Differentiation Between the Concerted and Stepwise Mechanisms for Aromatization (NIH-Shift) of Arene Epoxides

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Summary In order to differentiate between the kinetically equivalent mechanisms of either concerted proton migration and epoxide ring opening or stepwise formation of carbonium ion followed by proton migration to form in either case the keto form of the phenol, the primary kinetic isotope effects for aromatization of perdeuterio-dihydroepoxybenzene and [1-^{2}H]dihydro-1,2-epoxynaphthalene (k^H/k^D = *ca.* 1) as well as the substituent effects on the rate for benzene epoxide (ρ $-7{\cdot}3$ and $-7{\cdot}6$ for spontaneous and acid-catalysed paths, respectively) have been determined; the stepwise mechanism is strongly favoured.

THE rate equation of the aromatization of arene epoxides has been established[1,2] to be that in equation (1), where ArO is arene epoxide and k_0 and k_H are spontaneous and acid-catalysed rate constants, respectively. We have

$$d[ArO]/dt = [ArO](k_0 + k_H a_H) \quad (1)$$

set about to determine if the processes associated with k_0 and k_H involve concerted group (proton) transfer to produce the keto-tautomer of the phenol or stepwise epoxide ring opening to a carbonium ion followed by group migration.

Perdeuterio-1,2-dihydroepoxybenzene (II) was prepared from [1,2,3,4,5,6-^{2}H$_6$]cyclohexa-1,4-diene by a modification[3] of the original synthesis of dihydroepoxybenzene. The dihydroepoxynaphthalene (I),[3] 1-methyl- (III), 3-methyl- (IV), 4-methyl- (V), and 4,5-dimethyl-1,2-dihydro-1,2-epoxybenzene (IV)[4] were prepared as described previously and 4-chloro-1,2-dihydro-1,2-epoxybenzene was a gift from Dr. G. A. Berchtold. The observed pseudo-first-order rate constants for the aromatizations of (I)—(VII) were followed spectrophotometrically.[2]

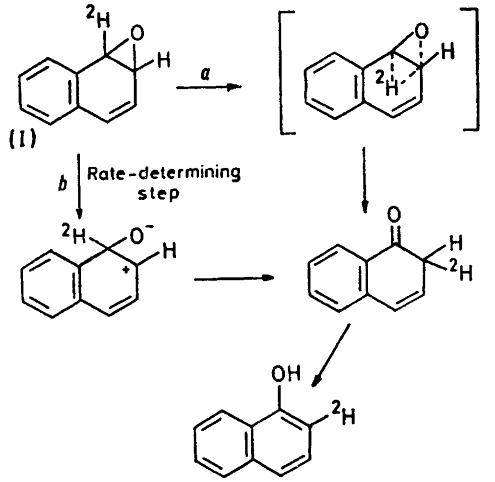
Table. *Spontaneous* (k_0) *and acid catalysed* (k_H) *rate constants for the disappearance of arene epoxide* [*except for* (I) *in which the appearance of* 1-*naphthol was monitored*]. *All reactions were conducted in aqueous dioxan* (50% *v/v*) *at* 30°, $\mu = 0{\cdot}1$ *with* KCl *unless otherwise noted.*

Arene epoxide	$10^4\, k_0/\mathrm{s}^{-1}$	$k_H/\mathrm{M}^{-1}\,\mathrm{s}^{-1}$
(I)	28·5[a]	450[a]
(II)	13·3[a]	32[a]
	0·274	3·89
(III)	5·20	105
(IV)	90·0	96
(V)	153	470
(VI)	528	4070
(VII)	0·29	0·50

[a] H_2O; $\mu = 1{\cdot}0$ with KCl.

Plots of log k_0 *vs.* σ^+ for (II), (V), (VI), and (VII) gave a ρ of $-7{\cdot}3 \pm 0{\cdot}4$ (correlation coefficient 0·980). A similar plot of log k_H was obtained (ρ $-7{\cdot}6 \pm 0{\cdot}2$, correlation coefficient 0·996). Since 3,4-dimethylphenol is produced in the aromatization of (VI), the logarithms of these rate constants were plotted *vs.* $\sigma_m^+ + \sigma_p^+$. The epoxides (III) and (IV) were not included in the plots because they both aromatize to *o*-methylphenol and the appropriate σ^+ value has not been determined.

The rates of aromatization of (I) and (II) were compared to those for naphthalene epoxide and benzene epoxide, respectively. Reactions involving intramolecular hydride shifts in triangular transition states as in path *a* are expected to have smaller kinetic isotope effects than those associated with linear transition states.[5] For example, in the Cannizzarro reaction[6] which involves a nintramolecular hydride transfer $k_H/k_D = 1{\cdot}8$; also, the hydrolysis[5a] of the pyridine–monodeuteriodiphenylborane complex and the solvolysis of 3-[^{2}H]-3-methyl-2-butyltoluenesulphonate[7] both of which involve triangular transition states give $k_H/k_D = 1{\cdot}5$ and 2·2, respectively. Thus if the aromatization of arene oxides proceeded *via* the concerted path (path *a*) a primary kinetic isotope effect of *ca.* 2·0 would be expected. For (I) $k_0^H/k_0^D = 1{\cdot}05$ and $k_H^H/k_H^D = 1{\cdot}04$ while for (II) $k_0^H/k_0^D = 1{\cdot}05$ and $k_H^H/k_H^D = 1{\cdot}00$. Thus there is no primary isotope effect in the isomerization of benzene epoxide and naphthalene epoxide. This lack of a primary kinetic isotope effect and the large negative ρ value observed for the aromatization of the substituted benzene epoxides provide strong evidence in favour of a developing positive charge in the transition state without H(D) transfer (path *b*) for both the spontaneous and acid-catalysed isomerization of arene epoxides to the corresponding phenols.



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