tially full retention of enantiomeric purity during the rearrangement and the formation of endo and exo products with identical C-1 configuration *eliminate the,* a priori least favorable,[20] *α-cleavage* (path i) *entirely*[22] *and the allowed concerted cycloaddition* (path iii) *at least as the major reaction course.* There remains a stepwise mechanism of type ii which alone, irrespective of the detailed pathway, can account for the formation of the major product **5** (and equally well also for **6**), barring its unlikely generation in a single ${}_{\sigma}2_s + {}_{\pi}2_a$ step which is forbidden in the terms of orbital symmetry control.[4,24]

The high stereoselectivity of this reaction deserves some speculative comment although a definitive interpretation must await precise knowledge of the intermediate(s) involved. Solvent dependent uv and NMR spectral changes[25] indicate that the ground-state conformational equilibrium of **1** in a polar medium favors the half-chair or boat forms with the dimethoxymethyl substituent in the (pseudo)equatorial position. The rearrangement to (1*S*)-**5** and -**6** requires the same conformation of triplet **1**. It would in fact be acceptable to assume that ground and excited states adopt similar conformational preferences in similarly polar solvents.

A stepwise reaction course corresponding to ii, as established now as the most likely mechanism[24] for (the major part of) the ODPM rearrangement of **1**, need not be general to similar transformations of any other *β,γ*-unsaturated ketone. Nevertheless, it is compatible with all other examples which have been studied in some detail.[23,26] Only two[19,23e] of those cases, which conform to the mechanistic expectations of an allowed ${}_{\sigma}2 + {}_{\pi}2$ cycloaddition, require as an additional condition that a single intermediate corresponding to **3** be formed and converted directly to product with inversion at the *β*-carbon.

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References and Notes

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(4) For a discussion of this case see R. B. Woodward and R. Hoffmann, *Angew. Chem., Int. Ed. Engl.*, **8**, 781 (1969).

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(7) The photolyses were carried out at ca. 25° after flushing of the solutions with nitrogen.

(8) The structures of products **1**, **5**, and **6**, which find their closest analogy in the previously reported homologous octalone series,[6a] are confirmed by spectral analysis to be reported in detail in our full publication. Key data are: **1**, uv (hexane) $\epsilon_{\max}{}^{283}$ 168, (CH_3OH) $\epsilon_{\max}{}^{306}$ 770; ir (CCl_4) 1725 and 1678 cm^{-1}; NMR ($CDCl_3$) doublets at δ 3.12 (CCl_4: 2.95) and 4.65 (2 H each, $J = 5$ Hz) and a singlet at 3.48 (6 H); **5**, ir (CCl_4) 1720 cm^{-1}; NMR ($CDCl_3$) singlets at δ 3.40 and 3.28 (3 H each) and a doublet at 4.53 (1 H, $J = 7$ Hz); **6** exhibits similar spectral characteristics.

(9) The CD data were measured in hexane at 22° and the $\Delta\epsilon$ values given are corrected for 100% enantiomeric purity.[10]

(10) Enantiomeric purities were determined in $CDCl_3$ by NMR (100 MHz) using $Pr(TFC)_3$ as a chiral shift reagent; experimental error is ±3%.

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(12) The absolute configurations of (−)-**5**, (−)-**6**, and (+)-**7** were established by comparison of their Cotton effects with those of appropriate model compounds of known configuration. Reference substances for **5** and **6**: dihydroumbellulone[13] and other bicyclo[3.1.0]hexan-2-one derivatives;[14] **7**: 19,19-dimethoxytestosterone acetate,[15] *B*-nor(−17*α*-methyl[16])testosterones,[13a] (1*S*,7a*S*)-(+)-1-hydroxy-7,7a-dihydro-7a-methyl-5(6*H*)-indanone and its *tert*-butyl ether.[17] The (*S*) configuration of (−)-**1** follows from its formation[6] from (*R*)-**7**.

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(24) A referee has pointed out that the possibility of a "forbidden" concerted cycloaddition cannot be ruled out without evidence for reaction intermediates.

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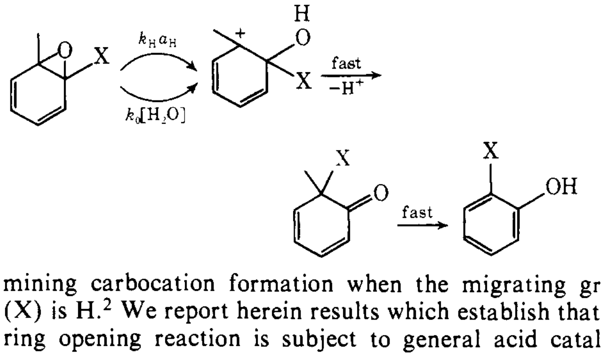
Modes of Acid Catalysis in the Aromatization of Arene Oxides

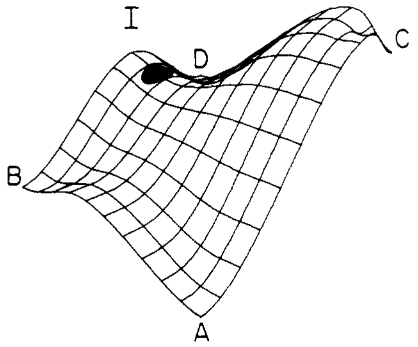
Sir:

The aromatization of arene oxides has previously been shown to occur by H_3O^+ (k_H) and spontaneous or water (k_0) catalysis (eq 1).[1] Both mechanisms involve rate determining carbocation formation when the migrating group (X) is H.[2] We report herein results which establish that the ring opening reaction is subject to general acid catalysis

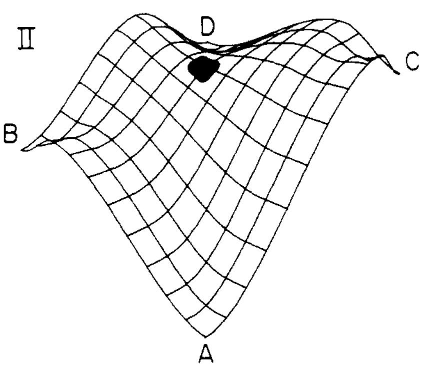


(1)

I



II



III

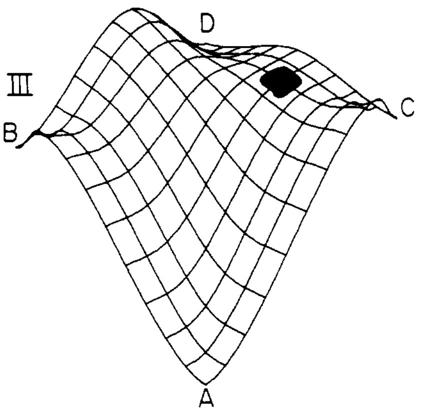


Table I. Rate Constants, Kinetic Solvent Isotope Effects, and Activation Parameters

	H_3O^+ catalyzed		H_2O catalyzed			
Arene oxide[a]	k_H, $M^{-1}\ s^{-1}$	$k_H^{H_2O}/k_D^{D_2O}$	$k_{H_2O}\ s^{-1}$	k_{H_2O}/k_{D_2O}	$\Delta H^{\ddagger}$,[b] kcal M^{-1}	$\Delta S^{\ddagger}$, eu[b]
Benzene oxide	30	0.5	1.20×10^{-3}	1.25	17.1	−15.4
Naphthalene 1,2-oxide	140	0.2	2.9×10^{-3}	1.30	13.4	−26.2
Phenanthrene 1,2-oxide	1000		3.10×10^{-2}	1.24	13.7	−20.1
Phenanthrene 3,4-oxide	2700		5.55×10^{-2}	1.25	12.3	−23.8
Phenanthrene 9,10-oxide	100	0.3	2.1×10^{-4}	1.29		

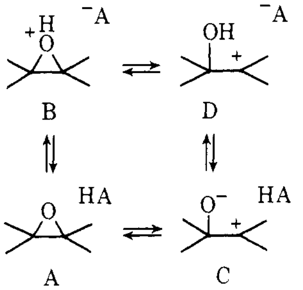
[a] Samples were from previous studies: benzene oxide and phenanthrene 9,10-oxide (ref 1), naphthalene 1,2-oxide (ref 2), phenanthrene 1,2 and 3,4-oxide (ref 3). [b] Values of E_a were determined from plots of log k_{obsd} vs. $1/T$, $\Delta H^{\ddagger} = E_a - RT$, $\Delta F^{\ddagger} = RT \ln (kT/hk_{obsd})$, $\Delta S^{\ddagger} = (\Delta H^{\ddagger} - \Delta F^{\ddagger})/T$; standard state 25° and time in seconds.

and, furthermore, that the k_0 and k_H associated mechanisms represent general acid catalysis with very little and very nearly complete proton transfer, respectively. General acid catalysis has previously been recognized in the aromatization of the K-region oxide, phenanthrene 9,10-oxide.[3] It is now evident that general acid catalysis of the ring opening reaction is a common feature of both K-region and non-K-region arene oxides.

The arene oxides employed in this study are listed in Table I. Below pH ~5.5 and above pH ~7.5, addition of general acids (CH_3CO_2H, HCOOH, H_2CO_3, etc.) up to 0.5 M does not alter the pseudo-first-order rate constants (k_{obsd}) for aromatization of the various oxides. In the pH range 5.5-7.5, however, the aromatization of the oxides is subject to general acid catalysis by acetic acid, cacodylic acid, $H_2PO_4^-$, and imidazole-H^+ (see insert to Figure 1). The second-order rate constants for buffer acid catalysis (k_{HA}) were obtained from the slopes of plots of k_{obsd} vs. $[A_T]$, where $[A_T] = [HA] + [A:]$, employing four to five concentrations of $[A_T]$ for each plot. Plots were obtained for 2-3 pH values and $k_{HA} = \text{slope}/a_H(K_a + a_H)^{-1}$ according to eq 2 where K_a is the acid dissociation constant of HA and a_H is the hydrogen ion activity as measured by the glass electrode. In Figure 1 the log k_{HA} values are plotted vs. the pK_a of HA in the Bronsted fashion. The slope of the lines ($-\alpha$) connecting the points vary from 0.8 to 0.1. The tangential $-\alpha$ value at pK_a 7 is ~0.6. In Table I are reported pertinent kinetic terms for the H_3O^+ and H_2O catalyzed isomerization of five arene oxides to their respective phenolic products. The kinetic deuterium solvent isotope effects for H_2O catalysis ($k_0^{H_2O}/k_0^{D_2O}$) are seen to range from 1.24 to 1.30, indicating some proton donation from H_2O to oxide in the transition state. The $\Delta S^{\ddagger}{}_{eu}$ values for the H_2O catalyzed reaction (−15 to −26) are of the magnitude usually associated with involvement of H_2O as a general acid or general base.[4] On the other hand, the values of $k_H^{H_2O}/k_D^{D_2O}$ are as previously reported for specific acid catalysis.[5]

$$k_{obsd} = k_H a_H + k_0 + k_{HA}[A_T] \frac{a_H}{K_a + a_H} \tag{2}$$

Rate determining carbocation formation may occur by way of the stepwise alternate routes of eq 3. A knowledge of



(3)

the free energies of formation of states B, C, and D from A (i.e., $\Delta G°_{A\to B}$, $\Delta G°_{A\to C}$ and $\Delta G°_{A\to D}$) along with the values of the edge free energies of activation in going from state to state (i.e., $\Delta G^{\ddagger}_{A\to B}$, $\Delta G^{\ddagger}_{B\to D}$, and $\Delta G^{\ddagger}_{A\to D}$) allows, at least in principle, the computation of a free energy contour map (method of alternate routes or "MAR"). The "MAR" free energy contour maps[6,7] of I, II, and III pertain to pH 0, 6, and 11, respectively.[5] In I the transition state associated with H_3O^+ catalysis (A → B → D) lies close to the B → D edge (80% H^+ transfer, $-\alpha \simeq 0.8$), while in III the transition state for H_2O catalysis is close to the C → D edge (40% H^+ transfer, $-\alpha = 0.4$). Thus, within the limits of the MAR computation, the mechanism for k_H borders on specific acid-general acid catalysis while the mechanism for k_0 borders on general acid catalyzed ring opening and spontaneous ring opening followed by a partially rate determining diffusion-controlled protonation by H_2O. Inspection of II reveals that near pH 6.0, the $\Delta G^{\ddagger}_{B\to D}$ and $\Delta G^{\ddagger}_{C\to D}$ values for the rate controlling steps of H_3O^+ and H_2O catalysis, respectively, are nearly identi-

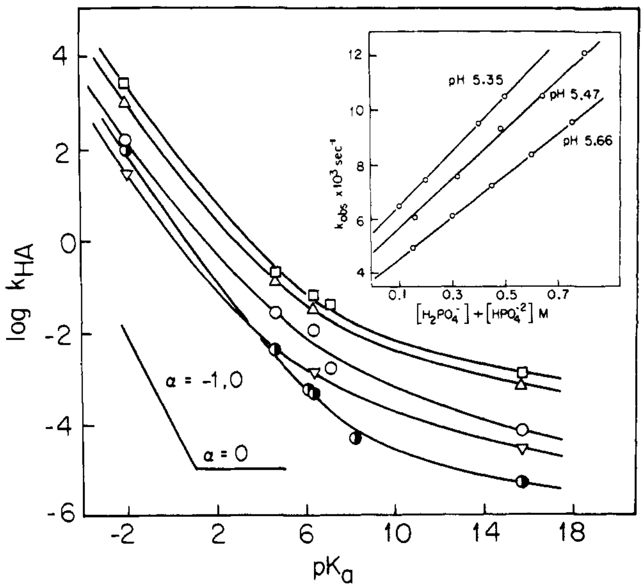


Figure 1. Plot of the log of the second-order rate constants for catalysis of aromatization of phenanthrene 3,4-oxide (□), phenanthrene 1,2-oxide (△), naphthalene 1,2-oxide (○), phenanthrene 9,10-oxide (◑), and benzene oxide (▽) vs. the pK_a of the acid catalyst: H_3O^+ (pK_a −1.74), acetic acid (pK_a 4.71), cacodylic acid (pK_a 6.23), $H_2PO_4^-$ (pK_a 6.42), imidazole (pK_a 7.14), Tris (pK_a 8.25), and H_2O (pK_a 15.75). Insert to figure: Plots of the observed first-order rate constants vs. total concentration of phosphate buffer for the aromatization of naphthalene 1,2-oxide at three pH values.

cal and a free energy minimum exists between A and D which provides for concerted general acid catalysis. From II it may be seen that this minimum corresponds to a transition state associated with ca. 60% C–O bond scission and 60% H–O bond scission ($-\alpha$ = 0.6). General acid catalysis of carbocation formation is, therefore, anticipated in the aromatization of the arene oxides. The experimental results reported herein support these quasi-theoretical predictions.

Jencks and co-workers have recently established Bronsted relationships extending from β = +1 to 0 for general base-assisted acyl transfer to α-effect amines.[8] The present study represents the first instance of a range of possible transition states in a general acid catalyzed reaction.

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(6) The method of alternate routes assumes that the free energy contour map is formed by addition of the weighed contribution of the edge reaction coordinates to each point on the map (B. M. Dunn, *Int. J. Chem. Kinet.*, **6**, 143 (1974)). The treatment differs from that applied by More O'Ferrall (R. A. More O'Ferrall, *J. Chem. Soc. B*, 274 (1970)) and Jencks (W. P. Jencks, *Chem. Rev.*, **72**, 705 (1972)) to their transect diagrams in that these authors create the interior of the map by a process of ratiocination based on details of experimental results (i.e., the interior of the transect diagrams are not computed from the edge free energy values and, thus, there is allowed an increasing degree of latitude in moving from the edge towards the center for the inclusion of concepts as the triple potential) (see T. C. Bruice, *Annu. Rev. Biochem.*, in press). The advantage of "MAR" awaits further exploration. Structures I, II, and III were generated by a computer program written by Dr. R. F. Williams (R. F. Williams, W. Palke, and T. C. Bruice, to be submitted for publication) which assumes that all reactions are Hammond-like (G. S. Hammond, *J. Am. Chem. Soc.*, **77**, 334 (1955)) and that the influence of each edge on any point on the map is the reciprocal of some function of the distance of the point from the edge.
(7) Edge free energy reactant coordinates were constructed by assuming that: (a) the pK_a of oxide is −2; (b) the pK_a of the alcohol moiety of state D is 10.7 (calculated by the method of J. P. Fox and W. P. Jencks, *J. Am. Chem. Soc.*, **96**, 1436 (1974)); (c) proton transport is diffusion-controlled in the thermodynamically favored direction; (d) thermodynamically favored ring closure of carbonium ions to oxide is associated with a $\Delta G^{\ddagger}$ of 3.8 kcal M^{-1}; and (e) the value of $\Delta G^{\ddagger}{}_{B\rightarrow D}$ approximates that of k_H and $\Delta G^{\ddagger}{}_{A\rightarrow C}$ that of k_0.
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*Book Reviews**

The Chemist in Industry (2): Human Health and Plant Protection. By E. S. STERN, J. F. CAVALLA, and D. P. JONES. Oxford University Press, New York, N.Y. 1974. viii + 87 pp. $9.75 (cloth); $4.95 (paper).

This is the second book of a series having the aim of giving to the college graduate background information needed to appreciate current developments and philosophy in the chemical industry. The title is potentially misleading, for the book is concerned with the nature of pharmaceutical and agrochemical industries, and has nothing to do with health conditions and security in a chemical plant.

The first half of the book starts with drug design, discusses specific types of biological effects, and continues through development to screening, clinical trial, formulation, and marketing. The second half begins with a general discussion of research on agrochemicals, followed by discussions of pesticides, control of plant diseases, plant growth regulators, fertilizers, and finally agrochemicals and the environment. Each half has a concluding essay entitled "The Future of the Industry"; these are frank and do not shrink from controversial issues.

The emphasis of the authors naturally reflects their British background, and some allowance must be made for differences when transferring the discussions to American industry. Nevertheless, it is a helpful and interesting orientation piece. It is quite short, but the brevity has the merit of encouraging one to read it.

Residue Reviews. Volume 55. Edited by F. A. GUNTHER and A. D. GUNTHER. Springer Verlag, New York, N.Y. 1975. vi + 152 pp. $16.80.

This volume in this series of reviews on pesticides and other contaminants is largely analytical in emphasis. More than half the book consists of a chapter on "Automation in the Pesticide Analytical Laboratory" by Daniel E. Ott (Department of Entomology, University of California, Riverside). Another long chapter is "Pesticides in Air: Sampling Methods", by L. P. van Dyk and K. Visweswariah (Plant Protection Research Institute, Pretoria, South Africa, and Central Food Technological Research Institute, Mysore, India, respectively). The last chapter is a short one, but not the less important: "Polychlorinated Biphenyl Residues in Silos in the United States", by L. B. Willett (Ohio Agricultural Research and Development Center) and J. F. Hess, Jr. (American,

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* Unsigned book reviews are by the Book Review Editor.