the disappearance of the ν_2 band using ferrioxalate actinometry. The quantum yields were found to be zero order in a concentration range of 0.007 to 0.040 M vanadium(III). GC analysis demonstrated that, for every mole of vanadium(III) consumed in the course of irradiation of ethanolic vanadium trichloride solution, 0.5 mol of acetaldehyde is produced. The overall reaction may be represented by

$$2V^{3+} + RCH_2OH + h\nu \rightarrow 2V^{2+} + RCHO + 2H^+ \quad (1)$$

The emission spectra (EMI) of vanadium(III) alcoholates in room temperature solution are shown in Figure 1 together with the excitation spectra (EXC) and the charge-transfer absorption spectra (ABS). The luminescence emission band[7] is a mirror image of charge-transfer absorption band. We assign the observed luminescence as a fluorescence from the charge-transfer excited state, $^3CT \rightarrow {}^3T_{1g}(F)$, though the lifetime has not been measured. The differences in energy between the emission and absorption maxima (the Stokes shifts) are as much as 9–12 kK, as expected from the broad absorption bands. A large Stokes shift indicates a marked distortion of the excited-state potential energy surface with respect to the ground state along the configuration coordinate. The excitation spectra[8] are not identical with the charge-transfer absorption spectra, as can be seen in Figure 1. The methanolic vanadium trichloride solution has an excitation spectrum beginning at 310 nm, while the ethanolic and 1-propanolic vanadium trichloride solutions begin at 295 nm. Table I shows fluorescence quantum yields Φ_f upon excitation at 290, 330, or 345 nm, as measured against quinine bisulfate in 0.1 N sulfuric acid as a standard.[9] The significant reduction in fluorescence quantum yields with lower wavelength excitation may be accounted for in terms of a critical vibration approximation[10,11] in a distorted charge-transfer excited-state surface with a shallow minimum along the reaction coordinate. The excitation at wavelengths shorter than 300 nm would cause dissociation of vanadium(III) alcoholates into fragments within the lifetime of a few vibrations in the excited state. At longer wavelengths, the dissociation process would compete with vibrational degradation process resulting in fluorescence.

In view of the experimental results, we assume the following mechanism upon irradiation with 313-nm light:

$$^3T_{1g}(F) + h\nu \rightarrow (^3CT)^* \quad (2)$$

$$(^3CT)^* \rightarrow \text{dissociation} \quad (3)$$

$$(^3CT)^* \rightarrow (^3CT)^0 \quad (4)$$

$$(^3CT)^0 \rightarrow {}^3T_{1g}(F) + h\nu' \quad (5)$$

$(^3CT)^*$ is a charge-transfer excited state of vanadium(III) alcoholate in an upper vibrational level (or continuous level) and $(^3CT)^0$ is one in the lowest vibrational level. Nonradiative processes leading to the disappearance of the excited state must be involved, but the present data do not allow a precise description concerning the mechanism. This problem is the focus of further investigation.

Acknowledgment. This work was supported by the Robert A. Welch Foundation Grant G-420. We thank Dr. J. Fendler for the use of his SPEX Fluorolog spectrometer in recording fluorescence data.

References and Notes

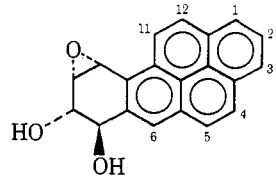
(1) (a) V. Balzani and V. Carassiti, "Photochemistry of Coordination Compounds", Academic Press, New York, N.Y., 1970; (b) J. F. Endicott, "Concepts of Inorganic Photochemistry", Chapter 3, A. W. Adamson and P. D. Fleichauer, Ed., Wiley-Interscience, New York, N.Y., 1975.
(2) The photoreduction of vanadium(III) to vanadium(II) has been recently found in an ethanolic vanadium trichloride solution: B. V. Korakin, T. S. Dzabiev, and A. E. Shilov, *Dokl. Akad. Nauk. SSSR*, **229**, 128 (1976).
(3) A. T. Casey and R. J. H. Clark, *Inorg. Chem.*, **8**, 1216 (1969).
(4) ν_1 15.0 kK (ϵ 8) and ν_2 22.3 kK (ϵ 16) for CH_3OH; ν_1 15.0 kK (ϵ 8) and ν_2 22.3 kK (ϵ 15) for C_2H_5OH; ν_1 14.8 kK (ϵ 8) and ν_2 22.0 kK (ϵ 16) for *n*-C_3H_7OH.
(5) ν_1' 17.5 kK and ν_2' 26.5 kK for CH_3OH; ν_1' 17.4 kK and ν_2' 26.3 kK for C_2H_5OH; ν_1' 16.9 kK (ϵ 6) and ν_2' 25.6 kK (ϵ 4) for *n*-C_3H_7OH. Isobestic points appeared at 525 and 625 nm for the course of the photoreduction.
(6) H. J. Selfert and T. Auel, *J. Inorg. Nucl. Chem.*, **30**, 2001 (1968).
(7) The addition of acetaldehyde to ethanolic vanadium(III) trichloride solution did not affect the emission spectrum. The ethanolic vanadium(II) dichloride solution did not show any emission upon excitation at UV light.
(8) These excitation bands are not identical with any absorption bands characteristic of aldehydes and alcoholic vanadium(II) dichloride solutions as final photoproducts.
(9) C. A. Parker and W. T. Rees, *Analyst*, **85**, 587 (1960).
(10) Y. Hass, G. Stein, and M. Tomiewicz, *J. Phys. Chem.*, **74**, 2558 (1970).
(11) S. McGlynn, *Chem. Rev.*, **58**, 1113 (1958).

Y. Doi, M. Tsutsui*
Department of Chemistry, Texas A&M University
College Station, Texas 77843
Received August 24, 1977

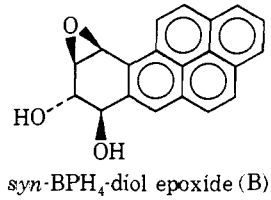
Structural Features Which Determine the Carcinogenesis, Mutagenesis, and Rates of Acid- and Water-Mediated Solvolysis of and Nucleophilic Attack upon Diol Epoxides, Bay-Region and Non-Bay-Region Tetrahydro Epoxides, and K-Region and Non-K-Region Arene Oxides

Sir:

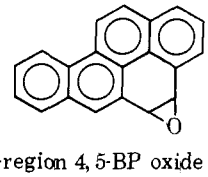
Microsomal mixed function oxidation of polycyclic aromatic hydrocarbons results in the formation of arene oxides. These are converted to phenols via the NIH shift[1] and to trans diols by epoxide hydrase.[2] Dependent upon the structure of the trans diol, further epoxidation by microsomal mixed function oxidase may lead to the production of tetrahydrodiol epoxides which in turn are hydrolyzed to tetrahydrotetrols. The mutagenic, cytotoxic, and carcinogenic properties of these products and intermediates have recently and are presently receiving considerable attention. The greatest effort has been expended upon compounds oxidatively derived from benzo[*a*]pyrene (BP), a ubiquitous environmental carcinogen. These studies have centered on the importance of the type of BP derivative and the various positional isomers in the causation of mutagenesis, necrosis, and carcinogenesis. Results to date indicate that there is no strict structural vs. activity relationship among the three activities and that the orders of activity may be changed in going from one test system to another.[3-8] Nevertheless, the tetrahydrobenzo[*a*]pyrenediol epoxides (A and B) and the K-region 4,5-BP oxide (C) appear to be the most interesting of the various BP derivatives. The reaction of these compounds with both nuclear DNA and polydeoxy nucleotides have yielded identifiable covalent adducts.[10] The modes of covalent bonding to DNA and polydeoxyribonucleic acids are dependent upon the nature of the BP derivative.[9-10]



anti-BPH_4 diol epoxide (A)



syn-BPH_4-diol epoxide (B)



K-region 4,5-BP oxide (C)

0002-7863/78/1500-3244$01.00/0

In all bioassays for mutagenesis or carcinogenesis the causative agent must reach the target without undergoing rearrangement or solvolysis. If DNA is the target, then the agent must presumably intercalate and remain stable long enough to undergo covalent bonding to the DNA. A "nucleophilic susceptibility index" (NSI) has been suggested[11] as a means of assessing the relative rates of nucleophilic addition vs. solvolysis and rearrangement. The NSI has been defined as the ratio (A/B) of the second-order rate constant for attack by β-mercaptoethanol anion (A) to the first-order rate constant for solvolysis of a given epoxide with water (B) relative to the same ratio for ethylene oxide (a general alkylating agent).[10a] When NSI $\geq$ 1.0, the agent has a "lasting ability in water" combined with an electrophilicity that makes it as good or better an alkylating agent than ethylene oxide. For example, the NSI for phenanthrene 9,10-oxide (a K-region oxide) is 2.0 while phenanthrene 1,2- and 3,4-oxides possess NSI values of 8×10^{-4} and 6×10^{-4}, respectively.[11b] It has been established that only the K-region oxide of phenanthrene is subject to attack by various nucleophiles.[11] This concept that the agent must last to act as an alkylating agent has been appreciated in studies with BP derivatives[12] and it has been established (qualitatively) that the finding with phenanthrene oxides may be extended to BP where the 4,5-BP oxide (K-region oxide) lasts in broth solutions at neutrality much longer than the 7,8-BP oxide and 9,10-BP oxide.[7] In this communication we describe our preliminary results on the rates of spontaneous and H_3O^+-catalyzed solvolysis of and the NSI values for the tetrahydrodiol epoxides of naphthalene and the tetrahydro epoxides of naphthalene and phenanthrene and compare these with previous results with phenanthrene oxides, etc. (Table I). Our objective has been to understand the various structure vs. reactivity parameters which we feel should be followed at least in qualitative order in the BP and benz[*a*]anthracene series.[13]

The pH vs. logarithm of the pseudo-first-order rate constants (k_{obsd}) profiles of the compounds of Table I (30 °C, H_2O, μ = 1.0 with KCl) accurately follow the rate law

$$k_{obsd} = k_0 + k_H[H_3{}^+O] = k_{H_2O}[H_2O] + k_H[H_3O^+] \quad (1)$$

This feature characterizes the solvolytic chemistry of arene oxides[14a] and epoxides in general.[14b] The value of k_0 refers to reaction with water perhaps as a nucleophile with epoxides and in the case of arene oxides as a proton donor.[15] The values of k_0 and k_H are provided in Table I along with the NSI indices.[11,16]

Changes in the values of k_H and k_0 and changes in structure do not coincide. Thus, allylic unsaturation increases the values of k_0 as would be anticipated for a reaction which proceeds through the formation of a carbocation[14a,b] (e.g., **2** > **1**, **8** > **7**, **4** > **3**, and **6** > **5**). The order is reversed when one compares the values of k_H (i.e., **1** > **2**, **7** > **8**, **3** > **4**, and **5** > **6**), although the acid-catalyzed opening of the epoxide ring of arene oxides[14a] involves rate-determining carbocation formation as does most likely the hydrolysis of epoxides.[14c] The structure–reactivity relationship for the water-mediated reaction is as anticipated so that some perturbing influence upon the acid rate constants must be sought. One possible cause for the reversal in the acid catalyzed reactions is an inductive decrease in the pK_a of the allylic unsaturated epoxides. The ratio of the rate constants for H_3O^+ and H_2O-catalyzed ring opening of epoxides are proportional

$$k'_H/k_H = \alpha(k'_0/k_0) \quad (2)$$

where the primed values represent the unsaturated compounds. The pK_a's of epoxides are experimentally unobtainable under our conditions. For preequilibrium protonation and ring opening of protonated epoxide (k_{Hr}), the experimental value of $k_H = k_{Hr}K_a$. Therefore

Table I. Rate Constants (30 °C, μ = 1.0 with KCl[a]) for Hydronium Ion (k_H, $M^{-1}\,s^{-1}$) and Spontaneous Solvolysis (k_0, s^{-1}) and Values of Nucleophilic Susceptibility Indices (NSI)

		k_H	k_0	k_s	NSI
1[b]		1.6×10^4	2.2×10^{-4}	-	
2[c]		3.0×10^1	1.2×10^{-3}	0.17	2×10^{-3}
3[d]		1.2×10^3	7.5×10^{-5}	0.36	8×10^{-2}
4[c]		1.4×10^2	2.9×10^{-3}	1.69	9×10^{-3}
5[e]		1.4×10^4	8.0×10^{-4}	5.09	1×10^{-1}
6[c]		2.7×10^3	5.55×10^{-2}	2.04	6×10^{-4}
7[e]		5.5×10^3	1.7×10^{-4}	2.45	2×10^{-1}
8[c]		1.0×10^3	3.1×10^{-2}	1.58	8×10^{-4}
9[c]		1×10^2	2.5×10^{-5}	3.38	2.0
10[f]		4.0×10^1	1.1×10^{-5}	0.51	7×10^{-1}
11[f]		6.0	8.5×10^{-5}	0.64	1.1×10^{-1}

[a] In calculation of k_0, the effect of chloride ion has been taken into account: D. L. Whalen and A. M. Ross, *J. Am. Chem. Soc.*, **98**, 7859 (1976). [b] At 25 °C: D. L. Whalen, *ibid.*, **95**, 3432 (1973). [c] P. Y. Bruice, T. C. Bruice, P. M. Dansette, H. G. Selander, H. Yagi, and D. M. Jerina, *ibid.*, **98**, 2965 (1976). [d] Prepared via *m*-chloroperbenzoic acid with 1,2-dihydronaphthalene. [e] Prepared by procedure of H. Yagi and D. Jerina, *ibid.*, **97**, 3185 (1975). The 3,4-oxide (mp 62–63 °C; NMR – δ 3.75 (H_3, 1 H); 4.6 (d, H_4, 1 H)) contained a small amount (<5%) of the 3-keto compound which did not affect the kinetics of the epoxide. This epoxide was used within 1 week of its preparation. [f] Prepared by a modification of the procedure of H. Yagi, D. R. Thakker, O. Hernandez, M. Koreeda, and D. M. Jerina, *ibid.*, **99**, 1604 (1977).

$$\frac{K'_a}{K_a} = \alpha(k'_0k_{Hr}/k_0k'_{Hr}) \text{ or } \Delta pK_a = \alpha \log (k'_0k_{Hr}/k_0k'_{Hr}) \quad (3)$$

relates the change in pK_a to the observed rate constants. For the pairs of related compounds (**3**/**4**, **5**/**6**, **7**/**8**) the required changes in pK_a are 2.5, 2.6, and 3.0 units, respectively. Since the opening of the protonated epoxide is anticipated to be associated with an earlier transition state than is the case for water-catalyzed ring opening, the values for ΔpK_a must be considered as maximum (α = 1). The inductive withdrawal by the double bond may account for much of the change.[17]

Examination of the rate constants of Table I reveals the following additional features: (i) in both acid- and water-promoted solvolysis, the least reactive oxides are the diol epoxides and the K-region arene oxide (their half-life at all pH values is greatest); (ii) at neutral and basic pH values all of the tetrahydro epoxides are less reactive than are the arene oxides with the single exception of the K-region arene oxide (**9**); and (iii) the reactivity of the *syn*-naphthalenediol epoxide (**11**) exceeds that for the anti isomer (**10**) at neutral and basic pH, but the opposite is true at acidic pH values (as is the case for the BPH_4-diol epoxides[18]). These results are consistent with the proposed internal hydrogen bonding in the syn isomers.[19,20] From these observations and others[11] it may be concluded that the K region behaves as an electron-deficient epoxide as do the

tetrahydrodiol epoxides. This feature must be of prime biological importance. Indeed, the chief chemical characteristics of the tetrahydrodiol epoxides are anticipated to be related to the electron-withdrawing properties of the two hydroxyl substituents.

It has been proposed that the "bay-region" tetrahydro epoxides of BP are particularly susceptible to solvolysis and nucleophilic attack owing to an enhancement in the stability of the benzylic carbocation formed upon ionic opening of the epoxide ring.[21] Comparison of the bay-region tetrahydro epoxide **5** with its isomer **7** reveals that both k_0 and k_H are greater by ~3- to 5-fold for the bay-region isomer. However, the same feature may be noted for the 1,2- and 3,4-phenanthrene oxides (**6** vs. **8**) although the predominant products are phenols formed from *allylic* rather than benzylic carbocations.[11] Examination of Table I reveals that the second-order rate constants for reaction of the various epoxides with thiol anions are almost independent of the structure of the epoxide (k_s = 0.17–5.09 M^{-1} s^{-1}; average 1.8 ± 1.2 M^{-1} s^{-1}). For this reason the nucleophilic susceptibility indices are determined primarily by k_0. The order of NSI values (i.e., **7** > **5** > **2** > **8** > **6** and **10** > **11** > **3** > **4**), if extrapolated to the similarly substituted BP derivatives, is broadly that of their carcinogenicity and mutagenicity. This is suggested to be related to either a relationship between k_0 and k_m/k_{cat} for the enzymes epoxide hydrase and glutathione conjugating enzyme[22] or to the possibility that epoxides which are not scavenged by these enzymes are those which reach gene material and their success in doing so is accounted for by their NSI values. In this regard it is known that A and B are very poor substrates for epoxide hydrase.[23]

Acknowledgment. This work was supported by a grant from the American Cancer Society.

References and Notes

(1) D. M. Jerina, J. W. Daly, B. Witkop, P. Zaltzman-Nirenberg, and S. Udenfriend, *J. Am. Chem. Soc.*, **90**, 6525 (1968); *Biochemistry*, **9**, 147 (1970).
(2) S. K. Yang, P. P. Roller, and H. V. Gelboin, *Biochemistry*, **16**, 3680 (1977).
(3) P. G. Wislocki, A. W. Wood, R. L. Chang, W. Levin, H. Yagi, O. Hernandez, P. M. Dansette, D. M. Jerina, and A. H. Conney, *Cancer Res.*, **36**, 3350 (1976).
(4) M. Miyato, K. Shudo, Y. Kitahara, G.-F. Huang, and T. Okamoto, *Mutation Res.*, **37**, 187 (1976).
(5) P. G. Wislocki, A. W. Wood, R. L. Chang, W. Levin, H. Yagi, O. Hernandez, D. M. Jerina, and A. H. Conney, *Biochem. Biophys. Res. Commun.*, **68**, 1006 (1976).
(6) A. W. Wood, P. G. Wislocki, R. L. Chang, W. Levin, A. Y. H. Lu, H. Yagi, O. Hernandez, D. M. Jerina, and A. H. Conney, *Cancer Res.*, **36**, 3358 (1976).
(7) A. W. Wood, R. L. Goode, R. L. Chang, W. Levin, A. H. Conney, H. Yagi, P. M. Dansette, and D. M. Jerina, *Proc. Natl. Acad. Sci. U.S.A.*, **72**, 3176 (1975).
(8) E. Bresnick, T. F. McDonald, H. Yagi, D. M. Jerina, W. Levin, A. W. Wood, and A. H. Conney, *Cancer Res.*, **37**, 984 (1977).
(9) (a) S. K. Yang, H. V. Gelboin, B. F. Trump, H. Antrup, and C. C. Harris, *Cancer Res.*, **37**, 1210 (1977); (b) W. M. Baird and L. Diamond, *Biochem. Biophys. Res. Commun.*, **77**, 162 (1977); (c) K. W. Jennette, A. M. Jeffrey, S. H. Blobstein, F. A. Beland, R. G. Harvey, and I. B. Weinstein, *Biochemistry*, **16**, 933 (1977); (d) K. Alexander and M. H. Thompson, *Cancer Res.*, **37**, 1443 (1977); (e) H. W. S. King, M. R. Osborne, F. A. Beland, R. G. Harvey, and P. Brooks, *Proc. Natl. Acad. Sci. U.S.A.*, **73**, 2679 (1976); (f) A. M. Jeffrey, K. W. Jennette, S. H. Blobstein, I. B. Weinstein, F. A. Beland, R. G. Harvey, H. Kasai, I. Mima, and K. Nakamishi, *J. Am. Chem. Soc.*, **98**, 5714 (1976); (g) M. Koreeda, P. D. Moore, H. Yagi, H. J. C. Yeh, and D. M. Jerina, *ibid.*, **98**, 6720 (1976); (h) G. Lowengart and B. L. Van Duuren, *Tetrahedron Lett.*, 3473 (1976).
(10) W. M. Baird and L. Diamond, *Biochem. Biophys. Res. Commun.*, **77**, 162 (1972).
(11) (a) P. Y. Bruice, T. C. Bruice, H. Yagi, and D. M. Jerina, *J. Am. Chem. Soc.*, **98**, 2973 (1976); (b) for a recent compilation see P. Y. Bruice and T. C. Bruice, *Biochemistry*, **17**, in press.
(12) M. D. Burke, H. Vadi, B. Jernström, and S. Orrenius, *J. Biol. Chem.*, **252**, 6424 (1977).
(13) T.C.B. has not felt that the available facilities would allow study of the highly carcinogenic BP analogues.
(14) (a) P. Y. Bruice and T. C. Bruice, *Acc. Chem. Res.*, **9**, 378 (1976); (b) F. A. Long and J. G. Pritchard, *J. Am. Chem. Soc.*, **78**, 2663 (1956); (c) C. H. Rochester, "Acidity Functions", Academic Press, New York, N.Y., 1970, p 138.
(15) P. Y. Bruice and T. C. Bruice, *J. Am. Chem. Soc.*, **98**, 2023 (1976).
(16) Determined as previously described: G. J. Kasperek and T. C. Bruice, *J. Am. Chem. Soc.*, **94**, 198 (1972).
(17) The pK_a values of amines are decreased by ~1.0 upon α,β unsaturation and by ~0.5 upon β,γ unsaturation: H. K. Hall, *J. Am. Chem. Soc.*, **79**, 5441 (1957); J. Clark and D. D. Perin, *Quant. Rev.*, **18**, 313 (1964). The value of ρ_I for this system (after converting from ρ^* to ρ_I employing a correction factor of 6.23 (M. Charton, *J. Org. Chem.*, **29**, 1222 (1964)) is ~−8. Pritchard and Long (J. G. Pritchard and F. A. Long, *J. Am. Chem. Soc.*, **78**, 2667 (1956)) have found the ρ^* for alkyl epoxides to be 1.95 which yields a ρ_I of ~12.2. Since ρ_I is much larger for epoxides than amines, the anticipated change in pK_a is expected to be >2.0.
(18) D. L. Whalen, J. A. Montemarano, D. R. Thakker, H. Yagi, and D. M. Jerina, *J. Am. Chem. Soc.*, **99**, 5522 (1977).
(19) P. B. Hulbert, *Nature*, **256**, 5513 (1975).
(20) Nonnucleophilic neighboring hydroxyl group participation is seen in many hydrolytic reactions (see T. C. Bruice and S. J. Benkovic, "Bioorganic Mechanisms", Vol. I, W. A. Benjamin, New York, N.Y., 1966, Chapter 1) and has been attributed to assistance in the solvation of the transition state (T. C. Bruice and T. H. Fife, *J. Am. Chem. Soc.*, **84**, 1973 (1962)).
(21) D. M. Jerina, R. E. Lehr, H. Yagi, O. Hernandez, P. M. Dansette, P. G. Wislocki, A. W. Wood, R. L. Chang, W. Levin, and A. H. Conney in "In Vitro Metabolic Activation in Mutagenesis Testing", F. J. de Serres, J. R. Bend, and R. M. Philpot, Ed., Elsevier, Amsterdam, 1976, pp 179–195.
(22) D. Jerina, *Arch. Biochem. Biophys.*, **128**, 176 (1968).
(23) D. R. Thakker, H. Yagi, A. Y. H. Lu, W. Levin, A. H. Conney, and D. M. Jerina, *Proc. Natl. Acad. Sci. U.S.A.*, **73**, 3381 (1976).
(24) A portion of this work will be submitted by A.R.B. in partial fulfillment of the requirements for the Ph.D.
(25) American Cancer Society postdoctoral fellow.
(26) Postdoctoral fellow of the National Institutes of Health.

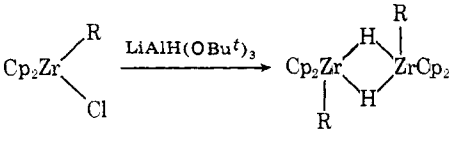
Allyn R. Becker,[24] John M. Janusz[25]
Donald Z. Rogers,[26] Thomas C. Bruice*
Department of Chemistry
University of California at Santa Barbara
Santa Barbara, California 93106
Received February 17, 1978

Hydrogenation of d^0 Complexes: Zirconium(IV) Alkyl Hydrides

Sir:

Catalytic reductive homologation of CO in Fischer–Tropsch procedures involves activation of molecular hydrogen. Zirconium(IV) species can reduce[1,2] or reductively homologate[2] CO, but Zr(IV)-based systems which function catalytically in this latter role require addition of hydrogen at the hydride oxidation level.[2] Zirconocene alkyl hydride complexes, $Cp_2Zr(R)H$ ($Cp = \eta^5$-C_5H_5), are models for plausible intermediates in the Zr(IV)-catalyzed reductive homologation of CO by aluminum hydrides,[2] and also in Cp_2ZrH_2-catalyzed hydrogenation of olefins.[3] Examination of the possible reaction between H_2 and $Cp_2Zr(R)H$ could therefore result in the development of modified CO reduction catalysts which can activate H_2 directly. We find that $Cp_2Zr(R)H$ does indeed react with H_2 to afford alkane (R–H) but by an unusual route.

Zirconocene alkyl hydrides (**2**) can be prepared[4] in yields of ~70% by reaction of $Cp_2Zr(R)Cl$[5] (**1**) with $LiAlH(OBu^t)_3$ at low temperature (−20 °C) in DME, from which they precipitate as white crystalline solids (reaction 1). For example, a solution of 4.55 g (12.7 mmol) **1a** in DME (25 mL), on



(1)

1 2

a, R = (cyclohexyl)methyl
b, R = cyclohexyl
c, R = ethyl
d, R = *n*-octyl
e, R = neopentyl

treatment with 1 equiv of a 1.1 M solution of $LiAlH(OBu^t)_3$ in DME, gave **2a** after 8 h at −20 °C. The compound, when isolated by filtration and washed with DME and hexane at low

0002-7863/78/1500-3246$01.00/0