

PREPARATION AND STEREOCHEMICAL CHARACTERIZATION OF THE DIASTEREOISOMERIC 1-PHENYL-4-t-BUTYLCYCLOHEXENE OXIDES AND 1-PHENYL-4-t-BUTYLCYCLOHEXANE-1,2-DIOLS

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Abstract—The *cis* and *trans* forms of 1-phenyl-4-t-butylcyclohexene oxide were prepared and their conversion into the corresponding glycols was investigated. Several methods, some of which highly stereospecific, were found for the preparation of all four possible diastereoisomeric glycols 5-8, as shown in Chart I. Dimethyl sulphoxide proved to be a good solvent for the diaxial cleavage of epoxides by alkali, while hydrolysis in the same solvent under acidic conditions led to the diaxial glycol 7 from the *trans* epoxide 3, and to the diequatorial one 8 from the *cis* epoxide 2. Relative configurations of all epoxides and glycols were deduced from their methods of preparation, their reactions and NMR spectra.

THE stereochemistry of the ring opening of aryl substituted epoxides in acidic media is strongly influenced by their structure and by the conditions under which the reaction is carried out: previous work has revealed courses ranging from a complete retention to a complete inversion of configuration.¹⁻⁷ In order to get more information on the importance of conformational factors in determining these differences in steric course it was thought desirable to prepare and study epoxides in which a phenyl substituted oxirane ring is fused to a conformationally rigid cyclohexane system. The diastereoisomeric 1-phenyl-4-t-butylcyclohexene oxides and 3-phenyl-2-cholestene oxides appeared as promising substrates for this purpose. The present paper deals with the preparation and some reactions of the former compounds, while a forthcoming publication will be concerned with the latter.⁸

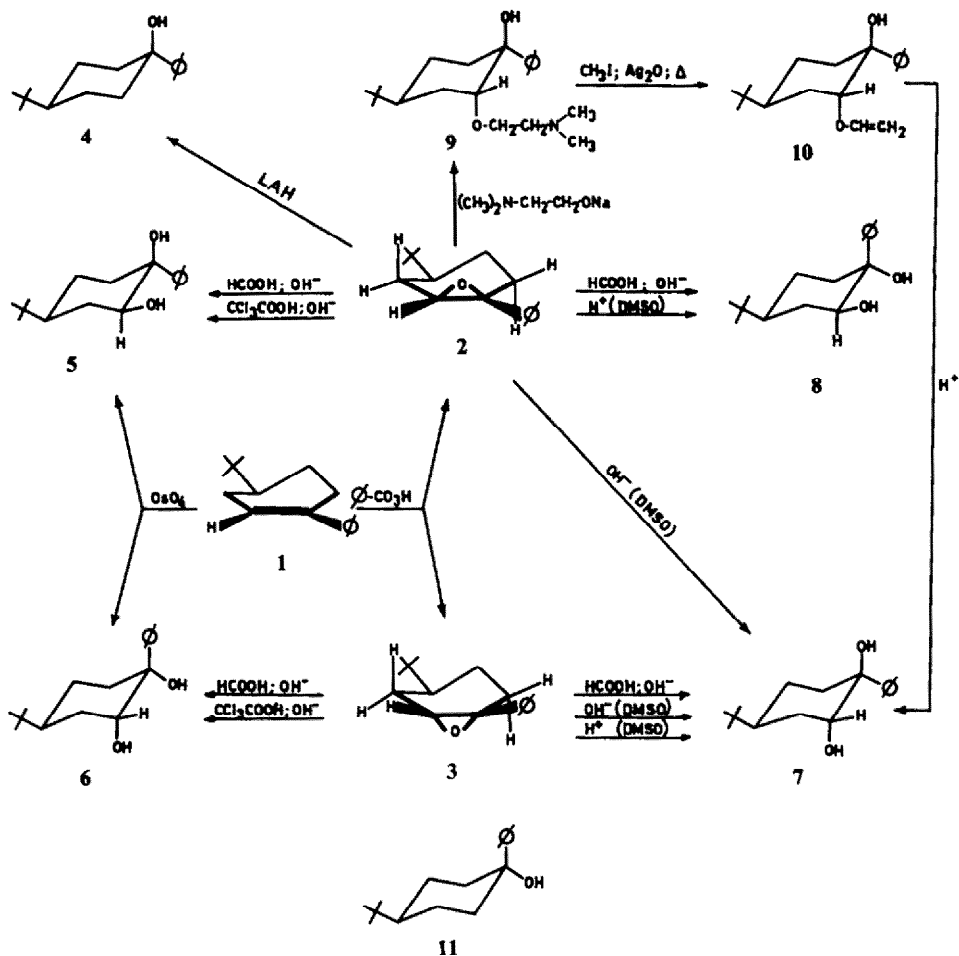
The treatment of 1-phenyl-4-t-butylcyclohexene (1) with peroxybenzoic acid gives a mixture of the two diastereoisomeric epoxides 2 and 3, in a ratio of about 1:1. A low stereoselectivity in reactions of this type has been observed before.⁹⁻¹¹ The separation of the two isomers is not easy, because of their high solubility in low-polarity solvents, and because the crude epoxidation mixture reacts with alcohols to give solvolysis products. It was found, however, that if ethanol containing some potassium hydroxide is used in the first crystallization, no solvolysis takes place; the product thus obtained can be recrystallized from pure ethanol without formation of side-products. Evidently, the first crystallization under alkaline conditions eliminates some impurity which catalyzes the reaction of the epoxides with the alcohol. It is thus possible to isolate in a pure state the less soluble isomer 2. Chromatography over alumina of the mixture that remains in the mother liquor gives the other isomer 3, even if in low yield.

The configuration of 2 was proved by its reduction to the known alcohol 4¹² with LAH. The possibility of the formation of 4 by isomerization of the epimeric alcohol

11 was ruled out when it was found that the latter survived the reaction conditions without any change.

A further proof of the configuration of 2 and 3 is provided by their NMR spectra. The single oxirane proton appears in the spectrum of 3 as a broad non-resolved peak centered at 7.11 τ , that of 2 as a doublet centered at 7.13 τ ($J = 4.5$ c/s), which must be coupled with bands that are concealed in the complicated cyclohexyl proton

CHART I



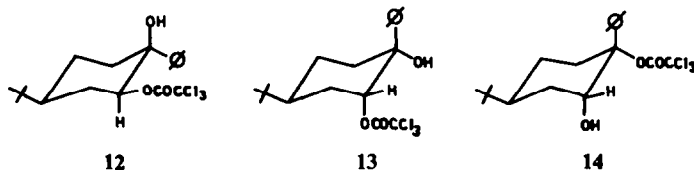
envelope. Tori *et al.*¹³ have deduced from the spectra of a large number of steroid epoxides a simple form of the Karplus equation:

$$J_{\text{H}^*\text{H}'} \sim 5.1 \cos^2 \phi \quad (1)$$

correlating the coupling constant between an oxirane proton (H^*) and an adjacent cyclohexyl proton (H') with the corresponding dihedral angle. Although this equation is quite approximative and possibly requires a correction for the case of phenyl

substituents. it can very well distinguish, at least qualitatively, between **2** and **3**. From a Dreiding model of the most stable half-chair conformation of **2** (the one indicated in Chart I) it can be seen that the dihedral angles between the plane containing the C_2-H^* bond and those containing the pseudo-equatorial and the pseudo-axial C_3-H bonds are approximately 20° and 100° . Application of Eq. (1) gives $J_{H^*H_{eq}} \sim 4.5$ c/s, $J_{H^*H_{ax}} \sim 0$ c/s, in very good agreement with the coupling constant observed in the spectrum of **2**. On the other hand, in the stable half-chair conformation of **3** the two dihedral angles are of about 60° , which would correspond to $J \sim 1.3$ c/s according to Eq. (1); therefore the peak is not resolved.

Reaction of the epoxide **2** with trichloroacetic acid in benzene led to a monoester, which was assigned structure **12** because it was stable to oxidation with Jones reagent; the ester was hydrolyzed to the glycol **5**. The epoxide **3** gave a mixture of the monoesters **13** and **14**, in which the former predominated, as oxidation led to the formation of some of the keto ester corresponding to **14**, while much **13** was recovered unchanged; hydrolysis of the crude mixture of **13** and **14** gave exclusively the diol **6**. It has been found before that reactions of phenyloxiranes with organic acids in low polarity solvents usually involve a *cis* attack with rupture of the benzylic C—O bond; the *cis* course can be explained by a reaction between the ions of an intermediate ion-pair in a cage of solvent.¹⁴ A subsequent rapid acyl migration can give the more stable secondary ester.^{3, 6, 15} While for epoxide **2** the latter shift is complete, it is not so for the isomer **3**, probably because it involves a migration from an equatorial



to an axial oxygen. The diols **5** and **6** can be obtained easily in high yield by reaction of the crude epoxidation mixture of **1** with trichloroacetic acid, hydrolysis and chromatographic separation on a column of alumina.

The *cis* configurations of **5** and **6** were confirmed by their formation in the reaction of **1** with osmium tetroxide. **5** is by far the major product of this reaction; this indicates a pronounced preference for the formation of the osmic ester in which the phenyl group assumes an equatorial conformation relative to the cyclohexane ring.

The diaxial *trans* diol **7** was first prepared in low overall yield through a stereospecific sequence that had been used before to obtain 1-phenyl-*trans*-cyclohexane-1,2-diol,⁶ involving an S_N2 -type opening of epoxide **2** with sodium 2-dimethylaminoethoxide to give **9**, followed by methylation, conversion into the quaternary hydroxide, pyrolysis to the vinyl ether **10** and hydrolysis of the latter.

The fourth glycol, the diequatorial isomer **8**, was obtained in mixture with **5** by reaction of the epoxide **2** with formic acid, followed by hydrolysis of the formic ester. Similarly, the epoxide **3** was transformed by formic acid into the glycols **6** and **7**. The non-stereospecific character of the cleavage with formic acid had already been observed in the case of 1-phenylcyclohexene oxide.⁶ All four glycols **5–8** can be obtained by treating **1** with performic acid, and can be separated almost completely through chromatography on alumina. The order of elution **7–5–6–8**, is in accordance with

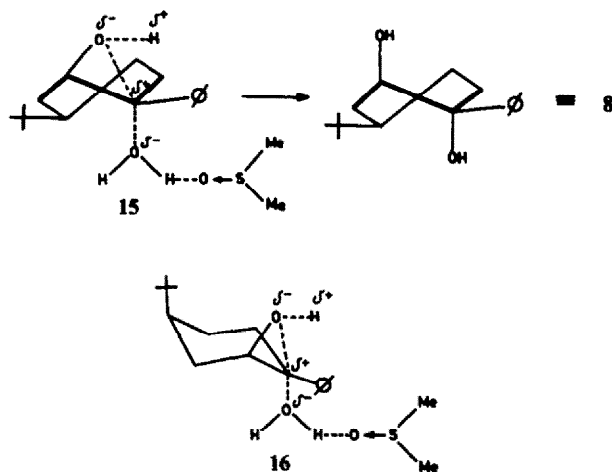
the principle that equatorial OH groups are bonded to the adsorbant more strongly than axial ones;¹² it is therefore to be expected that the diaxial isomer **7** is eluted first and the diequatorial one **8** last, while the fact that **5** precedes **6** could be explained by an interference of the equatorial Ph group of **5** with the approach of the equatorial β -OH group to the adsorbant.

Stereospecific methods for the preparation of the glycols in better yields were found through the use of dimethyl sulfoxide (DMSO). In search of a method to obtain the diaxial glycol **7** more simply than through the sequence outlined above, it appeared promising to prepare it by the hydrolytic cleavage in an alkaline medium of **2** or **3**, as it is known that these reactions follow, as a rule, a purely S_N2 -type mechanism.¹ Previous attempts to open 1-phenylcyclohexene oxide with potassium hydroxide⁶ in several polar solvents (alcohols, dioxan-water, etc) had given completely negative results, because sterically hindered epoxides resist substitution even under the most drastic conditions. The use of a mixture of DMSO and water led to much better results: both epoxides **2** and **3** were opened diaxially to give the glycol **7** as the only product. The properties of DMSO as a solvent which greatly increases nucleophilic properties and reaction rates in S_N2 reactions, because of selective solvation of the cation, are well known.¹⁶ The only previous report on the use of DMSO as a solvent for oxirane cleavage is by Virtanen,¹⁷ who observed a higher rate for the alkaline hydrolysis of ethylene oxide in this solvent than in dioxan.¹⁸

The formation of **7** from both **2** and **3** is in accordance with the rule of "diaxial opening".¹⁹ The rates of cleavage are greatly different, **2** reacting much more rapidly than **3**, in accordance with what would be expected for an S_N2 -type reaction, in which steric effects have more importance than the weakening of the benzylic C—O bond: starting from the preferred conformations of **2** and **3**, **7** is formed from **2** by attack of the base on the less hindered secondary carbon atom, but from **3** by attack on the more hindered tertiary one. The differences in the reactivities of the epoxides **2** and **3** provide a better method for the separation of the isomer **3**, than the chromatographic one described above: treatment of a mixture of **2** and **3** with potassium hydroxide in 85% DMSO-water at 100° for 16 hr leads to complete hydrolysis of **2**, while most of the **3** remains unchanged and is easily separated from the glycol **7** by extraction with petroleum ether.

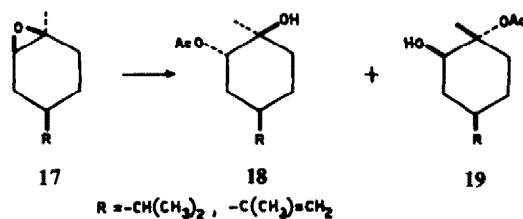
Interesting results were also obtained in the hydrolytic fission of the epoxides **2** and **3** with sulphuric acid in DMSO-water. Both compounds opened in an almost fully *trans* fashion, but, while **3** gave the diaxial glycol **7**, accompanied by only a small amount (< 10%) of the *cis* glycol **6**, **2** produced exclusively the diequatorial isomer **8**. Here, evidently, the breaking of the benzylic C—O bond is essential in determining the stereochemistry of the reaction. While the formation of **7** from **3** is in accordance with the rule of "diaxial opening", that of **8** from **2** apparently contradicts it, but can still be reconciled with it, if it is assumed that in the transition state of the reaction the cyclohexane ring assumes a boat, or skew-boat conformation (**15**); the passage from the half-chair form of the protonated epoxide to this transition state should not be very energy demanding, and anyway less so than the passage to the alternate chair with an axial *t*-butyl group (**16**).

The remarkable point is that while in acidic cleavages under different conditions (HCOOH, CCl₃COOH in benzene), the predominant or only course is *cis*, almost exclusively *trans* opening products are obtained in DMSO-water. DMSO strongly



bonds water molecules through formation of hydrogen bonds, thus increasing the nucleophilic properties of water;^{16, 20} on the other hand the basic properties of this solvent should decrease the tendency to protonation of the epoxide. Both effects should favour a "borderline S_N2 " mechanism,¹ as indicated in 15 in which the C—O bond is broken in the transition state enough to account for the benzylic opening, but not enough to give a free positive charge, which could lead to the more stable *cis* glycol, or at least to a mixture of *cis* and *trans* isomer.

Recent studies on the cleavage of limonene 1,2-oxides and carvomentene oxides with sodium acetate-acetic acid^{11, 21} have shown that the isomers 17 open to give the *trans* monoacetates 18 and 19 in a ratio of 9:1. While the main product 18 is the one to be expected from a diaxial opening in a chair-like transition state, 19 is the "effective diequatorial opening" product, which should be formed by a mechanism of the type discussed above for the passage from 2 to 8. Evidently, the presence of a phenyl group in place of a methyl, and of a *t*-butyl in place of an isopropyl or isopropenyl imposes stricter steric and electronic requirements: none of the *trans* product corresponding to 18 has been observed in any of the acidic cleavages of 2.



Although the configurations of the glycols 5-8 are established with sufficient certainty by their methods of preparation, a further proof is given by their NMR spectra. The easily recognizable bands corresponding to the protons α to the hydroxyl group (H_α , see Table 1) provide a straightforward way to distinguish the glycols 6 and 7, in which these protons are equatorial, from those 5 and 8, in which they are axial, by the consideration of the half-band widths.²² In the former two compounds

these bands are relatively narrow (half-band width ~ 6 c/s), and practically not resolved at 60 Mc, in accordance with what would be expected for the small e,e and e,a coupling constants. In the latter two compounds the bands are broader, and have the shape of distorted quartets with splittings of about 11 and 5 c/s, as would be expected for the X part of an ABX system with a large AX (a,a) and a small BX (a,e) coupling constant.²³ This method is more reliable for the distinction between axial and equatorial protons than the one based on the rule that usually the former resonate at higher fields than the latter,²⁴ when groups exhibiting a large diamagnetic anisotropy effect, such as the phenyl group, are near to the proton. This is shown by the data in Table 1; in the spectrum of glycol 6, the signal of the equatorial H_a is found at lower field than those of the axial H_a in the spectra of the glycols 5 and 8, in accordance with the normal rule. On the other hand the equatorial H_a of 7 resonates in the same region as the axial H_a of 5 and 8. This apparent discrepancy must be due to a different orientation of the phenyl group with respect to the H_a, as found in other similar cases.²⁵

The NMR spectra of the glycols 5–8 will be discussed more fully in a separate paper, together with their IR spectra, which provide further confirmation for the assigned configurations by the shapes of their OH stretching bands.

TABLE 1. H_a BANDS IN THE NMR SPECTRA OF THE 4-*t*-BUTYL-1-PHENYLCYCLOHEXANEDIOLS

Compound	τ (ppm)	Half-band width (c/s)
5	6.16	17
6	5.73	6
7	6.28	6
8	6.21	17

EXPERIMENTAL

M.p.s were determined on a Kofler apparatus. IR spectra were taken on paraffin oil mulls on a Perkin-Elmer Infracord Model 137, or on a Perkin-Elmer Model 237 grating spectrophotometer. NMR spectra were taken on CCl₄ (epoxides) or CDCl₃ solns (glycols) on a Varian DA-60 I spectrometer, with TMS as internal standard. All comparisons between compounds were made on the basis of IR spectra and mixed m.p.s. Pet ether refers to the fraction b.p. 30–50°. MgSO₄ was always used as the drying agent. In the nomenclature we have employed, *cis* and *trans* are referred to the oxirane oxygen, or to the 1-OH group.

4-*t*-Butylcyclohexanone, m.p. 48–49°, was prepared as described before,²⁵ and transformed into 1-phenyl-4-*t*-butylcyclohexene (I), b.p. 137–138°/0.9 mm, n_D^{20} 1.5447 (lit.²⁶ b.p. 106–107°/0.4 mm, n_D^{20} 1.5437) by the method of Garbisch.²⁶ The mixture of 1-phenyl-*cis*-4-*t*-butylcyclohexanol (4), m.p. 115–116° (lit.¹² m.p. 117–118°) and 1-phenyl-*trans*-4-*t*-butylcyclohexanol (11), m.p. 158–160° (lit.¹² m.p. 158–159°), which was obtained as an intermediate in the latter reaction, was separated into its components by chromatography.¹²

1-Phenyl-*cis*-4-*t*-butyl-1,2-epoxycyclohexane (2) and 1-phenyl-*trans*-4-*t*-butyl-1,2-epoxycyclohexane (3)

A soln of 25 g (0.117 mole) of I in 100 ml CHCl₃ was treated under stirring with 300 ml of a 0.49M (0.147 mole) soln of peroxybenzoic acid,²⁷ while keeping the temp below –7°. After 70 hr at 0°, the soln was washed with 10% Na₂CO₃ aq, dried and the solvent was evaporated under reduced press, to give 26.2 g of a mixture of 2 and 3 in about equal amounts. The composition of the mixture was estimated from the NMR spectrum of a soln of the crude product in CCl₄, on the basis of the heights of the *t*-butyl singlets, which appear at 9.16 τ for 2 and at 9.14 τ for 3; the method has an accuracy of about $\pm 5\%$.

The crude mixture of epoxides, which was impure with traces of CO compounds (IR), was crystallized from 2% ethanolic KOH to yield 11.35 g of **2**, which still contained about 10% of **3**; two more crystallizations from EtOH yielded 8.9 g of pure **2**, blades, m.p. 67–68°. (Found: C, 83.13; H, 9.53. $C_{16}H_{22}O$ requires: C, 83.43; H, 9.63%) Partial evaporation *in vacuo* of the mother liquor gave 4.5 g of a mixture of **2** and **3**, from which it was not possible to isolate pure **3** by fractional crystallization; 3.5 g of this mixture was chromatographed over 235 g of neutral Al_2O_3 (act. II); elution with pet ether gave first 0.52 g of almost pure **3**, then mixtures of **3** and **2** (0.50 g) and at last 0.79 g of pure **2**. Recrystallization of the first fractions from EtOH produced pure **3**, prisms, m.p. 64–65.5°. (Found: C, 83.53; H, 9.74. $C_{16}H_{22}O$ requires: C, 83.43; H, 9.63%.)

The epoxide **3** was obtained more easily in the following way: a soln of 3.1 g of a mixture, from which part of the epoxide **2** had been separated by crystallization, in 85 ml of DMSO and 15 ml of 2N KOH was heated 16 hr at 100°, then diluted with 500 ml water and extracted repeatedly with ether. The ether extracts were washed several times with water to eliminate the DMSO, dried and evaporated to give 2.9 g of a mixture of **3** with the glycol **7**. The latter compound (1.3 g) remained undissolved on treatment with a small amount of cold pet ether, while crystallization of the pet ether soluble part from EtOH at 0° yielded 1.07 g of **3**, m.p. 64.5–65.5°.

Solvolysis of the crude epoxides. When the crude mixture of **2** and **3** (0.10 g) was refluxed for 30 min in 3 ml of EtOH, the IR spectrum of the product showed that most of the epoxides had been transformed into different products exhibiting strong bands in the OH (2.96 μ) and C—O—C stretching regions (9.05 and 9.31 μ). No attempt at a further characterization of the products was made. The crude mixture of **2** and **3** was recovered practically unchanged from a similar treatment with 2% KOH in EtOH. The pure epoxides **2** and **3** were also recovered unchanged after reflux in EtOH.

Reduction of epoxide 2 with LAH. A soln of 50 mg of **2** in 20 ml of ether was refluxed 3 hr with 50 mg of LAH. After decomposition of excess hydride with 0.2 ml of H_2O and 0.2 ml of 2N NaOH, filtration, evaporation of the solvent and crystallization of the residue (49 mg) from pet ether, 1-phenyl-cis-4-t-butylcyclohexanol (**4**), m.p. 116–117°, was obtained. When 1-phenyl-trans-4-t-butylcyclohexanol (**11**) was refluxed with LAH under the conditions used for the reduction of **2**, the starting material was recovered unchanged.

Stereospecific Methods for the Preparation of Glycols

1-Phenyl-cis-4-t-butylcyclohexane-cis-1,2-diol (**5**)

A soln of 0.20 g (0.868 mmole) of the epoxide **2** in 6 ml of benzene was treated with 1.28 ml (1.04 mmole) of a 0.815M soln of CCl_3COOH in benzene, stored overnight, then washed with 10% Na_2CO_3 aq and evaporated. The residue (0.280 g) consisted of 1-phenyl-cis-2-trichloroacetoxy-cis-4-t-butylcyclohexanol (**12**). An analytical sample, prepared by crystallization from pet ether, had m.p. 134–136° (needles), λ_{OH} 2.83 μ , λ_{CO} 5.71 μ . (Found: C, 54.56; H, 6.05. $C_{18}H_{23}O_3Cl_3$ requires: C, 54.90; H, 5.89%) The product was recovered unchanged after treatment of its acetone soln with Jones reagent²⁸ for 10 min.

A soln of 0.100 g of the crude ester **12** in 3 ml of 2N KOH in EtOH was refluxed 10 min, diluted with water and extracted with ether. Evaporation of the dried soln yielded 0.056 g of practically pure glycol **5**. The analytical sample, was obtained from pet ether as clusters of needles, m.p. 150–150.5°. (Found: C, 77.64; H, 9.84. $C_{16}H_{24}O_2$ requires: C, 77.37; H, 9.74%.)

1-Phenyl-trans-4-t-butylcyclohexane-cis-1,2-diol (**6**)

This glycol was prepared from the epoxide **3** in the same way as described for **5**. The intermediate trichloroacetic ester consisted of a mixture, m.p. 69–77°, of much **13** and little **14**: oxidation with Jones reagent²⁸ led to a mixture which contained some keto ester as shown by the appearance of a small band at 5.81 μ beside the CCl_3CO — band at 5.69 μ . Saponification of the mixture of **13** and **14** as described above gave **6**. This compound crystallizes from pet ether in two polymorphic forms: one melting at 101.5–102.5°, the other one, which melts around 70°, resolidifies and melts again at 100–101.5°. (Found: C, 77.18; H, 9.67. $C_{16}H_{24}O_2$ requires: C, 77.37; H, 9.74%.)

The glycols **5** and **6** can also be obtained by the same method from crude mixtures of epoxides **II** and **III**, and cleanly separated by chromatography: thus, 3.0 g of a fraction enriched in **3** obtained from the mother liquor after separation of crystalline **2**, was transformed into 2.56 g of an oily mixture of **5** and **6**, which was chromatographed over 72 g of neutral Al_2O_3 (act. I). Elution with 10% ether in benzene gave 0.350 g of **5**, while further elution with increasing amounts of ether yielded 0.920 g of **6**.

1-Phenyl-cis-4-t-butylcyclohexane-trans-1,2-diol (7).

(a) From 1-phenyl-cis-4-t-butyl-trans-2-(2-dimethylaminoethoxy)cyclohexanol (9). To a soln of sodium 2-dimethylaminoethoxide, prepared by dissolving 0.115 g (5 mmole) of Na in 4.5 g (50 mmole) of 2-dimethylaminoethanol, was added 1.15 g (5 mmole) of the epoxide 2. After 12 hr reflux the mixture was poured into 50 ml of water, acidified, under cooling, with conc HCl aq and extracted with ether. The aqueous layer was made alkaline with NaOH aq and extracted again with ether: evaporation of the dried ether extract yielded 1.10 g of 9, which crystallized from pet ether in needles, m.p. 93.5–94.5°, λ_{OH} 3.25 μ . (Found: C, 75.52; H, 10.43. $C_{20}H_{33}NO_2$ requires: C, 75.19; H, 10.41%.)

A soln of 0.90 g (2.8 mmole) of 9 and 1.6 g (11 mmole) of MeI in 15 ml of MeOH was refluxed 11 hr, then evaporated to dryness under reduced press to give 1.27 g of the crude methiodide of 9; 1.21 g of the latter product in 50 ml of water was treated with Ag_2O which had been freshly prepared from 3.2 g of $AgNO_3$, the suspension was stirred 6 hr, then filtered. The filtrate was evaporated under reduced press, at 50°, and the residual quaternary hydroxide gradually heated at 40 mm, until at 130° its decomposition began; the reaction ended after 15 min at 140°. Extraction with benzene gave 0.50 g of the oily vinyl ether 10, which was hydrolyzed, without further purification, by shaking it with 4 ml of MeOH and 1.5 ml of 1N H_2SO_4 aq: acetaldehyde was liberated. The soln was diluted with water and extracted with ether. The washed and dried extract gave, after evaporation, 0.30 g of 7, which crystallized from pet ether in prisms, m.p. 139–140.5°. (Found: C, 77.40; H, 9.94. $C_{16}H_{24}O_2$ requires: C, 77.37; H, 9.74%.)

(b) *By acidic hydrolysis of epoxide 3.* A suspension of 3 (0.10 g) in 4.5 ml of DMSO and 1.5 ml of water was cooled at 5° and treated with an equally cooled mixture of 1 ml of 2N H_2SO_4 aq and 3 ml of DMSO. After 12 hr at 5°, during which time the mixture was occasionally stirred, all the epoxide had dissolved; water was added and the soln was extracted 3 times with ether. The ether layer was washed repeatedly with water to eliminate all the DMSO, then dried and evaporated. The IR spectrum of the residue (0.103 g) was very similar to that of the diol 7, but contained a carbonylic side-product (band at 5.85 μ) and small bands that could be attributed to the *cis*-glycol 6. A separation by preparative TLC (2-mm layer of F_{254} silica gel, 5% methanol in benzene as eluent), followed by extraction of the bands (the faster moving band contains the diol 7) with ether and weighing of the extract, showed that the diols 7 and 6 were present in a ratio of about 9:1. When the reaction was carried out under the same conditions, but with a smaller amount of water (0.10 g of 3, 9 ml of DMSO and 1 ml of 2N H_2SO_4 aq), a slightly larger quantity of 6 was formed, the ratio of 7 to 6 being about 8:2. In both cases crystallization from pet ether gave pure 7, m.p. 139–140°.

(c) *By alkaline hydrolysis of epoxides 2 and 3.* The crude mixture of epoxides can be transformed completely into the glycol 7 with KOH in DMSO— H_2O as described above for the preparation of 3, if the heating is continued for 60 hr, the hydrolysis of 3 being complete only after this time.

1-Phenyl-trans-4-t-butylcyclohexane-trans-1,2-diol (8)

A soln of 2 (0.60 g) in 12 ml of DMSO was treated at 5° with a mixture of 42 ml of DMSO and 6 ml of 2N H_2SO_4 aq, left 5 hr at 5° with occasional shaking, then worked up as described for the similar reaction of epoxide 3. The product (0.62 g) contained some carbonylic impurity (band at 5.85 μ). Analytical TLC showed that the only glycol present was 8. Crystallization from pet ether gave 0.39 g of pure 8, needles, m.p. 110–111° (Found: C, 77.39; H, 9.74. $C_{16}H_{24}O_2$ requires: C, 77.37; H, 9.74%.)

Non-stereospecific Preparations of the Glycols

Reactions of the epoxides 2 and 3 with formic acid

(a) The epoxide 2 (2 g) was added to 40 ml of 98% formic acid and 8 ml of ether, which had been cooled at -15° ; the mixture was stirred at same temp until 2 had completely dissolved, then left at -8° for 24 hr, neutralized with 40% NaOH aq and extracted with $CHCl_3$. After evaporation of the $CHCl_3$ the residue was saponified by refluxing it for 10 min with 25 ml of 1.2N KOH aq, the soln was diluted with water and the ppt (2.1 g) was chromatographed over 130 g of neutral Al_2O_3 (act. I). The column was eluted with 1,800 ml of benzene, 1,200 ml of 9/1 benzene–ether, 1,500 ml of 4/1 benzene–ether, 4,700 ml of 3/2 benzene–ether, 2,200 ml of 1/1 benzene–ether and 450 ml of 1/1 ether–EtOH. The 4/1 benzene–ether eluate gave 1.1 g of the *cis* glycol 5, while the 1/1 benzene–ether and ether–EtOH eluates yielded 0.7 g of the *trans* glycol 8.

(b) When the epoxide 3 (100 mg) was treated in the same way, 103 mg of a crude product was obtained, the IR spectrum of which indicated that it consisted of a mixture of the glycols 6 and 7; preparative TLC indicated that the ratio of 6 to 7 was about 3:1.

Reaction of 1-phenyl-4-t-butylcyclohexene (1) with peroxyformic acid

A mixture of 9 ml of 98% formic acid, 2.9 ml of 30.6% (w/v) H_2O_2 and 0.3 g anhyd KOAc was treated slowly, while keeping the temp below 0° , with a soln of 3.0 g of 1 in 3 ml of ether, then left 4 hr at 0° and 24 hr at 10° , diluted with water, neutralized with 50% NaOH aq and extracted with ether. The oily ether extract was hydrolyzed by refluxing it for 10 min with 4.3 g of KOH in 6 ml of water and 10 ml of MeOH. Dilution with water and extraction with CHCl_3 gave a semi-solid product (2.7 g) which was chromatographed over 72 g of neutral Al_2O_3 (act. I): 1,000 ml of benzene, 4,300 ml of 9/1 benzene-ether, 10,000 ml of 4/1 benzene-ether and 1,000 ml of ether eluted in succession the following products: 0.88 g of unchanged 1; 0.20 g of carbonyl containing (IR) material; 0.25 g of 7; 0.19 g of 5; 0.20 g of 6 and 0.29 g of a mixture of 6 and 8.

Reaction of 1-phenyl-4-t-butylcyclohexene (1) with OsO_4

A soln of 0.107 g (0.5 mmole) of 1, 0.127 g (0.5 mmole) of OsO_4 and 0.2 ml of pyridine in 6 ml anhyd ether was stored for 4 days. The ppt was collected, washed with ether, dissolved in CH_2Cl_2 and shaken with a soln of 0.2 g of NaOH and 0.5 g of mannitol in 8 ml of water. This treatment was repeated twice, until the organic layer had completely decolorized. Evaporation of the solvent gave 0.117 g of a product which was crystallized from pet ether to produce 80 mg of the glycol 5, m.p. $150\text{--}150.5^\circ$. IR analysis of the mother liquor showed that it consisted of a mixture of 5 and 6.

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