On the Stereochemistry of the Reductive Alkylation of Anthracene

M. Malissard, J. P. Mazaleyrat, and Z. Welvart*

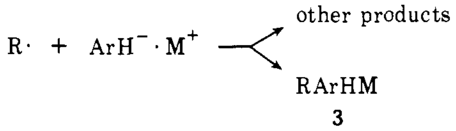
Contribution No. 12 from the Groupe de Recherche, C.N.R.S., 94320-Thiais, France. *Received March 21, 1977*

Abstract: The alkylation of lithium anthracene with optically active 2-octyl halides and mesylate occurs with a leaving group dependent partial inversion of configuration. The simplest rationalization of these results is a competition between electron transfer and S_N2 processes.

Several kinetic and mechanistic studies of the reaction of alkali metal adducts of aromatic hydrocarbons with alkyl halides were already reported[1-8] and the electron-transfer process (Scheme I) proposed by Garst[1,2] and Sargent[3] is widely accepted.

Scheme I

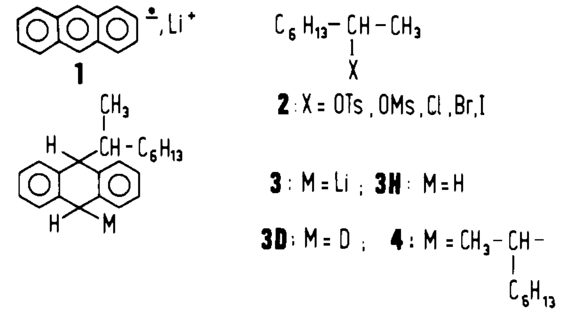
$$\underset{1}{\mathrm{ArH^{-}\cdot M^{+}}} + \underset{2}{\mathrm{RX}} \longrightarrow \mathrm{R\cdot} + \mathrm{ArH} + \mathrm{MX} \qquad (1)$$



$$\mathrm{R\cdot} + \mathrm{ArH^{-}\cdot M^{+}} \longrightarrow \text{other products}, \ \underset{3}{\mathrm{RArHM}} \qquad (2)$$

$$\underset{3}{\mathrm{RArHM}} + \mathrm{RX} \longrightarrow \underset{4}{\mathrm{RArHR}} + \mathrm{MX} \qquad (3)$$

$$\underset{3}{\mathrm{RArHM}} \xrightarrow[(\mathrm{D_2O})]{\mathrm{H_2O}} \underset{3\mathrm{H}\ \ 3\mathrm{D}}{\mathrm{RArHH(D)}} + \mathrm{MOH(D)} \qquad (4)$$



As far as the stereochemistry of this reaction is concerned, only very few results are known[9,10] in spite of important information which can be provided by this type of results on the genuine mechanism of the substitution process.

We report here the alkylation of lithium anthracene (**1**) with optically active alkylating agents **2**, in order to determine if the substitution occurs with racemization or with inversion of configuration of the *R* moiety.

Results and Discussion

The reaction of alkali metal anthracene **1** with alkyl halides gives mainly the 9,10-dialkyl-9,10-dihydroanthracene similar to **4**,[11,12] but, in order to perform a stereochemical study of the substitution, the primary product **3** or its protonated derivative **3H** has to be isolated.

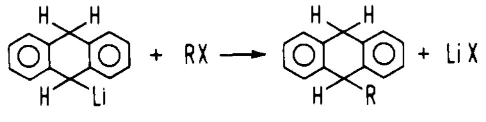
The second alkylation (step 3 in Scheme I) is ~50 times slower than the first one;[7] so the formation of the dialkylated product **4** can be minimized by the use of an excess (~50%) of lithium anthracene (**1**). Under these conditions the main product of the reaction is the 9-lithio-10-*sec*-octyl-9,10-dihydroanthracene (**3**). This was confirmed also by the deuterolysis of the reaction mixture, which gives a completely monodeuterated product **3D**.

Using optically active alkylating agents **2**, the product **3H** is isolated by VPC. The optical rotations of the different samples obtained are reported in part B of Table I.

The results reported in Table I show, in agreement with previous works,[13] that the reactions in Scheme I do not occur with tosylates, and that all substitution products **3H** have some optical rotation.

In order to determine the absolute configuration of compound **3H**, we prepared a sample by the known[14] stereoselective reaction shown in Scheme II.

Scheme II



5 **3H**

Reagent **5** is obtained by reaction of *n*-butyllithium with 9,10-dihydroanthracene.[15] According to Korte et al., benzylic type organolithium reagents react with alkyl halides with inversion of configuration,[14] and the results of reaction 2 are reported in part A of Table I.

Comparison of the A and B parts of Table I provides good evidence that the reaction of $ArH^{-}\cdot M^{+}$ with RX leads to a partial inversion of configuration, this inversion being much lower in Scheme I than in Scheme II involving reagent **5**. Assuming for this second reaction a nearly complete inversion, we have calculated approximately the amount of inversion observed for Scheme I with different RX, and this is reported in part C of Table I. This shows that the observed inversion ratio is leaving group dependent.

The substitution process depicted in Scheme I, involving a free radical R· intermediate, is in good agreement with racemization during the reaction, but does not account for the observed partial inversion of configuration. Competitive paths of higher kinetic order, such as S_N2 substitution involving dianion **6** (Scheme III) are ruled out by the reported first-order rate in $ArH^{-}\cdot M^{+}$.[1,5,7,16]

Scheme III

$$\underset{1}{2\,\mathrm{ArH^{-}\cdot M^{+}}} \rightleftharpoons \underset{6}{\mathrm{ArH^{2-}\ 2M^{+}}} + \mathrm{ArH}$$

$$\mathrm{ArH^{2-}\ 2M^{+}} + \mathrm{RX} \longrightarrow \mathrm{MX} + \mathrm{RArHM}$$

Therefore, in order to explain the observed inversion of configuration, the simplest interpretation is an S_N2 substitution (Scheme IV), which is in competition with electron transfer (ET) (Scheme I).[18] Both of these reactions involve the same

Table I. Optical Rotations $[\alpha]^{25}{}_{579}$ (Benzene) of 9-(2-Octyl)-9,10-dihydroanthracene (3H)[a]

	RX				
Reagent	ROTs, (+)-(*S*)	ROMs, (+)-(*S*)	RCl, (−)-(*R*)	RBr, (−)-(*R*)	RI, (−)-(*R*)
		A			
5	+30.3 +33.5 (*R*)	+29.8 (*R*)	−31.4 (*S*)	−34.0 (*S*)	−33.9 (*S*)
		B			
1	*b*	+12.8 +8.9 +8.2 +9.0 (*R*)	−4.4 −3.4 −4.1 (*S*)	−1.7 −1.6[c] −1.9[c] (*S*)	 − sign.[d] (*S*)
		C			
% inversion with **1** vs. **5**	*b*	25–40	11–14	5–6	*d*

[a] Each indicated value corresponds to a different experiment. In order to obtain comparable values, the optical rotations indicated have been calculated supposing the use of optically pure samples of RX. [b] See footnote 13. [c] Optical rotation of compound **3D** resulting from a reaction mixture quenched with D_2O. [d] We observe here some dispersion for the $[\alpha]$ value; so we do not know with confidence the actual percent of inversion.

Scheme IV

$$\underset{\mathbf{1}}{\mathrm{ArH^-\cdot M^+}} + \underset{\mathbf{2}}{\mathrm{RX}} \xrightarrow[\text{slow}]{e} \mathrm{MX} + \mathrm{RArH\cdot}$$

$$\xrightarrow[\text{fast}]{\mathrm{ArH^-\cdot M^+}} \underset{\mathbf{3}}{\mathrm{RArHM}} + \mathrm{ArH}$$

reagents **1** and **2** in their rate-determining step, and so they have the same kinetic order.

The occurrence of ET and S_N2 processes are well known with ambident nucleophiles[19] and their competition was reported in the reductive alkylation of 2,4,6-tri-*tert*-butylnitrosobenzene, each of these reactions giving different products.[20]

As far as aromatic radical anions are concerned, the S_N2 process has already been proposed for substitutions in the case of reagents **1** and **2**, the half-wave reduction potential difference of which is largely negative,[4,21] but direct experimental evidence was lacking. The decrease of inversion of configuration going from *sec*-octyl chloride to *sec*-octyl bromide (see Table I) is in agreement with this assumption. However, that is no longer the case for the reaction observed with mesylate. This compound, having a lower half-wave reduction potential than the corresponding halides,[22] gives here the most important amount of inversion of configuration (see Table I). In order to be able to rationalize this result, we have to take into account not only the half-wave reduction potential differences but also the energy necessary to bond breaking either by ET or by S_N2 processes. Obviously further investigations are necessary on the leaving group effect in the S_N2–ET competition.[23]

Finally, our results suggest too that the recently reported mechanistic change of the ET process, induced by the increase of the half-wave reduction potential of the reagents[6,24] could be actually an ET–S_N2 competition.

Experimental Section

Preparation of Reagents. (+)-(*S*)-2-Octyl tosylate and (+)-(*S*)-2-octyl mesylate are prepared by known methods[25] from (+)-(*S*)-2-octanol ($[\alpha^{20}{}_D]$ +7.74°; optical purity 95%[26]). The preparations of (−)-(*R*)-2-octyl chloride ($\alpha^{20}{}_D$ −30.85°; optical purity 95%[26]), (−)-(*R*)-2-octyl bromide ($\alpha^{20}{}_D$ −37.76°; optical purity 85%[26]), and (−)-(*R*)-2-octyl iodide ($\alpha^{20}{}_D$ −47.14°; optical purity 73%[26]) were also already reported.[27,28]

Alkylations of 9-Lithio-9,10-dihydroanthracene (5). To a solution of 0.05 mol of 9,10-dihydroanthracene in diethyl ether (250 cm^3) is added 13 cm^3 (0.05 mol) of a solution of *n*-butyllithium (4 M) in hexane. The resulting mixture is stirred for 45 min in a dry N_2 atmosphere, at room temperature. After addition of RX (0.01 mol), the mixture is stirred 1 h more and quenched with H_2O.

Alkylations of Lithium Anthracene (1). A solution of anthracene (11 g, 0.06 mol) and lithium (0.42 g, 0.06 g-atom) in diethyl ether (425 cm^3)-benzene (75 cm^3) is stirred for 4 h in a dry N_2 atmosphere, at room temperature. After addition of RX (0.01 mol), the mixture is stirred 1 h more and then quenched with H_2O or D_2O.

Isolation of Products. The excess of anthracene or 9,10-dihydroanthracene in the crude product is removed by crystallization from pentane. Compounds **3H** and **4** are isolated by preparative VPC (Aerograph Autoprep 700; column SE-30 15%, T = 250 °C) of the mother liquor. The purity of the different samples of compound **3H** is checked by analytical VPC.

9-(2-Octyl)-9,10-dihydroanthracene (3H). Anal. calcd for ($C_{22}H_{28}$): C, H. Properties follow: mass spectrum (70 eV), molecular peak at *m/e* 292; ^1H NMR ($CDCl_3$, TMS) 8 H at 7.23 (s), 1 H at 2.20 (d, J = 19 Hz), 1 H at 3.88 (s), 1 H at 3.76 (d, J = 6.5 Hz), 1 H at 3.73 (d, J = 19 Hz), 11 H at 0.9–2, 3 H at 0.85 (t), 3 H at 0.73 ppm (d, J = 6.5 Hz); the highest optical rotations observed for this compound are $[\alpha]^{25}$ (benzene, c 19.3 g/100 cm^3) −32.56 (589 nm), −34.04 (579 nm), −38.93 (546 nm), −67.49° (435 nm).

9,10-Di(2-octyl)-9,10-dihydroanthracene (4).[12] Properties follow: mass spectrum (70 eV), molecular peak at *m/e* 404; ^1H NMR ($CDCl_3$, TMS) 8 H at 7.23 (m), 2 H at 3.90 (d, J = 4.5 Hz), 22 H at 0.9–2.5, 6 H at 0.85 (t), 6 H at 0.82 ppm (d, J = 6.5 Hz). This compound is a mixture of several diastereoisomers. Other minor compounds, arising from alkylation on a lateral ring of anthracene, can be detected in the ^1H NMR spectra of the crude products (vinylic proton signals at 6.66, 6.53, 6.03, and 5.90 ppm and allylic or benzylic protons signals at 2.93 and 2.80 ppm).

9-(2-Octyl)-10-deuterio-9,10-dihydroanthracene (3D) was obtained by alkylation of lithium anthracene (**1**), in the same way as **3H** the mixture was quenched with D_2O instead of H_2O. The ^1H NMR spectra show 2.0 benzylic protons instead of 3.0 protons for compound **3H**. The mass spectra, by comparison of fragments at *m/e* 294, 293 (M_D), 292 (M_H), and 291 in the different samples of **3H** and **3D**, show a percent $M_D/(M_H + M_D)$ of 97–100% in compound **3D** (a better precision could not be obtained). All these data are in agreement with a nearly completely monodeuterated compound **3D**.

Yields. The yields of compound **3H** are determined by VPC of a aliquot of crude product (column SE-52, 5%; l = 1.6 m; Chromosorb G 012016; T = 250 °C), with docosane as internal standard. The yield average is 60–70% for the reaction with reagent **5** and 40–50% for the reaction with reagent **1** (in this later case, the only other products being present are compound **4** and compounds alkylated on a lateral ring).

Optical Rotations. The optical rotations are determined at 25 °C, in a thermostated 1-dm-long cell (Perkin-Elmer 141 M polarimeter). The concentrations of solutions of **3H** (in benzene) are included between 7 and 20 g/100 cm^3; we have checked the absence of a special concentration effect on the $[\alpha]$ values. In Table I, we reported $[\alpha]^{25}$ values at 579 nm, but we have also determined them at 589, 546, and 435 nm, and the calculated optical yield is the same for all wavelengths.

Acknowledgment. We thank Professor Shelton Bank (State University of New York at Albany) for discussion and for communications of his results before publication.

References and Notes

(1) J. F. Garst, *Acc. Chem. Res.*, 400 (1971).
(2) J. F. Garst, J. T. Barbas, and F. E. Barton II, *J. Am. Chem. Soc.*, **90**, 7159 (1968).
(3) C. D. Sargent and G. A. Lux, *J. Am. Chem. Soc.*, **90**, 7160 (1968).
(4) D. Lipkin, G. J. Divis, and R. W. Jordan, *Am. Chem. Soc., Div. Pet. Chem., Prepr.*, **13**, D. 60 (1968).
(5) D. J. Morantz and E. Warhurst, *Trans. Faraday Soc.*, **51**, 1375 (1955); H. V. Carter, B. J. McClelland, and E. Warhurst, *Trans. Faraday Soc.*, **56**, 343 (1960).

(6) J. F. Garst, R. D. Roberts, and B. N. Abels, *J. Am. Chem. Soc.*, **97**, 4925 (1975).
(7) S. Bank and D. A. Juckett, *J. Am. Chem. Soc.*, **97**, 567 (1975).
(8) J. F. Garst and C. D. Smith, *J. Am. Chem. Soc.*, **98**, 1520 (1976).
(9) J. Jacobus and D. Pensak, *Chem. Commun.*, 401 (1962), concerning the stereochemistry of cyclopropyl halide reduction by sodium naphthalenide.
(10) J. P. Mazaleyrat and Z. Welvart, *J. Chem. Soc., Chem. Commun.*, 546 (1972).
(11) G. M. Badger, F. Goulden, and F. L. Warren, *J. Org. Chem.*, **6**, 18 (1941); A. H. Beckett and R. G. Lingard, *J. Chem. Soc.*, 2409 (1959); L. M. Jackman and J. W. Lown, *ibid.*, 3776 (1962); W. Carruthers and G. E. Hall, *J. Chem. Soc. B*, 861 (1966); R. Gerdil and E. A. C. Lucken, *Helv. Chim. Acta*, **44**, 1966 (1961); D. A. Redford, Thesis, Saskatchewan University; *Diss. Abstr. B*, **28**, 4704 (1968).
(12) M. M. Lerer, *Ann. Off. Natl. Combust. Liq.* (*Fr.*), 861 (1933).
(13) With tosylate, in agreement with the already known results, the main product is 2-octanol (see W. D. Closson, P. Wriede, and S. Bank, *J. Am. Chem. Soc.*, **88**, 1581 (1966); E. Deschamps and J. P. Mazaleyrat, *C. R. Hebd. Seances Acad. Sci.*, **284C**, 455 (1977).
(14) W. D. Korte, L. Kinner, and W. C. Kaska, *Tetrahedron Lett.*, 603 (1970); L. H. Sommer and W. D. Korte, *J. Org. Chem.*, **35**, 22 (1970).
(15) B. M. Mikhailov and A. N. Biokhina, *Izv. Akad. Nauk SSSR*, **3**, 279 (1945); H. Cho, R. G. Harvey, and P. W. Rabideau, *J. Am. Chem. Soc.*, **97**, 1140 (1975).
(16) We have to point out that 5–10% of contribution of Scheme III to the substitution process cannot present an important deviation from the first-order rate, and there are no kinetic results available for the substitution of alkyl mesylate, which gives the highest inversion of configuration. However, a one-electron transfer was already pointed out for the R–OMs bond breaking.[17]
(17) J. R. Ganson, S. Schulenberg, and W. D. Closson, *Tetrahedron Lett.*, 4397 (1970).
(18) One of the referees pointed out that, in despite of the especially favorable experimental conditions for a nucleophilic displacement, the electron transfer is prevailing in the substitution of these alkyl halides. So the observed inversion of configuration can be rationalized not only by an S_N2 process but also by a more important contribution of Scheme III as well as by a purely radical process involving cage intermediates. We are in agreement with these comments, but in the present state of our knowledge a cage intermediate cannot rationalize the leaving group dependence of the observed inversion of configuration. So we offered here only the simplest alternative paths. Work in progress using different solvents and 2-octyl fluoride as alkylating agent will provide more information.
(19) N. Kornblum, *Angew. Chem. Int. Ed. Engl.*, **14**, 734 (1975), and references cited.
(20) M. Crozet, E. Flesia, and J. M. Surzur, *Tetrahedron Lett.*, 4563 (1975).
(21) G. J. Hoijtink, *Chem. Ing. Tech.*, **35**, 333 (1963).
(22) Methyl toluenesulfonate has a lower reduction potential than methyl halides and almost the same electron affinity is assumed for methyl methanesulfonate (see S. Bank and D. A. Noyd, *J. Am. Chem. Soc.*, **95**, 8203 (1973), and references cited).
(23) It was suggested recently that the localization of the electron in different orbitals of an aryl methanesulfonate may have also an important influence on the competitive reactions of these compounds (J. C. Carnahan, Jr., W. D. Closson, J. R. Ganson, D. A. Juckett, and K. S. Quaal, *J. Am. Chem. Soc.*, **98**, 2526 (1976)).
(24) S. Bank and D. A. Juckett, *J. Am. Chem. Soc.*, **98**, 7742 (1976).
(25) A. Streitwieser, Jr, T. D. Walsh, and J. R. Wolfe, Jr, *J. Am. Chem. Soc.*, **87**, 3682 (1965); R. K. Crossland and K. L. Servis, *J. Org. Chem.*, **35**, 3195 (1970).
(26) H. M. R. Hoffmann, *J. Chem. Soc.*, 1250 (1964).
(27) D. Brett, I. M. Downie, J. B. Lee, and M. F. S. Matough, *Chem. Ind.* (*London*), 1017 (1969).
(28) J. Gore, P. Place, and M. L. Roumestant, *J. Chem. Soc., Chem. Commun.*, 821 (1973).

Synthesis and Electronic Properties of 2a,8b-Dihydrocyclopent[*cd*]azulenes (Elassovalenes)

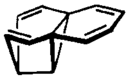
Leo A. Paquette,* C. C. Liao, Richard L. Burson,[1a] Robert E. Wingard, Jr.,[1b] C. N. Shih, Jose Fayos, and Jon Clardy[2]

Contribution from the Evans Chemical Laboratories, The Ohio State University, Columbus, Ohio 43210, and Ames Laboratory-USAEC/Department of Chemistry, Iowa State University, Ames, Iowa 50010.

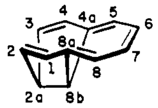
Received February 23, 1977

Abstract: The synthesis of 2a,8b-dihydrocyclopent[*cd*]azulene (elassovalene), its $Cr(CO)_3$ complex, and two methoxy derivatives, the determination of their ^1H, ^{13}C, UV, and PE spectra, and measurements of diamagnetic susceptibility are described. A common starting material for the entire range of compounds was urazole **5**. In a most efficient route, bromination–dehydrobromination of **5** provided the corresponding norcaradiene, oxidative hydrolysis of which gave elassovalene (**2**) directly. An alternative approach began with ozonolysis of **5**, conversion to dimesylate **7**, and treatment of the latter with strong base. A variety of oxygenated substituents could be placed upon the cyclohexene ring of **5**, sometimes with high levels of stereochemical control, depending upon the particular oxidative technique employed. Further functional group manipulation ultimately led to isolation of the air-sensitive 5- and 6-methoxyelassovalenes. The combined weight of spectral evidence reveals these molecules to possess at a minimum some degree of homoaromatic character in the bridged cycloheptatriene portion of their structure. This level of interaction is consistent in particular with ^1H NMR, PE, and diamagnetic exaltation criteria observed in particular for the parent hydrocarbon. These results, in contrast, do not provide reliable information on the level of transannular interaction, if any, at the "open" end of these molecules.

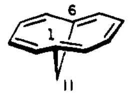
Interest in our laboratory has recently been focused on several facets of higher order homoaromaticity[3] and the possible realization of neutral homoaromatic character.[4,5] Consequently, when methodology for varied 2,8-annulation of semibullvalene, the system most closely approaching the realization of homoaromatic six-electron cyclic delocalization ($\Delta G^{\ddagger} = 5.5$ kcal/mol at -143 °C),[6] became available,[4] we were led to examine the effect of bridging this hydrocarbon at C_2 and C_8 with a 1,3-butadienyl moiety. The resultant molecule (**1**) was expected to be unstable relative to the pentaene form **2** to which it is related by a simple [3,3]-sigmatropic shift. Were a ring current to operate in **2**, a mesovalent Hückel-like molecule would be in hand and neutral homoaromaticity would be realized experimentally for the first time. For convenience, we have named this hydrocarbon "ellasovalene" from the Greek ϵλασσον which conveys the concept of lowered energy content (relative to **1**).[7]



1



2



3

Although the magnitude of homoaromatic stabilization which can be anticipated for uncharged molecules must be appreciably diminished relative to charged entities due to the lack of a driving force for charge delocalization, the structural similarity of bishomo[10]annulene **2** to **3**[8] and higher bridged annulenes[9] suggested that 2,3 overlap might gain significance. The existence in **3** of *non*-negligible 1,6 interaction as sug-

Paquette et al. / 2a,8b-Dihydrocyclopent[cd]azulenes