[Contribution from the Department of Chemistry, Massachusetts Institute of Technology]

# Proximity Effects. VIII. Solvolysis of *cis*-Cyclooctene Oxide; Synthesis of Alcohols in the Cyclooctane Series[1]

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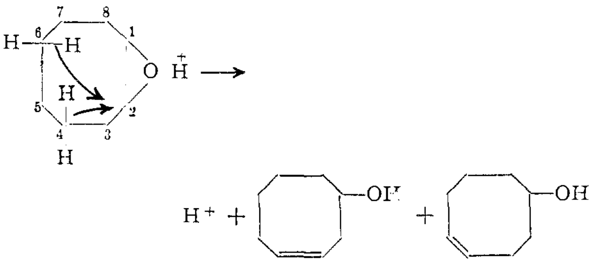
The solvolysis of *cis*-cycloöctene oxide in formic acid has been shown to yield, in addition to the *cis*-1,4- and *trans*-1,2-cycloöctanediols already reported, a lower boiling fraction containing 3-cycloöcten-1-ol and 4-cyloöcten-1-ol (15% total), a saturated alcohol that appears to be a bicycloöctanol (at least 0.1%), cycloöctanone (trace), 1,4- and 1,5-epoxycycloöctane (about 0.1% total) and an unidentified alcohol (about 1%). Three non-stereospecific syntheses of 1,4-cycloöctanediols are reported. *cis*- and *trans*-1,4-cycloöctanediol have been shown to be epimers by oxidation to the same diketone, which on reduction formed a mixture of the two glycols. The *cis* isomer has been converted to the *trans* through the monotosylate (not isolated). *trans*-1,3-Cycloöctanediol has been prepared, and its stereochemistry has been determined by establishing the configuration of the intermediate compound, *trans*-2,3-epoxycycloöctan-1-ol. *trans*-1,3-Cycloöctanediol has been converted to the *cis* isomer through the monotosylate (not isolated). Derivatives of various alcohols in the cycloöctane series have been prepared.

**Solvolysis of *cis*-Cycloöctene Oxide.**—Previous papers in this series have described reactions of cycloöctane derivatives that are influenced by what has been called a "proximity effect." The original example of such a reaction, *i.e.*, the solvolysis of *cis*-cycloöctene oxide in formic acid,[4] has now been reinvestigated. Additional products have been found, some of which appear to arise through the influence of proximity effects.

Repetitions of the solvolysis of *cis*-cycloöctene oxide resulted in isolation of the previously reported diols, *trans*-1,2-cycloöctanediol (5.6–19%) and *cis*-1,4-cycloöctanediol (23–30%). The structure and *cis* configuration of the latter diol have since been confirmed by synthesis.[5]

In addition, distillation of the alcohol mixture obtained in the solvolysis of the oxide gave a low-boiling fraction amounting to 16–17% of the weight of the oxide. This fraction yielded a phenylurethan which, after several recrystallizations, melted at 102.4–103.6°. This phenylurethan has been shown to be 3-cycloöcten-1-yl phenylurethan.[6] Infrared analysis, based upon the available spectra of 2-cycloöcten-1-ol, 3-cycloöcten-1-ol and 4-cycloocten-1-ol and upon the spectra of the corresponding phenylurethans, indicated that the low boiling material contained considerable 4-cycloöcten-1-ol in addition to 3-cycloöcten-1-ol. The presence of 4-cycloöcten-1-ol in the alcohol mixture was confirmed by preparation of a *p*-nitrobenzoate. The product, which was isolated in 13% yield, proved to be the *p*-nitrobenzoate of 4-cycloöcten-1-ol, m.p. 83–85°. The failure of 3-cycloöcten-1-yl *p*-nitrobenzoate to crystallize from the mixture was explained when an authentic sample was prepared and found to have a melting point of 32–33°. It is of interest that no appreciable amount of 2-cycloocten-1-ol, which might be considered a "normal" product of the *cis*-cycloöctene oxide solvolysis, appeared to be present in the alcohol mixture. The unsaturated alcohols therefore represent additional products formed by a transannular reaction. They could originate directly from the oxide by a concerted elimination reaction or could result from dehydration of the initially formed *cis*-1,4-cyclooctanediol.



1,3- or 1,5-hydride shift and loss of a proton from $C_3$, $C_5$ or $C_7$

Hydrogenation of the alcohol mixture resulted in uptake of 92–100% of one mole of hydrogen giving cycloöctanol, which was isolated as its phenylurethan in 85% yield. These results would be expected for an alcohol mixture consisting mostly of 3-cycloöcten-1-ol and 4-cycloöcten-1-ol.

In order to isolate any bicyclic alcohol that might be present in the low-boiling material, a sample was subjected to a separation procedure involving silver nitrate extraction, conversion of alcohols to the phenylurethans, ozonolysis (to remove the phenylurethans of unsaturated alcohols) and chromatography. From the chromatogram the phenylurethan of a saturated alcohol was obtained with an analysis in agreement with a bicycloöctyl phenylurethan structure. The yield was 0.1% based on *cis*-cycloöctene oxide. The presence of a bicyclic alcohol among the solvolysis products could be due to a transannular reaction in which the double bond of one of the cycloöctenols forms a bond bridging the cycloöctane ring subsequent to or concomitant with removal of the protonated hydroxyl group. The absence of either isomer of bicyclo[3.3.0]octan-2-ol[7] in the original alcohol mixture was shown by vapor phase chromatography. Comparison of melting points showed that the saturated phenylurethan of unknown structure is not derived from either of these bicycloöctanols. The structure of the unknown phenylurethan is being investigated.

When the low boiling distillate from *cis*-cyclooctene oxide solvolysis was collected in several

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[3] National Science Foundation Fellow, 1953–1954.

[4] A. C. Cope, S. W. Fenton and C. F. Spencer, This Journal, **74**, 5884 (1952).

[5] A. C. Cope and B. C. Anderson, *ibid.*, **79**, 3892 (1957).

[6] A. C. Cope and G. W. Wood, *ibid.*, **79**, 3885 (1957).

[7] A. C. Cope, H. H. Lee and H. E. Petree, to be published.

fractions, the first fractions contained a carbonyl compound that was shown to be cycloöctanone by comparison of the 2,4-dinitrophenylhydrazone with authentic cycloöctanone 2,4-dinitrophenylhydrazone.

Vapor phase chromatography of the first distillation fractions from the *cis*-cycloöctene oxide solvolysis revealed the presence of two major peaks which could not be attributed to any of the compounds previously identified. Comparison with known samples on the vapor phase column showed that the compounds were not cycloöctadienes or *cis*-cycloöctene oxide. Samples of the unknown materials were collected by condensation from the effluent gas from the vapor-phase apparatus. The infrared spectrum of one of the fractions indicated that it was a mixture of 1,4- and 1,5-epoxycyclooctane.[5,8] These ethers could be formed from the 3- and 4-cycloöcten-1-ol produced in the *cis*-cycloöctene oxide solvolysis.

The infrared spectrum of the second fraction indicated that it was an unsaturated alcohol. Further characterization of this compound will be reported in connection with another problem.

**Synthesis of Cycloöctanediols.**—Although stereospecific syntheses of 1,4- and 1,5-cycloöctanediols now have been accomplished[5,8] other methods of preparation are of interest as more practical sources of the glycols. Since *cis*-1,4-cycloöctanediol was available from solvolysis of *cis*-cycloöctene oxide, it was made the starting material for synthesis of *trans*-1,4-cycloöctanediol. Oxidation of *cis*-1,4-cycloöctanediol with N-bromosuccinimide in aqueous acetone gave 1,4-cycloöctanedione, characterized by preparation of the dioxime and bis-2,4-dinitrophenylhydrazone, in 63% yield. Hydrogenation of the diketone over Raney nickel gave a mixture of glycols which was separated by chromatography on alumina into approximately equal amounts of *cis*-1,4-cycloöctanediol and *trans*-1,4-cycloöctanediol. The latter glycol formed a bis-*p*-nitrobenzoate identical with a sample derived from the *trans*-1,4-glycol obtained by solvolysis of *trans*-cycloöctene oxide.[9]

Alternatively, the *cis*-1,4-cycloöctanediol was epimerized to the *trans* isomer *via* the crude mono-*p*-toluenesulfonate obtained by reaction of one molar equivalent of *p*-toluenesulfonyl chloride with *cis*-1.4-cycloöctanediol. Treatment of the product with tetraethylammonium acetate followed by hydrolysis and chromatography gave *trans*-1,4-cycloöctanediol (21%) and some recovered *cis*-1,4-cycloöctanediol (5%).

The bromination of 2-cycloöcten-1-yl acetate with N-bromosuccinimide also was studied as a possible route leading eventually to 1,4-cycloöctanediols. A bromoacetate was obtained in 43% yield which is formulated as 4-bromo-2-cycloöcten-1-yl acetate, but presumably exists as a mixture with its allylic isomer, 2-bromo-3-cycloöcten-1-yl acetate. Treatment with tetraethylammonium acetate in acetone followed by hydrogenation and saponification gave a glycol mixture in 47% yield, from which *trans*-1,4-cycloöctanediol was isolated in 19% yield (based on the glycol mixture) by crystallization from ethyl acetate. Chromatography of the mother liquors gave an additional 4% of *trans*-1,4-cycloöctanediol. When silver acetate in acetic acid was allowed to react with the allylic bromoacetate, a 53% yield of unsaturated diacetate was obtained which was converted to a saturated glycol mixture from which *trans*-1,4-cyclooctanediol was isolated in 37% yield (based on unsaturated diacetate).

Another sequence for the synthesis of 1,4-cyclooctanediols was based on the reported ease with which cyclopentadiene and 1,3-cyclohexadiene can be autoxidized.[10] *cis-cis*-1,3-Cycloöctadiene absorbed 40–43% of one mole of oxygen on stirring at room temperature with ultraviolet illumination for 28 hr. The crude reaction mixture was reduced directly with lithium aluminum hydride by modification of a procedure used for reduction of the polymeric peroxide of styrene to phenylethylene glycol,[11] and the resulting mixture of unsaturated glycols was hydrogenated. A mixture of cyclooctanediols was isolated in 8% yield. Treatment of the glycol mixture with acetone and copper sulfate afforded *trans*-1,2-cycloöctanediol isopropylidene ketal in 15% yield. Chromatographic analysis of the glycol residue (66% based on the glycol mixture) showed that it was composed of essentially pure *trans*-1,4-cycloöctanediol.

Previous papers in this series have described the preparation of all the possible cycloöctanediols by methods leading to products of known stereochemistry with the exception of the two epimeric 1,3-cycloöctanediols. Accordingly, the preparation of these diols, needed for comparison with diols obtained in the solvolysis of *trans*-cycloöctene oxide, was undertaken, beginning with 2-cycloöcten-1-ol. Epoxidation of the 2-cycloöcten-1-ol gave 2,3-epoxycycloöctan-1-ol as an oil which was hydrogenated over Raney nickel to give a mixture of 1,2- and 1,3-cycloöctanediols. Reaction of the glycol mixture with acetone in the presence of cupric sulfate gave *trans*-1,2-cycloöctanediol isopropylidene ketal in 75% yield. Crystallization of the glycol residue from the acetone–cupric sulfate reaction gave *trans*-1,3-cycloöctanediol in 12% yield. Assignment of configuration to the latter compound is based in part upon the above results, which show that the oxide group in 2,3-epoxycycloöctan-1-ol is *trans* to the hydroxyl group to the extent of at least 75% and also upon the result of lithum aluminum hydride reduction. When the latter reaction was carried out by addition of lithium aluminum hydride to 2,3-epoxycycloöctan-1-ol, a 1,3-cycloöctanediol identical with the 1,3-glycol obtained by hydrogenation with Raney nickel was isolated in 50% yield. It can thus have been formed only from *trans*-2,3-epoxycycloöctan-1-ol and must therefore be the *trans*-1,3-glycol. The lithium aluminum hydride reduction also gave *trans*-1,2-cycloöctanediol, isolated in 35% yield as the

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(8) A. C. Cope and A. Fournier, Jr., THIS JOURNAL, **79**, 3896 (1957).

(9) A. C. Cope, A. Fournier, Jr., and H. E. Simmons, Jr., *ibid.*, **79**, 3905 (1957).

(10) (a) N. D. Zelinsky and A. N. Titowa, *Ber.*, **64**, 1399 (1931); (b) K. Bodendorf, *Arch. Pharm.*, **271**, 1 (1933); (c) H. Hock and F. Depke, *Chem. Ber.*, **84**, 349 (1951).

(11) A. V. Tobolsky and R. B. Mesrobian, "Organic Peroxides," Interscience Publishers, Inc., New York, N. Y., 1954.

TABLE I

CYCLOÖCTANEDIOLS AND DERIVATIVES

| Cycloöctanediol | M.p., °C. | M.p. of bis-phenylurethan, °C. | M.p. of bis-$p$-nitrobenzoate, °C. | M.p. of di-$p$-toluenesulfonate, °C. |
|---|---|---|---|---|
| *cis*-1,2- | 77.5–79[a] | 175.5–176.8[a] | 166.2–166.9[b] | 94.5–95.5[c] |
| *trans*-1,2- | 31.0–32.5[m] | 176.2–177.4[a] | 111.6–112.6[d] | 124.6–125.2[e] |
| *cis*-1,3- | 57.0–58.0 | | 129.4–130.1[f] | |
| *trans*-1,3- | 106.5–108.0 | | 163.0–165.0[g] | |
| *cis*-1,4- | 85.0–86.5[a] | 186.0–187.5[a] | 161.5–162.7[h] | 96.5–98.5[a] |
| *trans*-1,4- | 90.0–91.0[i] | 180.2–181.7[j] | 156.2–156.7[k] | |
| *cis*-1,5- | 73.8–74.8[l] | | 181.4–182.8[l] | |
| *trans*-1,5- | Liquid[l] | | 182.3–183.3[l] | |

[a] Reported in ref. 4. [b] Calcd. for $C_{22}H_{22}O_8N_2$: C, 59.72; H, 5.01. Found: C, 59.38; H, 5.23. [c] Calcd. for $C_{22}H_{28}O_6S_2$: C, 58.38; H, 6.24. Found: C, 58.57; H, 6.25. [d] Calcd. for $C_{22}H_{22}O_8N_2$: C, 59.72; H, 5.01. Found: C, 59.95; H, 5.23. [e] Calcd. for $C_{22}H_{28}O_6S_2$: C, 58.38; H, 6.24. Found: C, 58.24; H, 6.13. [f] Calcd. for $C_{22}H_{22}O_8N_2$: C, 59.72; H, 5.01. Found: C, 59.64; H, 5.08. [g] Calcd. for $C_{22}H_{22}O_8N_2$: C, 59.72; H, 5.01. Found: C, 59.52; H, 4.92. [h] Reported in ref. 5. [i] Reported in ref. 6. [j] Calcd. for $C_{22}H_{26}O_4N_2$: C, 69.09; H, 6.85. Found: C, 69.16; H, 6.95. [k] Calcd. for $C_{22}H_{22}O_8N_2$: C. 59.72; H, 5.01. Found: C, 59.70; H, 5.13. [l] Reported in ref. 8. [m] Reported in ref. 4 as a liquid. This glycol crystallized approximately 7 years after it was first obtained as a viscous liquid, purified by distillation. It was purified by recrystallization from ether–pentane.

isopropylidene ketal. These results indicate that the epoxidation of 2-cycloöcten-1-ol results almost exclusively in addition of oxygen *trans* to the hydroxyl group, in contrast to the epoxidation of 2-cyclohexen-1-ol, which forms *cis*-2,3-epoxycyclohexan-1-ol.[12]

2-Cycloöcten-1-one also was investigated as an intermediate which could lead to 1,3-cycloöctanediols. Preparation of this known[13] ketone was accomplished in improved yield by oxidation of 2-cycloöcten-1-ol with active manganese dioxide in pentane. Epoxidation with sodium hydroperoxide in methanol gave 2,3-epoxycycloöctan-1-one. This epoxide was not investigated further, since the corresponding alcohol was obtained more readily.

*trans*-1,3-Cycloöctanediol was epimerized to the *cis* isomer *via* the crude mono-$p$-toluenesulfonate in a manner similar to that employed in the epimerization of *cis*-1,4-cycloöctanediol. *cis*-1,3-Cycloöctanediol was isolated in 20% over-all yield. *trans*-1,3-Cycloöctanediol was further characterized by oxidation with chromic anhydride–pyridine complex to give 1,3-cycloöctanedione, isolated as the bis-2,4-dinitrophenylhydrazone. The same method was employed to convert both *cis*- and *trans*-1,4-cycloöctanediol to 1,4-cycloöctanedione bis-2,4-dinitrophenylhydrazone The bis-2,4-dinitrophenylhydrazone of 1,2-cycloöctanedione also was prepared for comparison.

The melting points of all the cycloöctanediols and of the derivatives which have been prepared from them are collected in Table I. Melting points of derivatives of the cycloöctenols are listed in Table II.

## Experimental[14]

**Solvolysis of *cis*-Cycloöctene Oxide.**—Several repetitions of the solvolysis of *cis*-cycloöctene oxide on a large scale have given results of which the following are typical. *cis*-Cycloöctene oxide (80.5 g.) was added in portions over a period of 1 hr. to 1 l. of 90% formic acid heated on a steam-bath. After 2 additional hr. of heating, the formic acid was removed by distillation at 100 mm. The resulting mixture of formates was saponified by stirring with 300 ml. of 40% sodium hydroxide at the reflux temperature for 1 hr. The resulting two-phase mixture was extracted with 300 ml. of chloroform. Short-path distillation of the chloroform extract gave 60.0 g. of material which was distilled through a spinning-band column. A low-boiling material (13.2 g.) was collected in five fractions, b.p. 55–70° (1 mm.), and was shown by the methods described below to consist principally of 3- and 4-cycloöcten-1-ol. This fraction was followed by the glycol fraction, b.p. 115–130° (1 mm.), containing *trans*-1,2-cycloöctanediol and *cis*-1,4-cycloöctanediol.

TABLE II

CYCLOÖCTENOLS AND DERIVATIVES

| Cycloöctenol | M.p. of phenylurethan, °C. | M.p. of $p$-nitrobenzoate, °C. |
|---|---|---|
| 2-Cycloöcten-1-ol | 92.5– 93.0[a] | 104.5–105.0[b] |
| 3-Cycloöcten-1-ol | 101.5–102.5[c] | 32.0– 33.0[d] |
| 4-Cycloöcten-1-ol | 93.0– 94.0[e] | 83.0– 85.0[f] |

[a] Reported in ref. 13. [b] Calcd. for $C_{15}H_{17}O_4N$: C, 65.44; H, 6.23. Found: C, 65.57; H, 6.41. [c] Reported in ref. 6. [d] Calcd. for $C_{15}H_{17}O_4N$: C, 65.44; H, 6.23. Found: C, 65.31; H, 6.07. [e] Reported in ref. 5. [f] Calcd. for $C_{15}H_{17}O_4N$: C, 65.44; H, 6.23. Found: C, 65.55; H, 6.26.

**Identification of 3-Cycloöcten-1-ol and 4-Cycloöcten-1-ol.**—Earlier experiments indicated that the low-boiling material consisted mostly of 3-cycloöcten-1-ol or a mixture of cycloöctenols. This was shown by hydrogenation of a sample to cycloöctanol, identified as its phenylurethan, which was isolated in 85% yield, and by preparation of a phenylurethan from the low boiling material. Recrystallization of the unsaturated phenylurethan yielded 3-cycloöcten-1-yl phenylurethan, m.p. 102.4–103.6°, whose structure was known from ozonization.[6]

The presence of 4-cycloöcten-1-ol in the low boiling material was indicated by the infrared spectrum of the crude unsaturated phenylurethan, which contained bands characteristic of 4-cycloöcten-1-yl phenylurethan at 697 and 724 cm.$^{-1}$ as well as those of 3-cycloöcten-1-yl phenylurethan at 685, 705, 768 and 780 cm.$^{-1}$. The absence of any appreciable amount of 2-cycloöcten-1-yl phenylurethan was demonstrated by the fact that there was no band at 950 cm.$^{-1}$ where 2-cycloöcten-1-yl phenylurethan has an absorption band of medium intensity. Further evidence for the composition of the unsaturated alcohol fraction was obtained by comparison of its infrared spectrum with the spectra of authentic samples of 3-cycloöcten-1-ol (described below, strong band at 705 cm.$^{-1}$) and 4-cycloöcten-1-ol (strong band at 725 cm.$^{-1}$). The infrared spectrum of the low-boiling material from the *cis*-cycloöctene oxide solvolysis could be accounted for by assuming it to be a mixture of the two alcohols. Finally, the presence of 4-cycloöcten-1-ol in the low-boiling material was confirmed by isolation of a $p$-nitrobenzoate prepared from the alcohol mixture, which was shown by mixed m.p. and infrared spectrum to be identical with the $p$-nitrobenzoate prepared from authentic 4-cycloöcten-1-ol.

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(12) H. B. Henbest and R. A. L. Wilson, *Chemistry & Industry*, 659 (1956).

(13) A. C. Cope, M. R. Kinter and R. T. Keller, THIS JOURNAL, **76**, 2757 (1954).

(14) Melting points are corrected and boiling points are uncorrected. We are indebted to Dr. S. M. Nagy and his associates for analyses.

**Bicyclic Alcohol.**—The presence in the low-boiling material of a small amount of a saturated alcohol isomeric with the cycloöctenols was demonstrated by isolation of the phenylurethan of the alcohol as follows. Distillation fractions 4 and 5 of the low-boiling material (5.94 g.) were treated with 35 ml. of 20% silver nitrate to remove unsaturated compounds. The insoluble saturated compounds were then extracted with ether (35 ml.), and the ether layer was washed twice with 5-ml. portions of 20% silver nitrate. Vapor phase chromatography (described below) of the ether layer showed the presence of at least three components in addition to a band that may have been due to cycloöctenols not removed by the silver nitrate. Evaporation of the ether gave 0.16 g. of a product that was warmed with 0.19 g. of phenyl isocyanate on a steam-bath. Removal of the excess phenyl isocyanate under reduced pressure and ozonolysis followed by reduction with sodium borohydride gave a product that was chromatographed on alumina (Merck, acid-washed). This is the procedure used previously,[6] except that treatment of the reduction product with phenyl isocyanate was omitted. The saturated phenylurethan which was eluted with 20% ether in petroleum ether (0.14 g.) was recrystallized from methanol and water, m.p. 118–119.5°.

*Anal.* Calcd. for $C_{15}H_{19}O_2N$: C, 73.44; H, 7.81; N, 5.71. Found: C, 73.36; H, 7.62; N, 5.75.

**Cycloöctanone.**—Distillation fractions 1 and 2 of the low boiling material from *cis*-cycloöctene oxide solvolysis gave several peaks upon vapor phase chromatography, in contrast to fractions 4 and 5, which gave a single major peak. The infrared spectrum of fraction 1 showed a carbonyl peak at 1688 cm.$^{-1}$. This unusually low frequency for carbonyl absorption suggested the presence of cycloöctanone (reported[15] carbonyl absorption at 1692 cm.$^{-1}$). The presence of cycloöctanone was confirmed by the preparation of a 2,4-dinitrophenylhydrazone, m.p. 171.0–173.2°, undepressed in mixed m.p. with authentic cycloöctanone 2,4-dinitrophenylhydrazone, m.p. 174.8–175.1°.

**1,4- and 1,5-Epoxycycloöctanes and the Unidentified Component.**—At this point the two remaining major components of fractions 1 and 2 which gave peaks upon vapor phase chromatography were isolated from the effluent gas stream of the vapor phase apparatus by attaching small collecting vessels as the fractions were eluted from the column. The column employed for this separation was a 12-mm. Pyrex tube with a 180-cm. length of packing consisting of 30% Dow-Corning Silicone oil no. 550 on a ground firebrick support (38–80 mesh). The column was heated to 180° and employed helium introduced under a pressure of about 60 cm. as the gas phase. Detection involved use of thermistors to measure changes in the thermal conductivity of the effluent gases. In preparative use, amounts up to 0.7 ml. were separated on the above column. The purity of the components collected in this manner was then checked by analysis on a column similar to the one described above, except that it was constructed of 8-mm. tubing.

One of the components separated in this manner was present in appreciable quantity only in distillation fraction 1, indicating that it had a relatively low boiling point. The infrared spectrum of this component showed that it was a mixture of 1,4- and 1,5-epoxycycloöctane.[5,8] The yield, estimated by vapor phase chromatography, was 0.1%. The other component appeared in fractions 1 and 2, indicating a somewhat higher boiling point, and no information concerning its structure has been obtained except the infrared spectrum, which indicates that it is an unsaturated alcohol. The estimated yield was 1%.

**Cycloöctanediols.**—The glycol fraction obtained when the *cis*-cycloöctene oxide solvolysis products were distilled yielded *trans*-1,2-cycloöctanediol as the isopropylidine ketal (5.6%) and *cis*-1,4-cycloöctanediol (23.6%), separated by methods that have been described.[4] In the present case a residue of 9.7% (calculated as diols) did not crystallize. However, the residue consisted mostly of *cis*-1,4-cyclooctanediol as shown by the fact that short-path distillation followed by crystallization yielded additional *cis*-1,4-cyclooctanediol (corresponding to 4.5%) plus non-crystalline material that was chromatographed to give still more crystalline *cis*-1,4-cycloöctanediol. The chromatogram yielded, in addition, several non-crystalline components that were not investigated further. It is estimated that none of the non-crystalline materials was present in over-all yield of as much as 1%.

**3-Cycloöcten-1-ol.**—Authentic 3-cycloöcten-1-ol, used in the identification of the alcohols formed in the solvolysis of *cis*-cycloöctene oxide, was obtained from the phenylurethan of m.p. 101.5–102.5°, isolated from the low-boiling *cis*-cycloöctene oxide solvolysis products, known to be 3-cycloöcten-1-yl phenylurethan by ozonolysis.[6] The phenylurethan (2.3 g.) was added to 50 ml. of tetrahydrofuran containing 0.4 g. of lithium aluminum hydride. The mixture was heated under reflux for 24 hr. during which time two additional 0.4-g. quantities of lithium aluminum hydride were added. The cooled reaction mixture was diluted with 100 ml. of ether to facilitate the subsequent filtration, and 3 ml. of water was added. Filtration, followed by drying and distillation of the solvent, gave a residual liquid that was distilled through a semi-micro column, yielding 0.45 g. (38%) of 3-cycloöcten-1-ol, b.p. 68° (1.5 mm.).

*Anal.* Calcd. for $C_8H_{14}O$: C, 76.14; H, 11.18. Found: C, 76.29; H, 11.04.

The infrared spectrum of the alcohol and of the crude phenylurethan prepared from it showed that little if any 4-cycloöcten-1-ol was present in the product. The crude phenylurethan melted at 100–102° and was shown by mixed melting point and infrared spectrum to be 3-cyclooctenl-1-yl phenylurethan.

**1,4-Cycloöctanedione from *cis*-1,4-Cycloöctanediol.**—The oxidation of *cis*-1,4-cycloöctanediol to the corresponding diketone by benzoquinone in an Oppenauer-type oxidation is reported to give 15% yield.[4] The following procedure using N-bromosuccinimide[16] as the oxidizing agent gave 63% of the diketone. To *cis*-1,4-cycloöctanediol (10.5 g.) in 1500 ml. of acetone and 150 ml. of water was added 62.5 g. of N-bromosuccinimide followed by 5 ml. of glacial acetic acid. The mixture was cooled with a water-bath and allowed to stand for 2 hr. The solution was poured into 500 ml. of saturated sodium bicarbonate solution, and 200 ml. of 10% sodium thiosulfate was added. The mixture was filtered. and the filtrate was concentrated below 50° under reduced pressure and extracted with chloroform. The crude product was submitted first to short-path distillation at 1 mm. and then to fractionation through a semi-micro column, giving 6.41 g. (63%) of 1,4-cycloöctanedione, b.p. 73–76° (1 mm.). The diketone was a low-melting solid that had m.p. 46.8° after redistillation.

**1,4-Cycloöctanedione Bis-2,4-dinitrophenylhydrazone.**—The preparation of 1,4-cycloöctanedione was repeated on a small scale, except that the product from chloroform extraction was treated with 2,4-dinitrophenylhydrazine reagent. From 103 mg. of *cis*-1,4-cycloöctanediol, 361 mg. (101%) of 1,4-cycloöctanedione bis-2,4-dinitrophenylhydrazone was isolated. The product was recrystallized from nitrobenzene–ethanol to a constant melting point of 212° (introduced at 205°) and from mixed melting point and the infrared spectrum was identical with the derivative prepared from the pure diketone, although the melting point of the derivative by the latter route was higher (217.4°). Analytical data for a sample of 1,4-cycloöctanedione bis-2,4-dinitrophenylhydrazone prepared *via* oxidation of *cis*-1,4-cycloöctanediol with chromic anhydride–pyridine complex is reported elsewhere in this paper.

**1,4-Cycloöctanedione Dioxime.**—1,4-Cycloöctanedione (83 mg.) was heated under reflux with 0.5 ml. of absolute ethanol, 0.5 ml. of pyridine and 100 mg. of hydroxylamine hydrochloride for 2 hr. Evaporation of the solvent, followed by addition of water, gave 42 mg. (65%) of the dioxime. which after recrystallization from 95% ethanol melted at 169.5–170.2°.

*Anal.* Calcd. for $C_8H_{14}N_2O_2$: C, 56.45; H, 8.29. Found: C, 56.73; H, 8.30.

**Hydrogenation of 1,4-Cycloöctanedione.**—1,4-Cyclooctanedione (1.33 g.) in 4.3 ml. of 95% ethanol was hydrogenated over Raney nickel at 100° and 100 atmospheres. The crude product (1.03 g.) was chromatographed on 75 g. of neutral alumina of activity III, giving 229 mg. of *trans*-1,4-cycloöctanediol (eluted with 0.5% methanol in ether) and 231 mg. of *cis*-1,4-cycloöctanediol (eluted with 2% methanol

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(15) V. Prelog, *J. Chem. Soc.*, 420 (1950).

(16) L. F. Fieser and S. Rajagopalan, This Journal, **72**, 5530 (1950).

in ether), along with some intermediate fractions that contained both glycols.

**4-Bromo-2-cycloöcten-1-yl Acetate.**—In a typical preparation a mixture of 2-cycloöcten-1-yl acetate (8.02 g.), N-bromosuccinimide (8.50 g.), carbon tetrachloride (150 ml.) and benzoyl peroxide (0.04 g.) was heated under reflux for 20 min. After cooling, succinimide was separated by filtration, and the filtrate was washed with sodium bicarbonate solution. The solvent was removed without external heating and the residue was subjected to short-path distillation under reduced pressure followed by fractionation through a semi-micro column, giving 4-bromo-2-cycloöcten-1-yl acetate (5.08 g., 43%), b.p. 81.5° (0.27 mm.), $n^{25}\text{D}$ 1.5122.

*Anal.* Calcd. for $C_{10}H_{15}BrO_2$: C, 48.60; H, 6.12; Br, 32.35. Found: C, 48.39; H, 6.03; Br, 32.69.

**Cycloöctenediol Diacetate. A. From Tetraethylammonium Acetate.**—A solution of 4-bromo-2-cycloöcten-1-yl acetate (5.73 g.) in 75 ml. of dry acetone was heated under reflux for 20 hr. with 10 g. of tetraethylammonium acetate monohydrate. After filtration and removal of acetone under reduced pressure, water was added and the product was extracted with ether. The extract yielded 3.95 g. (75%) of cycloöctenediol diacetate upon distillation through a semi-micro column. An analytical sample had b.p. 90° (0.38 mm.), $n^{26}\text{D}$ 1.4700.

*Anal.* Calcd. for $C_{12}H_{18}O_4$: C, 63.68; H, 8.02. Found: C, 63.44; H, 8.15.

Selenious acid oxidation of *cis*-cycloöctene is reported to give 27% of cycloöctenediol diacetate of unknown stereochemistry.[17]

**Cycloöctanediols from Method A.**—Cycloöctenediol diacetate (6.32 g.) was hydrogenated over 0.21 g. of Adams platinum catalyst (which had been pre-reduced in 50 ml. of methanol) with absorption of 133% of one molar equivalent of hydrogen, indicating some hydrogenolysis of the allylic acetate. After saponification with 5 g. of sodium hydroxide and 10 ml. of water, the concentrated reaction mixture was extracted with chloroform. The dried chloroform extract yielded a glycol mixture (2.47 g., 62%, based on the unsaturated diacetate) which was crystallized from ethyl acetate. After seeding the ethyl acetate solution, 0.470 g. of *trans*-1,4-cycloöctanediol separated (19% based on the glycol mixture), m.p. 90.7–92°. Chromatography of the mother liquor resulted in isolation of cycloöctanol (10% by weight based on the glycol mixture) and additional *trans*-1,4-cycloöctanediol (4%).

**Cycloöctanediol Diacetate. B. From Silver Acetate.**—4-Bromo-2-cycloöcten-1-yl acetate (5.12 g.) was stirred overnight with 4 g. of silver acetate in 25 ml. of 100% acetic acid (prepared by adding acetic anhydride to glacial acetic acid). After separation of silver bromide, fractionation gave 2.44 g. (52.6%) of cycloöctenediol diacetate. This mixture was converted to saturated glycols as in method A. In order to separate any 1,2-cycloöctanediol that might be present, the glycol mixture was shaken with acetone and cupric sulfate.[4] Chromatography of the product on alumina resulted in isolation of *trans*-1,2-cycloöctanediol isopropylidene ketal, identified by its infrared spectrum, in a yield of 5%. A later series of chromatographic fractions consisted of *cis*- and *trans*-1,4-cycloöctanediols. The total amount of *trans*-1,4-cycloöctanediol was 0.565 g. (37% based on unsaturated diacetate), and as in the case of the 1,4-cycloöctanedione hydrogenation product, the separation of the epimeric glycols by chromatography was not complete.

**Epimerization of *cis*-1,4-Cycloöctanediol.**—*p*-Toluenesulfonyl chloride (3.8 g.) was added to a solution of *cis*-1,4-cycloöctanediol (2.88 g.) in pyridine (20 ml.). The crude monotosylate was isolated after the mixture stood overnight by pouring it into water, extracting with benzene and washing the extract with dilute hydrochloric acid and water. The crude monotosylate (5.3 g.) was allowed to react with tetraethylammonium acetate (4.5 g.) in acetone (150 ml.), first at room temperature (24 hr.) and then under reflux (24 hr.). The crude monoacetate was isolated and hydrolyzed with sodium hydroxide, giving 1.66 g. of a product that was chromatographed on alumina, separating an unsaturated alcohol fraction (270 mg.), *trans* 1,4-cycloöctanediol (605 mg., 21%) which was identified by its infrared spectrum, and *cis*-1,4-cycloöctanediol (145 mg., 5%).

**Autoxidation of 1,3-Cycloöctadiene.**—*cis-cis*-1,3-Cycloöctadiene[18] (22.3 g.) was placed in a flask connected to a gas buret and illuminated with a 275-watt sun lamp under a positive pressure of oxygen for 28 hr., with stirring. During this time 2.13 liters (40% of 1 molar equivalent) of oxygen was taken up, giving a viscous product that was reduced directly. A solution of the reaction mixture in 130 ml. of ether was added dropwise to a slurry of 7.82 g. of lithium aluminum hydride in 200 ml. of anhydrous ether, maintained below 20°. The excess lithium aluminum hydride was destroyed by addition of 40 ml. of ethyl acetate, followed by 60 ml. of saturated ammonium chloride solution. Filtration, followed by short-path distillation (0.3–0.7 mm., 90–180° bath temperature) gave 14.99 g. of low-boiling liquid and 7.79 g. of higher boiling material. The latter yielded 2.32 g. of crude glycols after redistillation and hydrogenation in the presence of pre-reduced platinum oxide. From the crude glycols there was obtained *trans*-1,2-cycloöctanediol isopropylidene ketal (0.43 g., 15%) by the method described previously under "Method B." Chromatography of the glycol residue yielded fractions amounting to 0.95 g. from which *trans*-1,4-cycloöctanediol bis-*p*-nitrobenzoate was prepared.

***trans*-2,3-Epoxycycloöctan-1-ol.**—Commercial 40% peracetic acid (12.0 ml.) to which sodium acetate trihydrate (2.4 g.) had been added to neutralize the sulfuric acid present was added to 2-cycloöcten-1-ol[13] (5.00 g.) maintained at 10–15°. The reaction mixture was made basic with excess sodium hydroxide and extracted with ether. Distillation through a semi-micro column gave 4.70 g. (84%) of *trans*-2,3-epoxycycloöctan-1-ol, b.p. 99–100° (1.8 mm.), $n^{25}\text{D}$ 1.4930.

*Anal.* Calcd. for $C_8H_{14}O_2$: C, 67.57; H, 9.93. Found: C, 67.65; H, 10.27.

**Hydrogenation of *trans*-2,3-Epoxycycloöctan-1-ol.**—Hydrogenation of a solution of 5.00 g. of *trans*-2,3-epoxycycloöctan-1-ol in ethanol in the presence of W-6 Raney nickel at 125° and 1300 p.s.i. gave 5.00 g. (99%) of a glycol mixture after short-path distillation of the product under reduced pressure. The 1,2-cycloöctanediol in the mixture was converted to the isopropylidene ketal,[4] and the latter compound (2.38 g., 75%) was isolated by distillation. The product, after chromatography on alumina, had an infrared spectrum identical with the spectrum of authentic *trans*-1,2-cycloöctanediol isopropylidene ketal and showed no bands attributable to *cis*-1,2-cycloöctanediol isopropylidene ketal. The ketal was further characterized by hydrolysis to the glycol[4] followed by conversion to the bis-*p*-nitrobenzoate.

***trans*-1,3-Cycloöctanediol.**—The glycol residue remaining after distilling the isopropylidene ketal from hydrogenation of *trans*-2,3-epoxycycloöctan-1-ol was recrystallized from benzene, giving 0.30 g. (12%) of *trans*-1,3-cycloöctanediol, m.p. 103–105°. An analytical sample that was recrystallized from benzene had m.p. 106.5–108°.

*Anal.* Calcd. for $C_8H_{16}O_2$: C, 66.62; H, 11.18. Found: C, 66.76; H, 11.11.

**Lithium Aluminum Hydride Reduction of *trans*-2,3-Epoxycycloöctan-1-ol.**—A slurry of lithium aluminum hydride (1.60 g.) in 30 ml. of ether was added to a solution of 1.5 g. of *trans*-2,3-epoxycycloöctan-1-ol in 25 ml. of ether. After 4 hr. the excess lithium aluminum hydride was destroyed by the addition of 5 ml. of ethanol, followed by concentrated sodium hydroxide. The ether layer was separated, and the aqueous layer was extracted with chloroform. Upon short-path distillation (100–130° at 1 mm.), 1.45 g. (96%) of a glycol mixture was obtained from the ether and chloroform extracts. The glycol mixture was separated in the manner described above for the hydrogenation products obtained from *trans*-2,3-epoxycycloöctan-1-ol, giving 0.65 g. (35%, based on glycols isolated) of *trans*-1,2-cycloöctanediol isopropylidene ketal, identified by its infrared spectrum, and 0.75 g. (50%) of *trans*-1,3-cycloöctanediol, m.p. 106.5–108°, undepressed on admixture with the glycol obtained by catalytic hydrogenation.

When the normal order of addition of reagents was employed, *i.e.*, when the epoxyalcohol was added to the lithium

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[17] V. D. Azatyan and R. S. Gyuli-Kevkhyan, *Doklady Akad. Nauk Armyan. S. S. R.*, **21**, 209 (1955); *C. A.*, **50**, 11257 (1956).

[18] A. C. Cope and L. L. Estes, Jr., This Journal, **72**, 1128 (1950).

aluminum hydride slurry, there was obtained 44% of *trans*-1,2-cycloöctanediol isopropylidene ketal and 31% of *trans*-1,3-cycloöctanediol, based on the weight of crude glycols, isolated in 82% yield.

**2-Cycloöcten-1-one.**—2-Cycloöcten-1-ol (5.00 g.) was dissolved in pure pentane (80 ml.) and active manganese dioxide[19] (23.5 g.) was added. After 6 hr. the slurry was filtered. The filtrate yielded 4.02 g. (82%) of a mixture of 2-cycloöcten-1-one and 2-cycloöcten-1-ol which was found to contain 59% of the ketone by comparison of the ultraviolet spectrum with the spectrum of the pure ketone.[13] Repetition of the oxidation gave 3.02 g. (62% over-all) of 2-cycloöcten-1-one of 98% purity as indicated by the ultraviolet spectrum.

**2,3-Epoxycycloöctan-1-one.**—In a modification of the method of Weitz,[20] sodium hydroxide (10 ml. of a 6 *N* solution) was added to a cooled mixture of 10 ml. of 30% hydrogen peroxide in 75 ml. of methanol. While maintaining a temperature of 0–5°, 2-cycloöcten-1-one (2.00 g.) in methanol (10 ml.) was added. After an hour the mixture was poured into 80 ml. of ice-water, and the solution was extracted with ether. The ether extract yielded 0.095 g. (5%) of recovered 2-cycloöcten-1-one, b.p. 83–84° (11 mm.), and 0.809 g. (36%) of 2,3-epoxycycloöctan-1-one, b.p. 115–116° (5 mm.). The latter compound was a solid which after sublimation had m.p. 92.0–93.0°.

*Anal.* Calcd. for $C_8H_{12}O_2$: C, 68.54; H, 8.63. Found: C, 68.46; H, 8.40.

**Oxidation of *cis*- and *trans*-1,4-Cycloöctanediol with Chromic Anhydride–Pyridine Complex.**—*cis*-1,4-Cyclooctanediol (0.100 g.) in dry pyridine (2 ml.) was added to the preformed complex[21] prepared from 0.555 g. of chromic anhydride and 6 ml. of pyridine. After stirring the mixture 30 minutes, it was allowed to stand overnight. The mixture was poured into 25 ml. of ice-water and extracted with four 40-ml. portions of chloroform. The extract was washed with dilute hydrochloric acid and dilute sodium bicarbonate and dried. Evaporation of the chloroform and treatment of the residue with 2,4-dinitrophenylhydrazine (0.270 g.) in ethanol (15 ml.) containing concentrated hydrochloric acid (5 drops) gave 1,4-cycloöctanedione bis-2,4-dinitrophenylhydrazone (0.250 g., 68%), m.p. 211.0–212.0° dec. after boiling the crude derivative with a large volume of ethanol. Recrystallization from nitrobenzene–ethanol gave an analytical sample, m.p. 211.8–212.0° (inserted at 205°).

*Anal.* Calcd. for $C_{20}H_{20}O_8N_8$: C, 48.00; H, 4.03. Found: C, 48.20; H, 4.15.

Oxidation of *trans*-1,4-cycloöctanediol (0.101 g.) by the same procedure gave 0.147 g. (42%) of 1,4-cycloöctanedione bis-2,4-dinitrophenylhydrazone, m.p. 211.3–211.5° after recrystallization from nitrobenzene–ethanol (1:1). No depression of melting point on admixture with an authentic sample was noted.

**1,3-Cycloöctanedione Bis-2,4-dinitrophenylhydrazone.**—Oxidation of *trans*-1,3-cycloöctanediol (0.100 g.) with chromic anhydride–pyridine complex followed by treatment with 2,4-dinitrophenylhydrazine as described for *cis*-1,4-cycloöctanediol gave 1,3-cycloöctanedione bis-2,4-dinitrophenylhydrazone (0.090 g., 26%), which had m.p. 233–234° (inserted at 225°) after recrystallization from nitrobenzene–ethanol.

*Anal.* Calcd. for $C_{20}H_{20}O_8N_8$: C, 48.00; H, 4.03. Found: C, 47.90; H, 4.16.

**1,2-Cycloöctanedione Bis-2,4-dinitrophenylhydrazone.**—Suberoin[4] (2.97 g.) was oxidized with cupric acetate monohydrate (8.36 g.) in methanol (2 ml.) and 50% aqueous acetic acid (20 ml.).[22] Distillation gave 1.76 g. (60%) of 1,2-cycloöctanedione, b.p. 58–60° (1 mm.), $n^{25}_{D}$ 1.4699. Part of the diketone (0.276 g.) was treated with 2,4-dinitrophenylhydrazine reagent, giving 0.970 g. (99%) of 1,2-cycloöctanedione bis-2,4-dinitrophenylhydrazone. Recrystallization from nitrobenzene gave a sample with m.p. 216.0–216.5° (dec., inserted at 210°).

*Anal.* Calcd. for $C_{20}H_{20}O_8N_8$: C, 48.00; H, 4.03. Found: C, 48.32; H, 3.96.

***p*-Nitrobenzoates.**—The *p*-nitrobenzoates of the various cycloöctenols and cycloöctanediols prepared during this study were obtained by treating the alcohols with *p*-nitrobenzoyl chloride in pyridine at room temperature for 0.5 to 3.0 hr. followed by isolation in the usual manner,[23] except that in some cases *p*-nitrobenzoic acid and other impurities were removed by passing a solution of the crude *p*-nitrobenzoate through a column of neutral alumina. The melting points and analyses of the new derivatives appear in Tables I and II.

**Di-*p*-toluenesulfonates.**—The preparations of the new di-*p*-toluenesulfonates (Table II) were similar to the one reported for *cis*-1,4-cycloöctanediol di-*p*-toluenesulfonate.[4]

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[22] H. S. Corey, Jr., Ph.D. Thesis, M.I.T., 1954.

[23] R. L. Shriner and R. C. Fuson, "The Systematic Identification of Organic Compounds," John Wiley and Sons, Inc., New York, N. Y., 1948, p. 164.

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# Proximity Effects. IX. Solvolysis of *trans*-Cycloöctene Oxide

BY ARTHUR C. COPE, ALBERT FOURNIER, JR., AND HOWARD E. SIMMONS, JR.[1]

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*trans*-Cycloöctene oxide has been prepared from *trans*-cycloöctene and peracetic acid. This oxide reacts exothermically with formic acid, forming a mixture of products that was isolated in 55% yield. Components of this mixture that have been isolated and the mole percentage of each include the following: first, products formed by a transannular hydride shift of the kind observed in previous work in this series: *trans*-1,4-cycloöctanediol, 33%; *trans*-1,3-cycloöctanediol, 1%; 4-cycloöcten-1-ol, 12%. In addition, three compounds formed by ring contraction were isolated. These were hexahydro-*o*-tolualdehyde (isolated as the acid), 25%; a liquid glycol $C_8H_{16}O_2$ (A) containing a C-methyl group, 16%; a second liquid glycol $C_8H_{16}O_2$ (B), also containing a C-methyl group, 13%.

*trans*-Cycloöctene oxide has been described by Ziegler and Wilms,[2] who prepared it from a sample of cycloöctene that is now known to be a mixture of *trans*- and *cis*-cycloöctene in a ratio of approximately 3:2.[3] In this work, *trans*-cycloöctene oxide was prepared from the pure *trans*-olefin and peracetic acid in 93% yield. Unlike *cis*-cycloöctene oxide, which is a crystalline solid, the *trans*-oxide is a liquid; differences in its infrared spectrum from the spectrum of the *cis*-oxide show that it is not contaminated by the *cis* isomer, and vapor phase chromatography indicated that the oxide prepared in this way is homogeneous.

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[1] National Science Foundation Fellow, 1953–1954.

[2] K. Ziegler and H. Wilms, *Ann.*, **567**, 1 (1950).

[3] A. C. Cope, R. A. Pike and C. F. Spencer, THIS JOURNAL, **75**, 3212 (1953).