of the allylic stabilization energy normally available[11] in uninhibited thermolyses.[12]

[11] (a) K. W. Egger, D. M. Golden, and S. W. Benson, *J. Am. Chem. Soc.*, **86**, 5420 (1964). (b) References cited in ref 2b. (c) We recognize that entropy effects may contribute to the observed *free energy* difference which therefore may not be directly comparable to the $\Delta\Delta H^{\ddagger}$ values.

[12] Although the result plausibly can be associated with a lower-lying transition state for diradical formation, the possibility exists that the *endo*-**1** → **2a** sigmatropic rearrangement is concerted. If so, the process is constrained to be suprafacial, and on orbital symmetry grounds the migrating carbon must suffer inversion of configuration.[13] This would be very unfavorable to the **2b**-forming path since the first step would require formation of a highly strained *trans*-fused **3**. The stereochemistry at C-7 in the *endo*-**1** → **2a** path is presently under investigation.

[13] R. B. Woodward and R. Hoffmann, *J. Am. Chem. Soc.*, **87**, 2511 (1965).

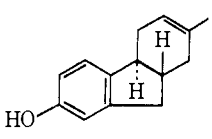
[14] National Institutes of Health Predoctoral Fellow, 1964–1966.

Jerome A. Berson, Robert S. Wood[14]
Department of Chemistry, University of Wisconsin
Madison, Wisconsin 53706
Received November 5, 1966

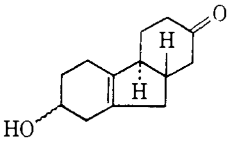
Birch Reduction of Phenols[1]

Sir:

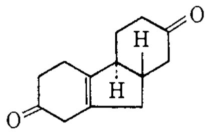
Birch reductions[2,3] of substances possessing free phenolic groups have been accomplished only in one special case, that of β-naphthol[4] and some of its derivatives.[5,6] On the basis of present concepts of the mechanism of the Birch reduction,[7] failure of such systems to undergo reduction must be ascribed to the high potential energy barrier to electron addition to the phenolate anion to form the required dianion radical intermediate.[8] In the course of studies of the stepwise reduction of 2-hydroxy-7-methoxyfluorene with lithium in ammonia[9] (1.5 *M*) it was noted that the mother liquors after removal of the major reaction product (I) contained several components, which on glpc[10] showed retention times shorter than that of I. Such mother liquors furnished after hydrolysis with 95% acetic acid the hydroxy ketone II (mp 152–153°;[11] $\lambda_{\max}^{\mathrm{KBr}}$ 3.0 μ (OH), 5.9 μ (CO), no benzenoid absorption; nmr, no vinyl protons), the structure of which was established by Jones oxidation to the known diketone III, mp 95–97°.[9] This finding indicated that Birch reduction of phenolic systems was possible and that the reaction might be driven to completion by a further increase in the metal concentration. This was indeed found to be the case. Increasing the initial concentration of lithium from 1.5 to 4 *M* led to essentially complete reduction of the phenolic ring.[12] When similar conditions were applied in the reduction of 5-indanol and *ar*-2-tetralol (0.045 *M* in substrate and 3.4 *M* in Li) Δ^8-hydrinden-5-ol (IV) and Δ^9-octalin-2-ol (V) were obtained in 70 and 46% yield, respectively. With 4.3 *M* Li the latter yield was 76%. IV had bp 65–68° (3 mm);[11] M^+ 138; nmr (A-60), one proton (multiplet) centered at 240 cps (C*H*OH), no vinyl protons; positive nitromethane reaction; phenylurethan, mp 119–121°;[11] nmr, one-proton (quintet) at 311 cps (J = 5.5 cps) (C*H*OR), no vinyl protons; and V had bp 72° (2 mm);[13] M^+ 152; phenylurethan, mp 134–135°,[11] nmr, one-proton (multiplet) centered at 307 cps (C*H*OR), no vinyl protons; positive nitromethane reaction. In contrast, 4-indanol was recovered unchanged under more drastic conditions (5.5 *M* Li) reminiscent of the unusually high concentrations of metal required for the reduction of compounds possessing the *ar*-1-methoxytetralin ring systems.[14,15]



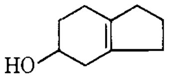
I



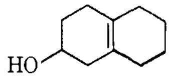
II



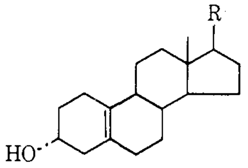
III



IV



V



VI, $\mathrm{R} = {<}^{\mathrm{OH}}_{\mathrm{H}}$

VII, $\mathrm{R} = {<}^{\mathrm{O-CH_2}}_{\mathrm{O-CH_2}}$

VIII, R = =O

The relative yields of IV and V obtained in parallel experiments suggested that the rate of reduction of 5-indanol was greater than that of *ar*-2-tetralol. Krapcho and Bothner-By[7] have shown by competition experiments that indan is reduced by Li–NH_3 2.5 times faster than tetralin. Applying this method to the reduction of 5-indanol and *ar*-2-tetralol (0.022 *M* each,

---

[1] This investigation was supported by Public Health Service Research Grant CA 07445 and by Research Career Program Award 5-K6-AM-21846 from the National Institute of Arthritis and Metabolic Diseases.

[2] H. Smith, "Organic Reactions in Liquid Ammonia. Chemistry in Non-aqueous Solvents," Vol. 1, Part 2, John Wiley and Sons, Inc., New York, N. Y., 1963.

[3] H. O. House, "Modern Synthetic Reactions," W. A. Benjamin, Inc., New York, N. Y., 1965, p 50 ff.

[4] C. D. Gutsche and H. H. Peter, *Org. Syn.*, **37**, 80 (1957).

[5] N. A. Nelson, R. S. P. Hsi, J. M. Schuck, and L. D. Khan, *J. Am. Chem. Soc.*, **82**, 2573 (1960).

[6] The great ease of reduction in this case can be understood if one assumes the reaction to proceed *via* the α,β-unsaturated keto form. Several reactions of β-naphthol appear to involve this tautomeric form. *Cf.* Roberts and Caserio, "Basic Principles of Organic Chemistry," W. A. Benjamin, Inc., New York, N. Y., 1964, p 908.

[7] A. P. Krapcho and A. A. Bothner-By, *J. Am. Chem. Soc.*, **81**, 3658 (1959).

[8] *Cf.*, however, R. A. Benkeser, C. Arnold, Jr., F. Lambert, and O. H. Thomas, *ibid.*, **77**, 6042 (1955), who reduced phenol with lithium in methyl- or ethylamine and produced cyclohexanone.

[9] J. Fried and N. A. Abraham, *Tetrahedron Letters*, 3505 (1965).

[10] Gas-liquid partition chromatography was performed on an F & M Model 400 instrument fitted with a 4-ft 3.8% SE 30 on Diatoport S column at a He flow rate of 100 cc/min.

[11] Analyses by J. Alcino, Metuchen, N. J.

[12] The complete composition of the reaction mixture will be described elsewhere. A typical reduction was conducted as follows. To a solution of 0.21 g-atom of Li in 50 ml of redistilled NH_3 at −40 to −50° is added 1.4 mmoles of 2-hydroxy-7-methoxyfluorene in 9 ml of dry THF without exclusion of air. Portions of ethanol (4 ml) are then added in 30-min intervals until the solution is decolorized (*ca.* 1.75 hr) and the reaction mixture is worked up in standard fashion.

[13] J. E. Starr and R. H. Eastman, *J. Org. Chem.*, **31**, 1393 (1966).

[14] A. J. Birch, A. R. Murray, and H. Smith, *J. Chem. Soc.*, 1945 (1951).

[15] W. S. Johnson, B. Bannister, and R. Pappo, *J. Am. Chem. Soc.*, **78**, 6331 (1956).

2.8 *M* Li) and analyzing the reaction mixture by glpc[16] we have found a ratio for $k_{\mathrm{indanol}}/k_{\mathrm{tetralol}}$ of 1.26,[7] indicating a considerably smaller rate difference for the phenolic systems than for the hydrocarbons. This may be rationalized as follows. The difference in bond angle strain which is reflected in the greater rate of reduction of indan with respect to tetralin becomes insignificant in the case of the corresponding phenols in view of the much greater energy barrier to reduction resulting from the like charges of the reacting species.

As representatives of the phenolic estrogens[17] we have subjected estrone and its 17-ethylene ketal, mp 171–172°,[11] $[\alpha]^{31}\mathrm{D}$ +30°, to Birch reduction in 0.014 *M* solution and an initial Li concentration of 4.3 *M*. Estrone furnished in 95% yield a product which consisted of 77% of $\Delta^{5(10)}$-estrene-3α,17β-diol (VI)[18] and 23% of a faster moving component (glpc analysis). The former was obtained by direct crystallization, mp 205–207°, and identified by comparison with an authentic sample.[19] The faster moving component could not be separated in pure form, but analysis of the mass spectra of mixtures of the latter with VI indicated that it must be a 5,10-dihydro derivative of VI.[20] Similarly, reduction of estrone 17-ethylene ketal furnished a 4:1 mixture of the ketal VII and its 5,10-dihydro derivative, mp 135–136°,[11] M^+ 318 and 320, which on hydrolysis with dilute acid afforded the corresponding 17-ketone VIII.[19] We have considered the possibility that the phenolic ring might be reduced at a slower rate in the case of estrone than of its ketal because of a possible long-range electrostatic effect of the 17-hydroxylate anion (formed on reduction of the 17-keto group of estrone) on the rate of electron addition to the phenolic ring. A competition experiment[21] involving these two substrates (0.01 *M* in each, 2.8 *M* Li) gave $k_{\mathrm{ketal}}/k_{\mathrm{estrone}} = 1.73$, suggesting that such long-range interactions may indeed be operative.

We consider it most likely that the above reductions take place in the bronze phase of the metal–ammonia system, which exhibits electron mobility characteristic of the metallic state and is known to contain solvated and at highest concentrations unsolvated electrons in equilibrium with dimeric or even polymeric metal species.[22] It is possible, therefore, that it is merely the higher concentration of electrons which drives the reaction. On the other hand, the possibility of contact ion-pair formation between phenolate and metal ions favored by high concentrations of the latter, thereby reducing electrostatic repulsion between substrate and the electron-carrying species, must also be considered.

---

(16) Column temperature 110°; retention times (minutes) 5-indanol, 4.4; *ar*-2-tetralol, 8.4; IV, 1.6; V, 3.3; Both IV and V contained 20% of a faster component at 1.4 and 2.6 min, respectively, which may represent dihydro derivatives of the former. *Vide infra.*

(17) *Cf.* C. Djerassi, "Steroid Reactions," Holden-Day, Inc., San Francisco, Calif., 1963, p 267 ff.

(18) J. A. Hartmann, *J. Am. Chem. Soc.*, 77, 5151 (1955). For correct stereochemistry at C-3, see S. B. Levine, N. H. Eudy, and E. C. Farthing, *Tetrahedron Letters*, 1517 (1963), and W. F. Johns, *J. Org. Chem.*, **29**, 1490 (1964).

(19) We wish to thank Dr. W. F. Johns of G. D. Searle and Co. for a sample of this compound.

(20) Of the possible structures we prefer that of 5α-estrane-3α,17β-diol, since exposure of pure VI to Li-NH_3 under the conditions employed for estrone led to a mixture showing the same ratio of components on glpc as the product obtained from estrone.

(21) Glpc at 210°; retention times (minutes): estradiol, 7.4; estrone 17-ethylene ketal, 11.5; VI, 4.8; VII, 7.8. Extraction with base separated estradiol from VII, but, surprisingly, left estrone ketal in the neutral fraction.

(22) "Solvated Electrons," Advances in Chemistry Series, No. 50, American Chemical Society, Washington, D. C., 1965.

Josef Fried, N. A. Abraham, T. S. Santhanakrishnan
Ben May Laboratory and Departments of
Chemistry and Biochemistry, University of Chicago
Chicago, Illinois 60637

Received December 12, 1966

Book Reviews

Principles of Polarography. By Professor JAROSLAV HEYROVSKY, Nobel Prize Laureate of Chemistry, 1959, and JAROSLAV KUTA, D.Sc. Academic Press Inc., 111 Fifth Ave., New York, N. Y. 1966. 581 pp. 17 × 24.5 cm. $19.50.

The appearance of an English edition of this book, originally published in the Czech language in 1963, has been awaited with great interest. Given a subject in which many thousands of papers have been written over a period of forty years, authors who represent the founder of the method and one of his outstanding collaborators, and the limitations of a single volume addressed primarily to third-year undergraduates, what topics are to be covered, and in what depth? Perhaps even more important, what topics are to be omitted, and what complications are to be avoided?

The authors have taken the approach of eliminating complex mathematical details, minimizing experimental descriptions, showing experimental results that stress basic principles, and discussing the results in relation to theory. It is difficult to quarrel with this approach, although we may wish for differing degrees of emphasis on the various topics, which often reflect the particular viewpoint of the Czech school. Thus a special chapter, "The Kalousek Commutator (Switch) and Related Methods" by J. Weber, serves to give due credit to Kalousek for his pioneering experiments, but it relegates to 4.5 pages (out of 18) the square wave and pulse polarographic methods which have the advantage of minimizing charging currents.

The organization of the book causes odd scattering effects on subjects not included in classical polarography. For example, chronopotentiometry is buried in Chapter XXII, entitled "Oscillographic Polarography," and linear voltage sweep voltammetry is covered partly in that same chapter, partly in Chapter VII, "Equation for a Reversible Polarographic Wave," and partly in Chapter XIV, "Irreversible Electrode Processes."

Overwhelming emphasis is placed on various forms of mercury electrodes. Although there is an excellent 3-page description of the Levich rotated disk electrode, little mention is made of this powerful tool for studies of kinetics and mechanisms.

Topics that are very briefly covered include pen and ink recording polarographs (barely mentioned), limiting current (amperometric) titrations (4 pages), polarography of organic substances (4.5 pages),