[e]	60	60		A	3.2

[a] See Figure 1b. Given as positive values. [b] The angle between the plane containing the benzene ring and the plane containing the naphthalene ring. See text for discussion. [c] Full geometry optimization: E = pseudoequatorial, A = pseudoaxial. [d] Represents a "local" minimum, see text. [e] Conformation (dihedral angles) generated by MM2 double dihedral driver option.

in Figure 1, MM2 calculations do indeed predict a distortion at the methyl substituent. This is clearly indicated by the dihedral angle between C_7–CH_3 (and C_{12}–H_{12}) and the benzene ring carbons, $C_{8'}$–$C_{11'}$. Measurement of a mechanical (Dreiding) model provides a dihedral angle of about 170° for the pseudoequatorial position, and, of course, this value is the same for either CH_3 or H substitution. MM2 calculations with 7-MeDHP provide a similar dihedral angle for the unsubstituted side (i.e., $C_{8'}C_{11'}C_{12}H_{12}$ = 168.6°), but the CH_3 group is "lifted up" by about 15° ($C_{11'}C_{8'}C_7CH_3$ = 154.8°).

In view of the significance of these molecular mechanics results to the arguments above, it appeared important to determine whether or not this type of calculation is meaningful for the dihydropleiadene system. Thus, we sought to confirm, by calculation, the rather unusual subsequent preference pattern noted above. By exchanging the pseudoequatorial (pe) CH_3 with its pseudoaxial (pa) H neighbor in the above calculation, we were able to find a "local minimum"[13] corresponding to the pseudoaxial CH_3 conformer. The comparison of total steric energies between pe CH_3 and pa CH_3 (Table II) indicate the pe conformer to be more stable by 0.8 kcal/mol. This is in excellent agreement with experimental results (88% pe). Similarly, pa ethyl is calculated to be very slightly more stable than that of pe (<0.1 kcal/mol), and experiment indicates pa ethyl to be 52.4% of the equilibrium mixture. With the isopropyl case, only the pa conformer can be detected experimentally, and once again the calcuations are in good agreement since the pa form is predicted to be 2.7 kcal/mol more stable than the pe conformer.

The extent of ring folding can be defined by the angle θ (as illustrated) for the seven-membered, central ring of DHP. This value was calculated for a number of DHP's using MM2 coordinates, and appears in Table II as the folding angle. In some cases, however, twisting occurs within the molecule, and so a more complete description of the geometries is presented in terms of dihedral angles involving the benzene ring ($C_{11'}$, $C_{8'}$, C_7, $C_{6'}$ and $C_{8'}$, $C_{11'}$, C_{12}, $C_{1'}$ in Figure 1b).



The calculated folding angles can be rationalized in the following way. Pseudoaxial substituents experience a serious steric interaction with the pseudoaxial hydrogen across the ring, and hence they "move apart" causing a slight flattening of the central, seven-membered ring. Thus the folding angles for the pseudoaxially substituted DHP's are 5–6° larger than DHP itself (calculated to be 120° which is essentially the value one measures from a Dreiding model). Pseudoequatorial substituents on the other hand have an opposite effect. A "lifting up" of the substituent to minimize interaction with the adjacent aromatic protons results in a greater folding of the central ring. This is especially noteworthy for pe isopropyl which has a folding angle of 95°.

Turning attention back to the anion model, it can be realized that flattening of the central ring in 7-MeDHP (i.e., as in the anion model) will bring the pe methyl "back down", providing increased steric interaction with the aryl protons. As we have suggested, this increased steric energy could result in the pseudoequatorial conformation becoming less favorable relative to pseudoaxial. We were able to demonstrate this effect with molecular mechanics calculations (MM2) using the dihedral driver option.[13] We began by optimizing the geometries of both pa methyl and pe methyl DHP with the dihedral angles $C_{11'}$, $C_{8'}$, C_7, $C_{6'}$ and $C_{8'}$, $C_{11'}$, C_{12}, $C_{1'}$ "fixed" at 60°. By "artificially" flattening the central ring (in 10° increments) using a double dihedral driver, we were able to determine total steric energies for pe vs. pa methyl conformations (i.e., simultaneous rotation around both bonds to ensure uniform flattening). As shown in Table II, only slight flattening was necessary for the pseudoequatorial form to surpass the pseudoaxial one in energy, as we predicted. In fact, the energy of the pseudoequatorial form rises rather steeply. Although the same value is reached at 0° from either direction, the data for the pseudoequatorial form at smaller folding angles (e.g., 10–30°) may be less meaningful since the methyl group "hangs up" on the peri hydrogens and is resistant to passing by until high energies are reached.[13] In any event, these calculations do, in fact, support the anion model provided herein.[14] We can also

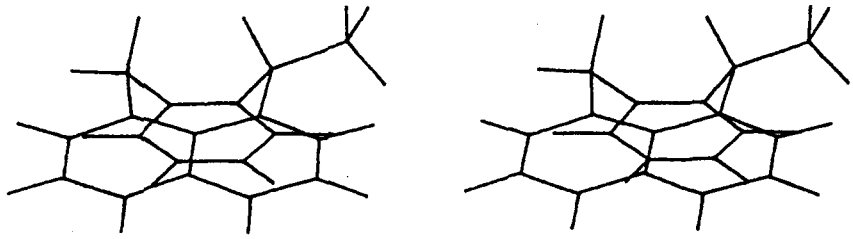
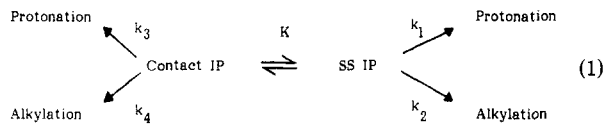


Figure 2. Stereoview of 7-methyl-7,12-dihydropleiadene.

include that neutral precursors do not necessarily provide good models for anion geometry.

Ion Pairing and the Role of the Cation. The arguments herein have been based solely on stereoelectronic effects in the anions, and so some comment should be made concerning the possible role of the cation. It should also be noted that these alkylations are assumed to be S_N2 processes (as opposed to electron transfer). This is based on the conclusions of Panek[1i] and Bank et al.,[1m] who have previously addressed this issue. Further complication due to the presence of aggregates also appears unlikely at these concentrations with large delocalized anions,[1i,15] and moreover, if some amount of aggregation was present, it would be unimportant to arguments herein due to the expected lack of reactivity relative to monomeric species.[16] Thus, if alkylation is proceeding through a monomeric, solvent-separated ion pair or free ion, then stereoelectronic arguments are justified.

The nature of ion pairing in dihydroanthracene monoanions has been investigated by NMR and UV spectroscopy.[1i,r,17] It appears that THF solutions at 0 °C (i.e., conditions used in this study) should contain solvent-separated ion pairs with perhaps a lesser amount of contact ion pairs. This would also appear consistent with the variable-temperature carbon-13 NMR work of O'Brien and co-workers with the related diphenylmethyl anion.[18] One must be cautious, however, in that the presence of solvent separated ion pairs as the predominant species does not necessarily dictate their importance in the alkylation process. As illustrated in eq 1, the relative importance of the ion pairs in alkylation or protonation reactions will depend on the relative rates, k_1–k_4, not K_{eq}. The cation



(1)

can play an important role in these cases, and, in fact, "cation-assisted" protonation has been suggested as leading to faster protonation (i.e., $k_3 > k_1$) of contact ion pairs in some instances.[19] With alkylation, however, solvent-separated ion pairs are considered to be the more reactive species[20] (or, of course, free ions) since there is no prior complexation. Bank and Juckett have similarly noted an increase in alkylation rate of naphthalene radical anion with freer ion pairing but faster protonation with contact ions.[21]

In conclusion, we suggest that the DHA and DHP anion systems are substantially delocalized, and that alkylation proceeds through (at least) solvent-separated ion pairs. Consequently, formulation of models based on stereoelectronic effects is justified.

Experimental Section

Calculations were performed with the Allinger MM2 molecular mechanics program.[13] Aromatic carbon atoms were defined in terms of the optimum C=C bond length (1.397 Å) and the C=C force constant (8.067 mdyn/Å).[4] In determining minima, bond rotation of substituents was carried out after the first geometry optimization to ensure the correct local or global minimum. For example, our initial optimization of pseudoaxial 7-*i*-PrDHP resulted in a minimum with the isopropyl methyls directed away from the central ring. However, a 180° rotation of the isopropyl group followed by reminimization produced a conformation with the isopropyl methyls directed across the central ring being "split" by H_{12}. This latter structure was found to be 2 kcal/mol more stable than the former.

NMR spectra were recorded on a Varian EM-390 in $CDCl_3$ with internal Me_4Si. Temperature determinations with variable-temperature experiments were made with a methanol chemical shift correlation. Gas chromatographic analyses were performed on a Shimadzu GC-6A employing either a 6 ft × 0.25 in., 10% SE-30, (DHA's) or 10% OV-1 (DHP's) column. Microanalyses were obtained for all new compounds by Galbraith Laboratories, Inc.

THF (distilled from benzophenone ketyl immediately before use), *n*-butyllithium (2.1 M in hexane; standardized before use), methyl iodide, ethyl bromide, and 2-bromopropane were all obtained from Aldrich Chemical Co. DHP's were purified by chromatography on 230–400 mesh silica gel (Merck); other commercial grades proved less satisfactory. Petroleum ether/carbon tetrachloride/ethyl acetate (98:1.1) was used as eluent.

Alkylation of 9,10-Dihydroanthracenes. This procedure is essentially the same employed previously for 9-*i*-PrDHA alkylations.[11] A solution of *n*-butyllithium (1.4 mmol) was added to the DHA (1.25 mmol) in 10 mL THF at −30 °C under nitrogen. After the mixture was stirred for 30 min, the temperature was lowered to −78 °C for an additional 30 min. Excess alkyl halide (in 3–5 mL of THF) was then added followed in a few minutes with solid NH_4Cl and then water. Products were isolated by ether extraction. The DHA's prepared by this method (cis and trans, Me_2, Et_2, Me/*i*-Pr, and Et/*i*-Pr) are known compounds.[1a,11] The starting monoalkyl DHA's were also made in this way.

7-Alkyl-7,12-dihydropleiadenes. The monomethyl, monoethyl, and monoisopropyl derivatives were prepared in much higher yield than previously reported.[22] A solution of *n*-butyllithium (2.1 mmol) was added by syringe to a stirred solution of 7,12-dihydropleiadene[23] in 20 mL of THF at 0 °C under nitrogen. After 30 min, a solution of the alkyl halide (excess, in 5 mL of THF) was added followed in 5 min by solid NH_4Cl and then water.

(14) Preliminary carbon-13 NMR studies with 7-LiDHP in THF indicate considerable delocalization of charge into the aromatic rings (i.e., flattening).
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(20) (a) Reference 24, p 230. (b) Reference 21, Vol. 1, p 126. (c) Klumpp, G. W. "Reactivity in Organic Chemistry"; Wiley-Interscience: New York, 1982; p 367.
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(23) Lansbury, P. T.; Bieron, J. F.; Klein, M. *J. Am. Chem. Soc.* **1966**, *88*, 1477.

Isolation by ether extraction provided nearly quantitative yields. Products were chromatographed on silica gel or recrystallized prior to use in subsequent reactions. Alkylation reactions conducted at temperatures below 0 °C gave markedly lower yields.

Methylation of 7-MeDHP. The deprotonation was carried out as described above for DHP itself, and methyl iodide was used as the alkylation agent. Products were identical (NMR) with those previously described,[22] and results are summarized in Table I.

Ethylation of 7-MeDHP. Similar reaction using ethyl bromide afforded a pale yellow oil, which crystallized on standing. NMR and GLPC indicated 93% 7-Me-12-EtDHP (cis/trans, 40:60) along with 6% recovered starting material. Recrystallization from methanol gave pure *cis*-7-methyl-12-ethyl-7,12-dihydropleiadene[24] as white needles: mp 158–158.5 °C; NMR ($CDCl_3$) δ 7–7.6 (10 H, m, aryl), 5.4 (1 H, q, H_7), 5.07 (1 H, t, H_{12}), 2.4 (2 H, m), 1.9 (3 H, d), 1.18 (3 H, t).

Anal. Calcd for $C_{21}H_{20}$: C, 92.60; H, 7.40. Found: C, 92.56; H, 7.64.

Isolation of the trans isomer was accomplished by careful silica gel chromatography of the mother liquor above. Recrystallization from methanol gave pure *trans*-7-methyl-12-ethyl-7,12-dihydropleiadene as white needles: mp 90–90.5 °C; NMR ($CDCl_3$) δ 7–7.6 (10 H, m), 4.95 (1 H, q, H_7), 4.2 (1 H, t, H_{12}), 2.3 (2 H, m), 1.8 (3 H, d), 0.98 (3 H, t).

Anal. Calcd for $C_{21}H_{20}$: C, 92.60; H, 7.40. Found: 92.74; H, 7.66.

Isopropylation of 7-MeDHP. Analogous reaction using isopropyl bromide furnished a yellow solid. NMR and GLPC indicated 90% 7-Me-12-*i*-PrDHP (cis/trans, 10:90) and 10% recovered starting material. Chromatography on silica gel following by recrystallization from methanol gave pure *trans*-7-methyl-12-isopropyl-7,12-dihydropleiadene as white needles: mp 81–83 °C; NMR ($CDCl_3$) δ 7–7.7 (10 H, m), 5.25 (1 H, q, J = 6.6 Hz), 3.72 (1 H, d, J = 9.6 Hz), 2.72 (1 H, m), 1.85 (3 H, d), 1.11 (3 H, d), 0.97 (3 H, d).

Anal. Calcd for $C_{22}H_{22}$: C, 92.30; H, 7.70. Found: C, 91.90; H, 7.96.

The cis isomer could not be obtained. Attempted epimerization of the trans isomer with *n*-butyllithium and TMEDA resulted in olefin formation.

Methylation of 7-EtDHP. Analogous deprotonation of 7-EtDHP followed by reaction with methyl iodide furnished a yellow solid. NMR and GLPC analysis indicated 93% 7-Me-12-EtDHP (cis/trans, 78:22) along with 3% unreacted starting material. (See above for characterization.)

Ethylation of 7-EtDHP. Similar reaction with ethyl bromide provided 89% 7,12-Et_2DHP (cis/trans, 41:59) and 3% unreacted starting material. Recrystallization from methanol gave pure *cis*-7,12-diethyl-7,12-dihydropleiadene as white needles: mp 145–146 °C; NMR ($CDCl_3$) δ 7–7.6 (10 H, m), 5.1 (2 H, t), 2.4 (4 H, m), 1.17 (6 H, t).

Anal. Calcd for $C_{22}H_{22}$: C, 92.30; H, 7.70. Found: C, 92.31; H, 7.95.

Silica gel chromatography of the mother liquor followed by recrystallization from methanol afforded pure *trans*-7,12-diethyl-7,12-dihydropleiadene as white crystals: mp 86–87 °C; NMR ($CDCl_3$) δ 7.1–7.7 (10 H, m), 4.53 (2 H, t), 2.4 (4 H, m), 1.1 (6 H, t) [the triplet at 4.53 ppm broadened with lower temperatures, and two triplets resulted separated by 72 Hz; T_c = −19 °C].

Anal. Calcd for $C_{22}H_{22}$: C, 92.30; H, 7.70. Found: C, 92.20; H, 8.00.

Isopropylation of 7-EtDHP. Analogous reaction using isopropyl bromide produced 93% 7-Et-12-*i*-PrDHP (cis/trans, 10:90) and 2% starting material. Chromatography on silica gel followed by recrystallization from methanol gave pure *trans*-7-ethyl-12-isopropyl-7,12-dihydropleiadene as white needles: mp 102–103 °C; NMR ($CDCl_3$) δ 7.1–7.8 (10 H, m), 5.02 (1 H, br t), 3.74 (1 H, d, J = 9.9 Hz), 2.8 (1 H, m), 2.4 (2 H, m), 1.2 (6 H, d), 1.0 (3 H, t).

Anal. Calcd for $C_{23}H_{24}$: C, 91.90; H, 8.10. Found: 91.61; H, 8.17.

Methylation and Ethylation of 7-*i*-PrDHP. These reactions gave primarily trans products as summarized in Table I. See above for characterization of these products.

Isopropylation of 7-*i*-PrDHP. Analogous deprotonation followed by reaction with isopropyl bromide gave *trans*-*i*-Pr_2DHP exclusively together with 8% unreacted starting material. Chromatography on silica gel followed by recrystallization from methanol provided pure *trans*-7,12-diisopropyl-7,12-dihydropleiadene as white needles: mp 154–156 °C; NMR ($CDCl_3$) δ 7–7.8 (10 H, m), 4.7 (1 H, br s), 3.7 (1 H, br s), 2.9 (2 H, br s), 1.2 (6 H, br m) [lowering the temperature results in sharpening of the signals and at 10 °C the signals at 4.7 and 3.7 ppm appear as sharp doublets; T_c = 48 °C. At 70 °C, the isopropyl group appears as two (diastereotopic) sharp doublets].

Anal. Calcd for $C_{24}H_{26}$: C, 91.70; H, 8.30. Found: C, 91.40; H, 8.17.

Acknowledgment. We gratefully acknowledge support from the U.S. Department of Energy, Office of Basic Energy Science, and the Indiana University Computer Network. We would also like to thank Professor K. B. Lipkowitz for his assistance with the molecular mechanics calculations.

Registry No. 9-MeDHA, 17239-99-5; 9-EtDHA, 605-82-3; 9-*i*-PrDHA, 17573-50-1; 7-MeDHP, 7119-78-0; 7-EtDHP, 15529-85-8; 7-*i*-PrDHP, 14529-25-0; *cis*-9,10-Me_2DHA, 13417-34-0; *trans*-9,10-Me_2DHA, 13417-35-1; *cis*-9-Et-10-MeDHA, 20826-53-3; *cis*-9-*i*-Pr-10-MeDHA, 21438-93-7; *cis*-7,12-Me_2DHP, 17430-41-0; *trans*-7,12-Me_2DHP, 17430-42-1; *cis*-7-Et-12-MeDHP, 100021-36-1; *trans*-7-Et-12-MeDHP, 100021-37-2; *cis*-7-*i*-Pr-12-MeDHP, 100021-38-3; *trans*-7-*i*-Pr-12-MeDHP, 100021-39-4; *trans*-9-Me-10-EtDHA, 23660-35-7; *cis*-9,10-Et_2DHA, 20826-55-5; *trans*-9,10-Et_2DHA, 23660-32-4; *cis*-9-*i*-Pr-10-EtDHA, 52135-39-4; *trans*-9-*i*-Pr-10-EtDHA, 52135-03-2; *cis*-7,12-Et_2DHP, 100021-40-7; *trans*-7,12-Et_2DHP, 100021-41-8; *cis*-7-*i*-Pr-12-EtDHP, 100021-42-9; *trans*-7-*i*-Pr-12-EtDHP, 100021-43-0; *trans*-9-Me-10-*i*-PrDHA, 33608-27-4; *cis*-9,10-*i*-Pr_2DHA, 24316-21-0; *trans*-9,10-*i*-Pr_2DHA, 25340-82-3; *trans*-7,12-*i*-Pr_2DHP, 100021-44-1; EtBr, 74-96-4; MeI, 74-88-4; *i*-PrBr, 75-26-3.

(24) Cis/trans assignments for previously unreported DHP's were made by one or more of the following observations: (a) axial protons at C_7 and C_{12} absorb at lower field (5–5.5 ppm) than their equatorial counterparts (3.5–4 ppm), (b) equatorial protons exhibit a nuclear Overhauser enhancement when the (nearby) aromatics are irradiated, and (c) trans isomers often show temperature-dependent NMR spectra.[10,25]

(25) A complete proton and carbon-13 NMR study of these compounds is in progress.