*Anal.* Calcd for $C_{19}H_{20}N_2O$: C, 78.04; H, 6.90; N, 9.58. Found: C, 78.16; H, 6.84; N, 9.36.

**Hydrogenation of 5,5-Dimethyl-3,4-diphenyl-5*H*-pyrazole 1-Oxide (19).** **19** (121 mg) was hydrogenated using $PtO_2$ in 5 ml of $Ac_2O$ and 7 ml of HOAc at 1 atm. Products were taken up in ether which was washed with water and dried. Evaporation yielded 123 mg (85%) of oil, identified from its spectra as 1-acetyl-5,5-dimethyl-3,4-diphenyl-$\Delta^2$-pyrazoline.

**2-Bromo-3-methyl-1,2-diphenylbutan-1-one.** To a solution of 5.9 g (0.025 mol) of 3-methyl-1,2-diphenylbutan-1-one[34] in 60 ml of $CCl_4$ was added 4.0 g (0.025 mol) of $Br_2$, and the solution was stirred at 26° for 2 days until the reddish color of the $Br_2$ had disappeared and gaseous evolution had ceased. Evaporation yielded 7.9 g (quantities) of the crude bromide as a light green oil: ir (film) 3060, 2980, 2940, 2880, 1680, 1600, 1580, 1495, 1445, 1390, 1370, 1230, 1185, 1030, 935, 845, 825, 755, 700, 660, 630, 530, 475 $cm^{-1}$; nmr ($CCl_4$) $\tau$ 9.31 (3 H, d), 8.90 (3 H, d), 7.30 (1 H, septet), 2.91 (6 H, m), 2.50 (4 H, m).

**3-Methyl-1,2-diphenyl-2-buten-1-one.** To 7.9 g (0.025 mol) of 2-bromo-3-methyl-1,2-diphenylbutan-1-one in 50 ml of dry DMF was added 4.25 g (0.10 mol) of LiCl, and the mixture was heated to 125–130° under $N_2$ for 1.5 hr. The solution was poured into water and extracted with two 200-ml portions of ether. The extracts were combined, and washed with four 500-ml portions of water, and dried over $MgSO_4$. Evaporation yielded a highly colored oil, which was distilled through a short column to yield 5.4 g (92%) of very light yellow oil: bp 140–142° (1 mm); ir (film) 2990, 2960, 2930, 2890, 2820, 2760, 1665, 1600, 1580, 1490, 1445, 1375, 1320, 1295, 1275, 1230, 1165, 1045, 1025, 860, 795, 765, 705, 730, 474 $cm^{-1}$; nmr ($CCl_4$) $\tau$ 8.31 (3 H, s), 822 (3 H, s), 2.78 (8 H, m), 2.09 (2 H, m); uv (EtOH) $\lambda_{max}$ 279 m$\mu$ ($\epsilon$ 2720), 246 (14,210); mass spectrum *m/e* (%) 236 (75.9), 235 (48.4), 221 (35.1), 131 (34.6), 105 (100), 91 (34.0), 77 (31.4),

*Anal.* Calcd for $C_{17}H_{16}O$: C, 86.40; H, 6.83. Found: C, 86.55; H, 7.01.

**5,5-Dimethyl-3,4-diphenyl-$\Delta^2$-pyrazoline (21).** To 0.236 g (0.001 mol) of 3-methyl-1,2-diphenyl-2-buten-1-one in 5 ml of methanol was added 0.289 g (0.009 mol) of 97% hydrazine, and the resulting solution was stirred at ambient temperature under $N_2$ for 30 hr. Evaporation gave 0.246 g (99%) of the white solid, **21**.

**5,5-Dimethyl-3,4-diphenyl-5*H*-pyrazole.** To 1.7 g (0.007 mol) of **21** were added 25 ml of $CH_2Cl_2$ and 15 ml of water contalning 1 g of KOH. To this rapidly stirred mixture was added dropwise, over a 10-min period at 26°, a solution of 1.27 g (0.007 mol) of $Br_2$ in 3 ml of $CH_2Cl_2$. After stirring for 4 hr the aqueous solution was removed and the $CH_2Cl_2$ layer was washed with water and dried. Evaporation yielded an impure solid product which was recrystallized from hexane to give 1.1 g (65%) of pure product: mp 124°; ir (KBr) 3000, 2900, 1630, 1590, 1550, 1480, 1445, 1420, 1325, 1245, 1170, 1155, 1075, 1065, 1030, 1015, 955, 915, 850, 780, 760, 718, 710, 690 $cm^{-1}$; nmr ($CCl_4$) $\tau$ 8.57 (6 H, s), 2.80 (8 H, m), 2.40 (2 H, m); uv (EtOH) $\lambda_{max}$ 303 m$\mu$ ($\epsilon$ 4190) 232 (14,900); mass spectrum, *m/e* (%) 248 (4.9), 220 (72.9), 206 (31.6), 205 (100), 204 (23.4), 203 (25.7), 77 (20.8).

*Anal.* Calcd for $C_{17}H_{16}N_2$: C, 82.22; H, 6.50; N, 11.28. Found: C, 82.40; H, 6.46; N, 11.17.

**5,5-Dimethyl-3,4-diphenyl-5*H*-pyrazole 1-Oxide (19).** To 248 mg (0.0010 mol) of 5,5-dimethyl-3,4-diphenyl-5*H*-pyrazole in 15 ml of $Et_2O$ was added 1 g of solid $K_2CO_3$, and the solution was cooled to 0°. A solution of 0.0019 mol of $CF_3CO_3H$ (**24**) in 4 ml of ether was then added dropwise to the rapidly stirred solution. After 1 hr, the solution was poured into an aqueous solution of $K_2CO_3$ and additional ether was added. The ether solution was then washed with water and dried. Evaporation gave 250 mg of the virtually pure oxide. Chromatography on silica gel with $CH_2Cl_2$ yielded 200 mg (76%) of analytically pure **19**.

**Photolysis of 4,4-Diethyl-3,5-dimethyl-4*H*-pyrazole 1-Oxide[35] (18).** A solution of 1.20 g of **18** in 100 ml of $CH_2Cl_2$ was photolyzed through Corex and under $N_2$ with a 450-W lamp. Samples were periodically withdrawn and checked on the ir spectrometer until the characteristic stretch at 1580 $cm^{-1}$ had disappeared (about 2.5 hr). After concentration of the solution a glpc analysis on a 5-ft Carbowax column at 180° revealed the presence of at least seven products, although there was one very dominant component. Column chromatography on silica gel ($CH_2Cl_2$) removed many of the impurities and the major component, **20**, was removed from the column with $CHCl_3$ as a light yellow oil (0.344 g, 29%): ir (film) 2975. 2930, 2880, 1650, 1495, 1440, 1390, 1265, 675, 625 $cm^{-1}$; nmr ($CCl_4$) $\tau$ 9.47 (6 H, t), 8.30 (4 H, m), 8.25 (3 H, m), 7.95 (3 H, m); uv (EtOH) $\lambda_{max}$ 315 m$\mu$ ($\epsilon$ 3530), 227 (2380); mass spectrum, *m/e* (%) 168 (37.0), 97 (28.6), 69 (25.2), 55 (100), 41 (28.6).

*Anal.* Calcd for $C_9H_{16}N_2O$: C, 64.25; H, 9.59. Found: C, 64.00; H, 9.78.

**Acknowledgment.** We wish to acknowledge support of this research by the donors of the Petroleum Research Fund of the American Chemical Society and by the Research Corporation.

(34) M. Tiffeneau and A. Orekhoff, *Bull. Chim. Soc. Fr.*, **33**, 211 (1923).

(35) H. Gnichtel and J. J. Schonerr, *Chem. Ber.*, **9**, 618 (1966).

# Methyl Migration in the Aromatization of *p*-Xylene 1,2-Oxide[1]

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**Abstract:** *p*-Xylene 1,2-oxide (**4a**) has been prepared and its rearrangement to mixtures of 2,4- and 2,5-xylenol in aqueous solutions at various pH values has been investigated. When the reaction was carried out in basic, neutral, and weakly acidic solutions, the major product was found to be 2,4-xylenol, the formation of which involves migration of the methyl substituent on the oxirane ring from C-1 to C-2. The relative amount of 2,5-xylenol formed in the aromatization tended to increase with decreasing pH of the reaction medium, but only when the reaction was carried out in strongly acidic solution did the 2,5 isomer become the predominant product. The rearrangement to 2,4-xylenol provides a chemical model for a number of enzymatic hydroxylations which involve concomitant 1,2 shifts of alkyl side chains and which have been postulated to proceed *via* arene oxide intermediates.

The enzymatic hydroxylation of aromatic rings has been shown to be accompanied by intramolecular migration of the atom or group originally present at the site of substitution (the "NIH shift").[2] A mechanism involving the enzyme-catalyzed formation of an arene

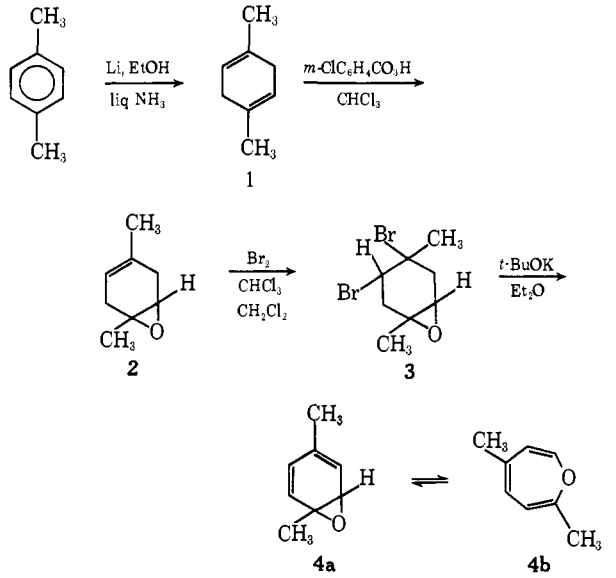
(1) Presented at the Sixth Middle Atlantic Regional Meeting of the American Chemical Society, Baltimore, Md., Feb 1971.

(2) (a) G. Guroff, J. W. Daly, D. M. Jerina, J. Renson, B. Witkop, and S. Udenfriend, *Science*, **157**, 1524 (1967); (b) J. Daly, G. Guroff, S. Udenfriend, and B. Witkop, *Arch. Biochem. Biophys.*, **122**, 218 (1967); (c) J. Daly and G. Guroff, *ibid.*, **125**, 136 (1968); (d) J. Daly,

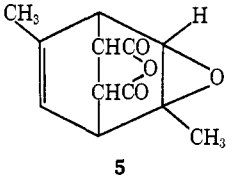
oxide, followed by the spontaneous rearrangement of this unstable intermediate to a phenol, has been proposed, and a chemical model for such a rearrangement of an arene oxide with deuterium as the migrating species has recently been described.[3] In this paper, we wish to report some observations on an analogous nonenzymatic rearrangement of an arene oxide in which the migrating species is a methyl group.

*p*-Xylene 1,2-oxide[4] (**4a**) was synthesized by the sequence of reactions outlined in Scheme I. Reduction

**Scheme I**

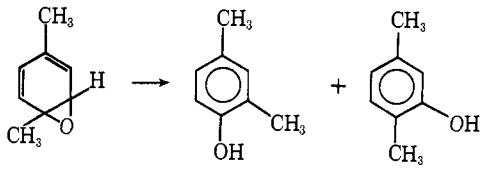



of *p*-xylene by a modified Birch procedure provided 1,4-dimethyl-1,4-cyclohexadiene (**1**), which was oxidized with a limited amount of *m*-chloroperoxybenzoic acid in chloroform to give the epoxide **2**. Bromination of this compound in chloroform–methylene chloride at −65° afforded the dibromo epoxide **3**, which was then dehydrobrominated with potassium *tert*-butoxide in ether at −5° to give the desired product. Characterization of the product by ir, uv, and nmr indicated that, as expected on the basis of earlier results with other arene oxides,[5] it consisted of an equilibrium mixture of the arene oxide (**4a**) and oxepin (**4b**) valence tautomers, with the oxepin form predominating at room temperature in the absence of solvent and in solution in solvents of low polarity (cyclohexane, isooctane, carbon tetrachloride). The presence of the arene oxide form was confirmed by reaction with maleic anhydride to give a Diels–Alder adduct **5**, the composition, ir, and nmr spectra of which were consistent with the assigned structure.



**5**

The purified arene oxide–oxepin mixture proved to be relatively stable on storage at 0° in glassware which had been rinsed with aqueous ammonia and in solutions in nonpolar solvents at room temperature. Under these conditions no changes were observed in the uv, ir, or nmr spectra during periods of up to 3–4 weeks. Acids, even in trace amounts, brought about a rapid isomerization to a mixture of 2,4- and 2,5-xylenol,



which were separated by column chromatography and identified by melting point, derivatization, and comparison of ir and nmr spectra with those of authentic samples of the xylenols. A similar isomerization occurred within a few minutes when the arene oxide–oxepin mixture was shaken with water *at any pH*. Extraction of the isomerization products from the aqueous mixtures with ether, followed by treatment with Tri-Sil[6] and gas chromatography of the resultant trimethylsilyl derivatives, gave the results listed in Table I.

**Table I.** Gc Analysis of Aromatization Products Formed by *p*-Xylene 1,2-Oxide in Water at Various pH Values

| pH | Rel areas of gc peaks of TMS derivatives | |
|---|---|---|
| | 2,4-Xylenol | 2,5-Xylenol |
| 13.5 | 94 | 6 |
| 10.0 | 92 | 8 |
| 8.5 | 86 | 14 |
| 7.5 | 86 | 14 |
| 6.0 | 87 | 13 |
| 4.5 | 74 | 26 |
| 3.5 | 54 | 46 |
| 1.0 | 37 | 63 |

Except at very low pH, *p*-xylene 1,2-oxide isomerizes predominantly to 2,4-xylenol, revealing that, except in strongly acidic solutions, the preferred mode of aromatization of this arene oxide in aqueous media occurs *via* C–O bond cleavage at C-2 and migration of the methyl group from C-1 to C-2. The rearrangement appears, therefore, to be mechanistically similar to the NIH-shift type of rearrangement which Jerina, Daly, and Witkop[3] have shown to occur in the aromatization of toluene 3,4-oxide. However, the dependence of product composition on pH which has been observed in the present study clearly indicates that at least two distinct reaction pathways with different transition states and different regiospecificities are involved in the aromatization of *p*-xylene 1,2-oxide in aqueous media: one, a hydronium ion catalyzed reaction, in which oxirane ring opening occurs preferentially at the more substituted C–O bond, and another, a water-catalyzed reaction, in which cleavage occurs at the less-substituted C–O bond and is accompanied (or followed) by a 1,2

D. Jerina, and B. Witkop, *ibid.*, **128**, 517 (1968); (e) D. M. Jerina, J. W. Daly, B. Witkop, P. Zaltzman-Nirenberg, and S. Udenfriend, *Biochemistry*, **9**, 147 (1970).

(3) D. M. Jerina, J. W. Daly, and B. Witkop, *J. Amer. Chem. Soc.*, **90**, 6523 (1968).

(4) Chemical Abstracts name: 1,4-dimethyl-7-oxabicyclo[4.1.0]-hepta-2,4-diene.

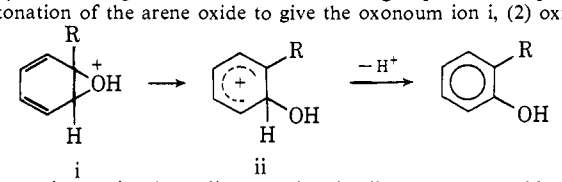
(5) See, for example, the review by E. Vogel and H. Günther, *Angew. Chem., Int. Ed. Engl.*, **6**, 385 (1967).

(6) Pierce Chemical Co.'s brand of silylating reagent, consisting of trimethylchlorosilane and hexamethyldisilazane in pyridine.

shift of the methyl substituent.[6a] It would be of interest to know whether the methyl migration is concerted with, or occurs subsequent to, the oxirane ring opening and whether the labeling 4-methyl group exerts any significant influence on the course of the reaction. Experiments designed to provide information on both of these points are currently underway.

The present results provide additional support for the view that arene oxides are intermediates in enzymatic oxidations in which hydroxylation of an aromatic ring is accompanied by migration of an alkyl side chain, *e.g.*, the phenylalanine hydroxylase reaction with *p*-methylphenylalanine as substrate,[2c] in which the migrating group is methyl, and the phenylpyruvate oxidase reaction,[7] in which the side-chain $CH_2CO$-$COOH$, originally present at the site of hydroxylation, is transformed to $CH_2COOH$ and shifted to the adjacent carbon.[8] The demonstration that alkyl groups as well as hydrogen atoms undergo spontaneous NIH shifts during nonenzymatic aromatization of arene oxides, in conjunction with the recently reported detection of naphthalene 1,2-oxide as an intermediate in the microsomal hydroxylation of naphthalene,[2e] strongly suggests that the essential role of the enzyme in all aromatic hydroxylations by mixed-function oxidases is to generate the appropriate arene oxide, which then rearranges spontaneously to the phenolic product.

(6a) Note Added in Proof. Similar conclusions regarding the mechanism have been reached by G. J. Kasperek and T. C. Bruice (*J. Amer. Chem. Soc.*, **94**, 198 (1972)) on the basis of a kinetic study of the aromatization of several arene oxides. In connection with their detailed interpretation of the acid-catalyzed rearrangement, however, it may be important to point out that the assumed "requirement" of an NIH shift of hydrogen in the aromatization of arene oxides *at low pH* has never actually been demonstrated. Only two model studies of the NIH shift of hydrogen in isotopically labeled arene oxides have been reported (toluene-*4-d* 3,4-oxide[3] and naphthalene-*1-d* 1,2-oxide (Kasperek and Bruice)), and in both of these studies the high deuterium-retention values which are consistent with an NIH-shift mechanism were obtained in experiments conducted at pH ~7–8. The only value reported for deuterium retention after rearrangement of an arene oxide in a strongly acidic solution (toluene-*4-d* 3,4-oxide in 0.1 *N* HCl, 37% D retention[3]) is considerably lower than the values obtained at higher pH. The available data, therefore, strongly suggest that the NIH shift may not be an essential feature of the acid-catalyzed pathway at all but may be associated only (or predominantly) with the "spontaneous" or water-catalyzed reaction. It seems likely that the major pathway for the acid-catalyzed rearrangement involves the following sequence of steps: (1) protonation of the arene oxide to give the oxonoum ion i, (2) oxirane




i ii

ring opening to give the cyclic carbonium ion ii (or the more stable of the two possible carbonium ions in the case of substituted arene oxides), and (3) aromatization of ii to the phenol by loss of the proton at the carbinol carbon *without an intervening NIH shift*. Further studies of appropriately substituted and labeled arene oxides are needed to clarify this aspect of the problem.

(7) K. Tanaguchi, T. Kappe, and M. D. Armstrong, *J. Biol. Chem.*, **239**, 3389 (1964).

(8) A recent study[9] of the mechanism of the most familiar example of the latter type of enzymatic reaction, the conversion of *p*-hydroxyphenylpyruvate to homogentisate, indicates that the oxidative decarboxylation of the side chain occurs before its migration to the adjacent position on the aromatic ring. Although the stepwise mechanism suggested for this reaction by the Swedish investigators does not explicitly involve an arene oxide intermediate, one of their proposed intermediates, VI, may be regarded as either a zwitterion form or a resonance form of an arene oxide. Their data are not incompatible, therefore, with a mechanism involving an arene oxide as an intermediate in the *p*-hydroxyphenylpyruvate oxidase reaction.

(9) B. Lindblad, G. Lindstedt, and S. Lindstedt, *J. Amer. Chem. Soc.*, **92**, 7446 (1970).

## Experimental Section[10]

**1,4-Dimethyl-1,4-cyclohexadiene (1).** This compound was prepared by a modification of the original Birch procedure,[11] using lithium instead of sodium as the reductant.[12] The product in some runs was found by gc analysis to be contaminated with unreacted *p*-xylene, which could not be completely removed by fractional distillation because of the proximity of the boiling points of the starting material and the product. In these cases, complete reduction to the desired dihydro compound was achieved by subjecting the diene–xylene mixture to a second reduction carried out in the same way as the first. Pure 1,4-dimethyl-1,4-cyclohexadiene (as monitored by gc on two columns of different polarity), which does not appear to have been fully characterized by earlier investigators, was obtained as a colorless liquid with bp 141–142°; $n^{25}D$ 1.4697; ir (neat) 3.35 (s), 3.40 (s), 3.48 (s), 6.91 (s), 7.26 (m), 7.67 (w), 8.46 (m), 9.46 (m), 10.53 (s), 11.09 (w), 12.54 (w), 13.08 (s) $\mu$; nmr ($CCl_4$) $\delta$ 5.21 (m, 2), 2.47 (br s, 4), 1.61 ppm (br s, 6).

*Anal.* Calcd for $C_8H_{12}$: C, 88.82; H, 11.18. Found: C, 88.92; H, 11.15.

**1,4-Dimethyl-1,2-epoxycyclohex-4-ene (2).** This compound was prepared from **1** by an adaptation of the procedure described by Paquette and Barrett[13] for the preparation of the 1,2-dimethyl isomer. Distillation of the crude product gave 55–65% yields of the epoxide as a colorless liquid: bp 64–66° (15 mm); $n^{25}D$ 1.4654; ir (neat) 3.33 (s), 3.45 (s), 3.53 (m), 6.92 (s), 7.03 (s), 7.25 (s), 8.13 (m), 8.32 (m), 11.7 (s), 13.3 (s) $\mu$; nmr ($CCl_4$) $\delta$ 5.06 (m, 1), 2.89 (m, 1), 2.30 (m, 4), 1.61 (m, 3), 1.30 ppm (s, 3).

*Anal.* Calcd for $C_8H_{12}O$: C, 77.38; H, 9.74. Found: C, 77.32; H, 9.74.

High-boiling residues from the distillation of crude **2** crystallized on cooling; recrystallization of this material from cyclohexane gave **1,4-dimethyl-1,2,4,5-diepoxycyclohexane** as colorless platelets: mp 80.5–81.5°; ir (Nujol) 12.0 $\mu$ (epoxy ring).

*Anal.* Calcd for $C_8H_{12}O_2$: C, 68.54; H, 8.63. Found: C, 68.50; H, 8.62.

**4,5-Dibromo-1,4-dimethyl-1,2-epoxycyclohexane (3).** Bromination of **2** was carried out by a procedure similar to that described for the preparation of the 1,2-dimethyl isomer.[13] The crude product was recrystallized from petroleum ether to give 45–50% yields of the dibromide as colorless prisms: mp 64–66°; nmr ($CCl_4$) $\delta$ 4.33 (m, 1), 3.0 (m, 1), 2.5–2.9 (m, 4), 1.92 (s, 3), 1.46 ppm (s, 3).

*Anal.* Calcd for $C_8H_{12}Br_2O$: C, 33.83; H, 4.26. Found: C, C, 33.87; H, 4.35.

***p*-Xylene 1,2-Oxide (4a) $\rightleftharpoons$ 2,5-Dimethyloxepin (4b).**[14] Treatment of **3** with potassium *tert*-butoxide as in the analogous method for the preparation of 2,7-dimethyloxepin[13] gave, after removal of the solvent in a rotary evaporator, approximately quantitative yields of the crude oxide–oxepin mixture as a yellow-orange oil. Short-path distillation of small amounts (not more than 5 g at a time) of this material provided analytically pure samples of **4** in yields of 55–60%: bp 49–51° (9 mm); uv max (isooctane) 284 nm ($\epsilon$ 1600); uv max (absolute EtOH) 274 nm ($\epsilon$ 1940); ir (neat) 3.30 (s), 3.36 (s), 3.45 (s), 6.04 (s), 6.12 (s), 6.28 (m), 6.91 (s), 7.12 (m), 7.25 (s), 7.44 (w), 7.73 (m), 8.10 (s), 8.45 (s), 8.68 (s), 8.96 (s), 9.53 (s), 9.67 (s), 9.94 (w), 10.4 (w), 10.9 (m), 11.4 (m), 11.6 (m), 12.3 (s), 12.7 (m), 13.2 (s), 13.5 (w), 14.0 (w) $\mu$; nmr ($CCl_4$) $\delta$ 5.73 (d, 1), 5.3 (m, 3), 1.8 ppm (m, 6).

*Anal.* Calcd for $C_8H_{10}O$: C, 78.65; H, 8.25. Found: C, 78.40; H, 8.33.

**Diels–Alder Adduct of 4a with Maleic Anhydride (5).** A solution of 0.50 g (4.1 mmol) of **4** and 0.40 g (4.1 mmol) of maleic anhydride in 10 ml of ether was allowed to stand at room temperature for several days, during which time the yellow color slowly disappeared and a white crystalline solid was deposited. Recrystallization of this product from benzene–cyclohexane provided 0.46 g (51%) of colorless crystals: mp 143–144°; ir (Nujol) 5.42 (m), 5.62 (s), 8.1 (s,

(10) Melting points and boiling points are uncorrected. Elemental analyses were performed by Clark Microanalytical Laboratory, Urbana, Ill. Infrared spectra were obtained with a Perkin-Elmer Model 137 Infracord. Nuclear magnetic resonance spectra were recorded on a Hitachi (Perkin-Elmer) Model R-20B spectrometer, using tetramethylsilane as an internal standard.

(11) A. J. Birch, *J. Chem. Soc.*, 430 (1944).

(12) *Cf.* A. P. Krapcho and A. A. Bothner-By, *J. Amer. Chem. Soc.*, **81**, 3658 (1959).

(13) L. A. Paquette and J. H. Barrett, *Org. Syn.*, **49**, 62 (1969).

(14) All glassware with which this product came in contact was rinsed with concentrated aqueous ammonia and dried at 100° before use.

broad), 9.08 (s), 9.92 (s), 9.49 (m), 9.82 (m), 10.53 (s), 10.84 (s), 11.13 (m), 11.27 (m), 12.0 (s), 12.7 (m), 13.8 (m), 14.7 (m) $\mu$; nmr ($CDCl_3$) $\delta$ 5.66 (broad m, 1), 3.1–3.5 (m, 5), 1.78 (d, 3, $J$ = 2 Hz), 1.51 ppm (s, 3).

*Anal.* Calcd for $C_{12}H_{12}O_4$: C, 65.45; H, 5.49. Found: C, 65.65; H, 5.39.

**Aromatization of 4 in Aqueous Solution.** In a typical experiment, 0.1–0.2 g of freshly prepared **4** was added to 10 ml of 0.1 *M* aqueous buffer solution having the desired pH value, and the mixture was shaken vigorously for 10 min. The resultant solution was extracted with three 10-ml portions of ether, the combined extracts were dried ($Na_2SO_4$), and the solvent was removed by evaporation under reduced pressure at room temperature. A few milliliters of $CCl_4$ was added to the residue and the solution was again evaporated under reduced pressure. The addition and removal of $CCl_4$ was repeated several times, and the residue was then utilized for ir, nmr, and gc analysis.

The ir and nmr spectra of these products were composites of the spectra of 2,4- and 2,5-xylenol. No attempt was made to estimate quantitatively the relative amounts of the two phenols in these mixtures on the basis of the spectroscopic data, but variations in the relative intensities of characteristic absorption bands were consistent with the compositions determined by gc analysis.

For gc analysis, 50 mg of the product mixture to be examined was treated with 0.5 ml of Tri-Sil[6] to convert the phenols to their more volatile trimethylsilyl ethers, and the resultant mixture was analyzed on a Carle Basic Gas Chromatograph, Model 6500, at 150°, using a column packed with 8% di-*n*-nonyl phthalate on 60–80 mesh diatomite. The peaks corresponding to the TMS derivatives of 2,4- and 2,5-xylenol were identified by calibrating the instrument with the silylation products prepared from authentic samples of the xylenols; the retention time for the 2,4-xylenol TMS derivative was 15–20% longer than that for the 2,5-xylenol TMS derivative. Relative peak areas (Table I) were determined by cutting out and weighing the paper enclosed by the peaks. Calibration of this procedure with xylenol mixtures of known composition indicated that the results were accurate to within approximately ±2%.

**Isolation and Identification of Aromatization Products.** A solution of 0.50 g of the oxide–oxepin mixture **4** in 10 ml of ether was shaken with 20 ml of 0.1 *N* HCl until the yellow color disappeared. The aqueous layer was washed with several small portions of ether, and the combined ether layers were dried ($MgSO_4$) and evaporated under vacuum at room temperature to give 0.42 g (84% recovery) of a pale yellow oil. This was dissolved in benzene and chromatographed on a 2 × 50 cm column of silica gel (SilicAR CC-7), using benzene–petroleum ether (1:1, gradually increasing to 3:1) as the eluting solvent. Removal of the solvent from appropriate fractions of the eluate in a rotary evaporator at room temperature provided 274 mg of a faster moving product as a crystalline solid (fraction I) and 73 mg of a slower moving product as a colorless oil (fraction II).

Fraction I was recrystallized from cyclohexane to provide colorless crystals, mp 74–75°, which showed no depression when mixed with authentic 2,5-xylenol and which gave an ir spectrum identical with that of the latter compound.

Fraction II gave an ir spectrum identical with that of 2,4-xylenol and, on treatment with 3,5-dinitrobenzoyl chloride in pyridine, it was converted into a crystalline 3,5-dinitrobenzoate which melted at 162.5–163.0° after recrystallization from ethanol; lit. mp of 2,4-dimethylphenyl 3,5-dinitrobenzoate, 164.6°.[15]

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# Stereochemical Factors in Epoxide Polymerization by Base and Coordination Catalysts

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**Abstract:** The amorphous fraction accompanying isotactic poly(propylene oxide) or poly(*tert*-butylethylene oxide) formed by coordination catalysts was shown by degradation to the dimer glycols to involve inversion of configuration at every ring opening at the secondary carbon atom for (*R*)- (or (*S*)-) PO and to involve *no* stereoselection in the coordination step for *tert*-BuEO. The crystalline poly(*tert*-BuEO) formed by polymerization with *tert*-BuOK was similarly shown to give equal amounts of erythro and threo dimer glycol. It is proposed that these dimer units arise from regular alternate isotactic and syndiotactic placements (iso,syn). Aryl glycidyl ethers polymerized by *tert*-BuOK gave crystalline fractions shown to be isotactic (by comparison with crystalline polymer formed by coordination catalysts). The amount of the crystalline fractions decreased in the order *p*-$CH_3O$ > *p*-$CH_3$ > H > Cl ≃ 2,6-$(CH_3)_2$. Crystallinity for both *tert*-BuEO and aryl glycidyl ethers was markedly diminished in the presence of DMSO, HMPT, or dicyclohexyl-18-crown-6 macrocyclic ether. All of these observations are in accord with a model for the transition state involving coordination of the potassium ion at the active chain end with at least the next two adjacent ether groups.

## I. Amorphous Polymer from Coordination Catalysts

By ozone degradation to dimeric glycol, it has been previously shown that the principle irregularity in the structure of the amorphous poly(propylene oxide) accompanying the isotactic polymer prepared by coordination catalysts does not arise from random configurations (atactic sequences), but from head-to-head sequences.[2] Price and Tumolo[2] advanced the hypothesis, based only on the optical rotation of such amorphous polymer fractions from the (*R*) (or (*S*)) monomer, that each insertion of a head-to-head unit involved an

(1) From the doctoral dissertations of M. K. Akkapeddi (Stereochemistry and Kinetics of Base-Catalyzed Polymerization of Epoxides, 1971), B. T. DeBona (The Stereochemistry of Abnormal Diads in Amorphous Poly(propylene oxide), 1971), and B. C. Furie (The Structures of Poly(*tert*-butylethylene oxides), 1970).

(2) C. C. Price and A. L. Tumolo, *J. Polym. Sci., Part A-1*, **5**, 175 (1967); C. C. Price, R. Spector, and A. L. Tumolo, *ibid., Part A-1*, **5**, 407 (1967).