Discussion

The results of these experiments, limited though they are, lead to one or two interesting conclusions. The very low rate of isomerization of the olefin indicates that if the rapid initial absorption of olefin occurs through a carbonium ion intermediate, then the carbonium ion formation is not reversible. This conclusion, though seemingly contrary to the usual concepts of organic chemistry, was also forced upon Price and Berti[5] by their studies of the BF_3–D_2O catalysis of stilbene polymerization and upon Purlee and Taft[6] by their observations of the hydration of olefins in sulfuric acid solutions. It is a particularly difficult conclusion in the present case because 2-butene does not polymerize rapidly and it is difficult to conceive of other reactions which could remove the carbonium ion as rapidly as it forms. However, as two or three molecules of butene seem to be taken up very rapidly, stabilization of a carbonium ion is not impossible. Taft, *et al.*,[7] suggested as a solution to this problem that the initial reaction product is a π-complex which then slowly isomerizes, in a rate-controlling step, to a carbonium ion which undergoes further rapid reaction. However, this view is directly opposite to that of Evans and co-workers (see below) who believe that an initially formed carbonium ion isomerizes to a π-complex.

The other interesting feature of the perchloric acid–butene reaction is, of course, the strong absorption spectrum. Evans and co-workers[8] have observed rather similar spectra in the dimerization of a number of diphenylethylenes in the presence of a series of strong acids and have presented strong evidence for their belief that the initially formed chromophore is a classical carbonium ion. This ion, they suggest, then isomerizes to a colored π-complex. It is possible that the butene spectra are of a similar type and, if so, their weaker intensity may be attributed to the lower basicity of the butene with a resulting less favorable equilibrium even with the very strong acids required to produce color. This argument, however, is a dangerous one because we have, as yet, no evidence directly relating the colored compounds to a reaction process. Furthermore, the visible color of carbonium ions is always attributed to resonance in the aromatic system and it is by no means certain that aliphatic carbonium ions would show it; certainly, the displacement toward shorter wave lengths in the present case seems small for the replacement of two aryl groups by alkyls. We have recently noted[9] in the reaction of alkyl vinyl ethers with boron fluoride the formation of intense colors which undergo an astonishing series of changes and which may be related to the present case, but we have no explanation for them either. It is possible, perhaps, that all of these spectra are of the charge-transfer type.

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[5] C. C. Price and G. Berti, This Journal, **76**, 1219 (1954).

[6] E. L. Purlee and R. W. Taft, *ibid.*, **78**, 5807 (1956).

[7] R. W. Taft, E. L. Purlee, P. Riesz and C. A. DeFazio, *ibid.*, **77**, 1584 (1955).

[8] A. G. Evans, N. Jones and J. H. Thomas, *J. Chem. Soc.*, 1824 (1953); A. G. Evans, N. Jones, P. M. S. Jones and J. H. Thomas, *ibid.*, 2757 (1956).

[9] G. L. Latremouille, G. T. Merrall and A. M. Eastham, This Journal, **82**, 120 (1960).

[Contribution No. 1600 from the Sterling Chemistry Laboratory of Yale University, New Haven, Conn.]

The Epoxidation of Some Allylic Alcohols[1,2]

By Martin L. Sassiver and James English

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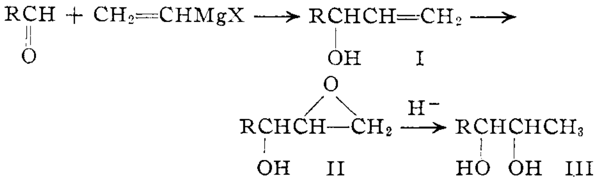
The composition of the mixtures of stereoisomers produced on epoxidation of a series of allylic alcohols ($RCHOHCH{=}CH_2$) has been determined.

During the course of some other research we became interested in the steric course of the epoxidation by peracids of substituted allylic alcohols of the type I.



$$\underset{\underset{\displaystyle O}{\|}}{RCH} + CH_2{=}CHMgX \longrightarrow \underset{\underset{\displaystyle OH}{|}}{RCH}CH{=}CH_2 \ \text{I} \longrightarrow \underset{\underset{\displaystyle OH}{|}}{RCH}\overset{O}{\overbrace{CH{-}CH_2}} \ \text{II} \xrightarrow{H^-} \underset{\underset{\displaystyle HO}{|}}{RCH}\underset{\underset{\displaystyle OH}{|}}{CH}CH_3 \ \text{III}$$

Henbest and Wilson[3] have observed a marked effect of the free OH group on the stereochemistry and rate of epoxidation of some cyclic analogs of I. Epoxidations also are known in the sterol and carbohydrate fields in which the stereochemistry of cyclic allylic alcohol groups has been elucidated.[4]

Since there seems to have been no recorded study of simple aliphatic allylic alcohols from this point of view, a series of models (I) were prepared in which R was methyl, ethyl, isopropyl and *t*-butyl. All of the carbinols (I) were known compounds and were synthesized by the reaction of the appropriate aldehyde with vinylmagnesium chloride or bromide. The alkylvinylcarbinols were epoxidized with an excess of monoperphthalic acid in ether for about 48 hours, during which time an equivalent of peracid was consumed. The reaction mixtures were quenched in cold alkali and extracted with ether to give about 50% yields of

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[1] Taken from the dissertation presented by Martin L. Sassiver to the Graduate School of Yale University in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[2] This work was supported by the United States Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command under Contract No. AF 49(638)37.

[3] H. B. Henbest and R. A. Wilson, *J. Chem. Soc.*, 1958 (1957).

[4] P. A. Plattner, H. Heusser and A. B. Kulkarni, *Helv. Chim. Acta*, **32**, 265 (1949); R. Albrecht and C. Tamm, *ibid.*, **40**, 2216 (1957); T. Posternak and H. Friedli, *ibid.*, **36**, 251 (1953); B. Helferich, *Adv. in Carbohydrate Chem.*, **7**, 219 (1952).

mixtures of *threo-* and *erythro*-1,2-epoxy-3-alkyl-3-propanols (III). Although these stereoisomeric mixtures of epoxy-alcohols could be fractionated from non-stereoisomeric impurities by vapor phase chromatography (V.P.C.), this technique was not successful in separating the *threo* and *erythro* components from each other. Therefore the mixtures of *threo-* and *erythro*-epoxy alcohols were reduced with a large excess of lithium aluminum hydride (in approximately 60% yields) to the corresponding mixtures of *threo-* and *erythro*-1-alkyl-1,2-propanediols. A satisfactory resolution of the resulting mixtures of *threo-* and *erythro*-diols was achieved through the use of a 10 ft. Ucon-polar column.[5]

Independent syntheses of *threo-* and *erythro*-1-isopropyl-1,2-propane-diols (I, R = isopropyl) by *cis*-hydroxylation of the known *cis-* and *trans*-4-methyl-2-pentenes[6] served to identify this pair of isomers. Their infrared spectra and V.P.C. retention times were compared with the fractions from hydride reduction of the mixture of epoxides. Authentic *threo-t*-butyl-1,2-propanediol also was prepared in the same way from *trans*-4,4-dimethyl-2-pentene. In both cases the *erythro* isomer showed the greater retention time in the vapor phase analysis. The identities of the *erythro-* and *threo*-methyl- and ethylcarbinols (I, R = CH_3, R = C_2H_5) were deduced by analogy with the isopropyl and *t*-butyl cases from their V.P.C. behavior under the same conditions.

Since the yields of epoxide mixtures were less than quantitative, an experiment was carried out to determine the effect, if any, of these losses on the *erythro–threo* isomer ratio in the final diols. A sample of the mixture of isomeric oxides (II) from epoxidation of 4-methyl-1-pentene-3-ol (I), R = isopropyl), found by reduction and V.P.C. analysis to be 64% *threo* and 36% *erythro*, was submitted to the action of perphthalic acid under the standard conditions and worked up in the usual manner. A loss of about 25% of the epoxide mixture was observed, presumably from solubility,[3] hydrolysis, cleavage[7] or polymerization; the *erythro–threo* ratio in the reduction products was, however, essentially unchanged (62% *threo*, 38% *erythro*). Hence, it is felt that destruction of epoxides at this stage is not stereoselective and that the observed ratios of diols represent those produced during epoxidation.

The epoxides (II) were reduced completely by treatment with lithium aluminum hydrides since no unchanged material could be detected in the infrared or by V.P.C. analysis. The less than quantitative recovery of diols is attributed to the water-soluble nature of these substances. No evidence for 1,3 diols or other side products could be obtained except for faint carbonyl bands in the infrared in some samples. Eliel and Delmonte[8] found in analogous situations that hydride attack under our conditions occurs exclusively at the primary carbon.

The results of determinations of isomer ratios are shown in Table I.

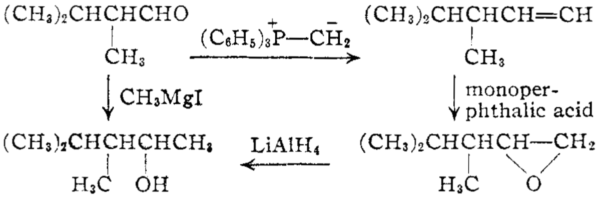
TABLE I

EPOXIDATION OF ALLYLIC ALCOHOLS (I)

R	Yield of II mixture,[a] %	Yield of III mixture,[a] %	*threo*-III, %	*erythro* III, %
CH_3	41	55	61	39
C_2H_5	54	60	60	40
i-C_3H_7[b]	56–68	70–84	62–68	32–38
t-C_4H_9	64	60	56	44

[a] Based on V.P.C. purified material. [b] Variations observed in several runs using different work-up procedures. Duplicate experiments were reproducible to ±2% in % yield of *threo-* and *erythro*-III.

Since the variations in R had relatively small effect on the *erythro–threo* ratio, it seemed of interest to replace the OH group in I by a non-polar group of comparable bulk. To this end 3,4-dimethyl-1-pentene was synthesized as shown from 2,3-dimethylbutanal[9] by the Wittig[10] procedure. The isomeric 3,4-dimethyl-2-pentanols also were prepared by the action of methylmagnesium bromide on this aldehyde. In a series of reactions, outlined above, similar to those carried out with the alkylvinylcarbinols, 3,4-dimethyl-1-pentene was epoxidized with monoperphthalic acid, and the stereoisomeric mixture of epoxides so produced was reduced with lithium aluminum hydride to a mixture of *threo-* and *erythro*-3,4-dimethyl-2-pentanols. These alcohols were resolved on a 10-ft. Ucon-polar V.P.C. column and found to consist of a mixture of 48% *threo*:52% *erythro* isomer. The 3,4-dimethyl-2-pentanols independently synthesized by the reaction of methylmagnesium iodide with methylisopropylacetaldehyde were produced in a 67%:33% mixture of stereoisomers. The major component was assigned the *erythro* configuration, and the minor component was assigned the *threo* configuration, after Cram's rule.[10,11]



It should be noted that the epoxidation of 3,4-dimethylpentene-1 resulted in only 23% yield, which may be attributed to the very small scale on which the reaction was run, necessitating fairly dilute concentrations of the reactants. Barring stereospecific side-reactions, which were shown to be absent in the alkylvinylcarbinol epoxidations, the stereochemical results are felt to be independent of yield, since epoxidation reactions have been demonstrated to be kinetically controlled.[12]

It seems worthy of note that although the Grignard addition to 2,3-dimethylbutanal shows con-

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[5] This material was obtained from the Wilkens Instrument and Research Co., Walnut Creek, Calif.

[6] From Phillips Petroleum Co.

[7] V. I. Pansevitch-Kolyada, *J. Gen. Chem., U.S.S.R.*, **26**, 1343 (1946).

[8] E. L. Eliel and D. W. Delmonte, THIS JOURNAL, **80**, 1744 (1958).

[9] R. A. Barnes and W. M. Budde, *ibid.*, **68**, 2339 (1946).

[10] D. J. Cram and F. A. Abd Elhafez, THIS JOURNAL, **74**, 5828 (1952).

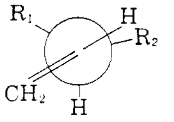
[11] I. Elphimoff-Felkin and H. Felkin, *Bull. soc. chim. France*, 450 (1957).

[12] D. Swern, *Org. Reactions*, **7**, 378 (1953).

siderable (67:33) stereospecificity, the formally analogous addition of oxygen to 3,4-dimethyl-1-pentene gave nearly a 50:50 mixture. This would support Cram's assignment of a large effective bulk to the carbonyl oxygen in aldehydes in their reaction with Grignard reagents.

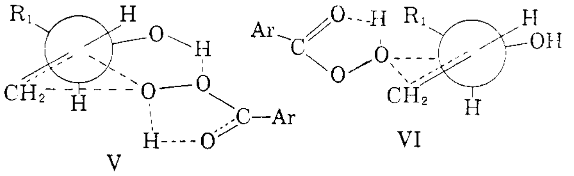
The fact that a degree of stereospecificity is observed with the allylic alcohols examined and not with 3,4-dimethyl-1-pentene leads to the speculation that here, as in the cases examined of Henbest and Wilson,[3] the peracid may be involved with the hydroxyl group in the formation of an intermediate prior to epoxidation.

Assuming, from the postulations of Zimmerman and Chang,[13] that the preferred conformation of the allylic alcohols is as shown IV, we are led to suggest that the interaction between the peracid molecule and the hydroxyl group makes the *threo*-producing intermediate, or transition state V, favored with respect to the *erythro*-producing conformation VI



IV

$R_1 = CH_3, C_2H_5, i\text{-}C_3H_7, t\text{-}C_4H_9$
$R_2 = CH_3, OH$



V VI

threo-Isomer predominance might be predicted on steric grounds alone, without the intervention of peracid–hydroxyl interaction, since conformation V apparently is less hindered than conformation VI. However it would then be difficult to accommodate the lack of stereospecificity observed in the case of the hydrocarbon IV ($R_1 = i\text{-}C_3H_7$, $R_2 = CH_3$), since the stereochemical interactions in this instance would be very similar to those encountered in the epoxidation of isopropylvinylcarbinol. Therefore we are led to the conclusion that the energy differences between V and VI are due primarily to the availability of the hydroxyl group to the attacking peracid molecule in V, and its non-availability in VI.

Experimental[14]

Alkylvinylcarbinols.—The alkylvinylcarbinols described below were made by the reaction of vinylmagnesium bromide[15] or vinylmagnesium chloride[16] with the appropriate aldehyde. Acetaldehyde and propionaldehyde were freshly distilled, isobutyraldehyde was used as supplied, and pivaldehyde was synthesized by the method of Campbell.[17] All of the alkylvinylcarbinols showed a strong band at *ca.* 10.9 mμ, and their purity was determined by V.P.C. Both methylvinylcarbinol and ethylvinylcarbinol were found to be contaminated with varying amounts of lower-boiling substances, but these substances did not appear to interfere with the subsequent experiments.

TABLE II

ALKYLVINYLCARBINOLS, $RCHOHCH{=}CH_2$

R	Yield, %	Purity, %	B.p. °C.	B.p. Mm.	Lit. bp. °C.	Lit. bp. Mm.
CH_3	40	68	90–100	760	93–95	760[18]
C_2H_5	47	71	100–108	760	74–75	700[18]
$i\text{-}C_3H_7$	60	90	53–59	45	124–125	760[19]
$t\text{-}C_4H_9$	55	94	62–65	45	51–52	25[19]

1,2-Epoxy-3-alkyl-3-propanols.—The alkylvinylcarbinol was added to an ethereal solution of monoperphthalic acid[20] at room temperature. A slight warming of the reaction mixture was noted, but cooling was not required. The stoppered reaction flask was wrapped in aluminum foil and stored at room temperature. The uptake of peracid was followed by iodometric titration of aliquots of the reaction mixture; about 24 to 36 hours was required for complete reaction. Workup was accomplished by filtering off the precipitated phthalic acid and pouring the filtrate into 2 volumes of excess, cold saturated potassium carbonate solution containing some dissolved sodium thiosulfate. The two-phase system was shaken vigorously until the ether layer was neutral to *p*H paper and non-oxidizing to starch–iodide paper. The ether layer was separated and the aqueous layer was extracted with several portions of ether (total volume of ether equal to the original organic layer). The combined ether extracts were dried over sodium sulfate and distilled at atmospheric pressure to remove the ether. The residue was distilled *in vacuo* to yield a stereoisomeric mixture of the 1,2-epoxy-3-alkyl-3-propanols. The products were analyzed by V.P.C. and analytical samples were obtained by this technique. In the following descriptions, the percentage purity of the epoxy-alcohols represents the purity of the stereoisomeric mixtures, relative to other materials present in the vapor phase chromatograms. Concerning these analyses, it was found that a V.P.C. column with a detergent substrate at 98–125° was the only one of several columns which was successful in purifying the epoxy-alcohols. These rather sensitive materials could not be eluted from Ucon-polar or Apiezon columns, and were quite strongly adsorbed and partially rearranged by a silicone column.

Further Experiments on the Epoxidation of Isopropylvinylcarbinol.—The monoperphthalic acid epoxidation of isopropylvinylcarbinol was repeated exactly as described above, and the reaction mixture was divided into two equal parts. Part one was worked up by the previously described alkaline quench procedure, giving a 68% yield of a stereoisomeric mixture of 1,2-epoxy-3-isopropyl-3-propanols and a still-pot residue of 4.7% (by weight). An aliquot of the aqueous work-up solution was continuously extracted with ether for 3 days to yield 3% of an impure oily residue. A periodic acid titration of an aliquot of the acidified work-up solution showed the presence of 3% of periodic acid-consuming material, based upon the molecular weight of isopropylglycerol, a postulated product of epoxide cleavage.

Part two was worked up after the method of Henbest and Nicholls[9] by adding solid calcium hydroxide to the reaction mixture and stirring for 24 hours. At that time a negative starch–iodide test and a neutral *p*H paper test were observed. The mixture was filtered and the solids were washed with three 75-ml. portions of dry ether. The combined ether solution was distilled at atmospheric pressure to remove the solvent, and the residue was distilled *in vacuo* to give 63% yield of a stereoisomeric mixture of 1,2-epoxy-3-isopropyl-3-propanols and 10% of a stillpot residue.

A 4-g. portion of the epoxy-alcohol mixture isolated in part one was added to an ether solution containing one equivalent (based upon epoxide) each of monoperphthalic acid (dissolved) and phthalic acid (undissolved). No consumption of peracid was noted after 36 hours, at which

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[13] H. E. Zimmerman and W. H. Chang, THIS JOURNAL, **81**, 3636 (1959).

[14] Percentage purity of liquids was determined by vapor phase chromatography, V.P.C.

[15] H. Normant, *Compt. rend.*, **239**, 1510 (1954).

[16] H. E. Ramsden, *J. Org. Chem.*, **22**, 1602 (1957).

[17] K. N. Campbell, THIS JOURNAL, **59**, 1980 (1937).

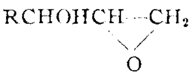
[18] J. Wieman and J. Gardan, *Bull. soc. chim. France*, 433 (1958).

[19] M. B. Green and W. J. Hickinbottom, *J. Chem. Soc.*, 3268 (1957).

[20] E. E. Royals and L. L. Harrell, Jr., THIS JOURNAL, **77**, 3405 (1955).

TABLE III

1,2-EPOXY-3-ALKYL-3-PROPANOLS,



$RCHOHCH{-}CH_2$ (O bridging CH and CH_2)

R	Yield, %	Purity, %	B.p. °C.	B.p. Mm.	n^{25}	Carbon, % Calcd.	Carbon, % Found	Hydrogen, % Calcd.	Hydrogen, % Found
CH_3	41	84	76–80	45	1.4228	54.53	54.33	9.15	9.37
C_2H_5	54	82	80–86	37	1.4327	58.80	58.78	9.87	9.81
i-C_3H_7	56	80	82–90	42	1.4358	62.04	61.88	10.41	10.45
t-C_4H_9	64	90	60–68	11	1.4379	64.58	64.50	10.84	10.91

time the reaction was worked up in the manner described for part one to give a 75% recovery of epoxy-alcohols and 1.5% of a still-pot residue.

Lithium Aluminum Hydride Reduction of the 1,2-Epoxy-3-alkyl-3-propanols.—An ether solution of the 1,2-epoxy-3-alkyl-3-propanol isomer mixture was added dropwise to a well-stirred suspension of lithium aluminum hydride in ether, and the reaction mixture was stirred at room temperature for 24 hours, at which time it was decomposed by addition of excess ethyl acetate, followed by ethanol and water. The decomposed mixture was incompletely neutralized by pouring it into *ca.* 100 ml. of cold saturated ammonium sulfate solution. The ether layer was separated and the aqueous layer was extracted with two 100-ml. portions of ether. The combined ether extract was dried over sodium sulfate and distilled at atmospheric pressure to remove the solvent. The residue was distilled *in vacuo* to yield the stereoisomeric mixture of 1-alkyl-1,2-propanediols. The products were analyzed by V.P.C. and analytical samples were obtained by this method. It should be noted that both the detergent and Ucon-polar columns were satisfactory for the purification of the diols, but only the latter substrate effected resolution of the *threo*- and *erythro*-diols. By use of a 10-ft. Ucon polar column at 155–160°, a satisfactory resolution of these isomers could be achieved.

Even under optimum conditions, however, a complete separation the V.P.C. peaks was not achieved. An extrapolation of the curve of the more rapidly eluted *threo* isomer into that of the *erythro* isomer was carried out based on the observed shape of the curve of the pure, independently synthesized *erythro* form (R = *i*-propyl, *t*-butyl) in order to obtain a quantitative estimate of the composition. Figure 1 shows a typical V.P.C. curve; variations in the extrapolation method had only a minor effect on the isomer ratios.

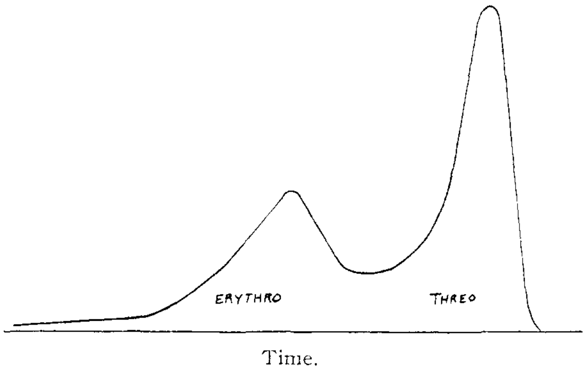
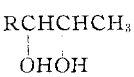


Fig. 1.

threo-**1-Isopropyl-1,2-propanediol.**—A solution of potassium permanganate (80 g., 0.5 mole) in water (1500 ml.) was added slowly to a rapidly stirred, ice-cooled suspension of *trans*-4-methylpentene-2 [42 g., 0.5 mole, Phillips 95% grade) in water (400 ml.) over a 3-hour period. After the reaction stood at room temperature overnight, the precipitated manganese dioxide was filtered off and the filtrate was saturated with potassium carbonate (with cooling). The water was extracted with four 100-ml. portions of ether. The ether was dried over sodium sulfate and distilled off at atmospheric pressure, leaving a residue which was distilled to give *threo*-1-isopropyl-1,2-propanediol, 11 g. (18%), b.p. 86–90° (11 mm.), which solidified in the receiver. Several recrystallizations from hexane gave white needles, m.p. 59–59.7°.

TABLE IV

1-ALKYL-1,2-PROPANEDIOLS,



$RCH(OH)CH(OH)CH_3$

R	Yield, %	Purity, %	B.p. °C.	B.p. Mm.	$n^{25}D$	% *threo*	% *erythro*
CH_3[21]	55	99	60–62	3	1.4311	61	39
C_2H_5[22]	60	98	55–57	2	1.4370	60[a]	40[b]
i-C_3H_7[23]	71	95	90–92	11	....	63[c]	37[c]
t-C_4H_9	60	..	....			56[d]	44[e]

[a] $n^{25}D$ 1.4345. [b] $n^{25}D$ 1.4353. [c] Identical in infrared to synthetic samples below. [d] M.p. 76–77.5°. *Anal.* Calcd. for $C_7H_{16}O_2$: C, 63.59; H, 12.20. Found: C, 63.76; H 12.11. [e] M.p. 72°. Found: C, 63.48; H, 11.97.

Anal. Calcd. for $C_6H_{14}O_2$: C, 60.98; H, 11.94. Found: C, 61.41; H, 12.00.

erythro-**1-Isopropyl-1,2-propanediol.**—In a manner similar to the procedure described for the *threo* compound, potassium permanganate hydroxylation of *cis*-4-methylpentene-(Phillips 95% grade) gave *erythro*-1-isopropyl-1,2-propanediol, 13%, b.p. 86–88° (11 mm.), which was recrystallized several times from hexane to give the solid diol, m.p. 49–49.5°.

Anal. Found: C, 61.38; H, 12.07.

threo-*t*-**Butyl-1,2-propanediol.**—*trans*-4,4-Dimethylpentene-2 was synthesized by the pyrolysis of 3-acetoxy-4,4-dimethylpentane, after the procedure of Cramer and Miller.[24] A mixture of olefins was obtained, b.p. 73–76°, which was shown by V.P.C. to contain 78% of the *trans*-olefin (30% yield), $n^{23}D$ 1.3968, strong *trans*-double bond absorption at 10.3 μ (reported[2] b.p. 76.6–76.7° (760 mm.), $n^{20}D$ 1.3983).

trans-4,4-Dimethylpentene-2 (0.386 g., 0.004 mole), dissolved in an equal volume of benzene, was added to osmium tetroxide (0.5 g., 0.002 mole) dissolved in 20 ml. of benzene containing 1 ml. of pyridine. The reaction turned black instantly and was kept in a stoppered, aluminum foil-wrapped flask for 22 hours. It was decomposed by adding water (35 ml.), sodium sulfate (4 g.), sodium bicarbonate (4 g.) and methanol (25 ml.) and stirring the mixture for 5 hours. Then chloroform (150 ml.) was added and the mixture was stirred for 30 min. The chloroform layer was separated and the aqueous layer was extracted with two 100-ml. portions of chloroform. The combined chloroform extract was washed with saturated salt solution and dried over sodium sulfate. The chloroform was evaporated, leaving a residue which was recrystallized from hexane to give *threo*-1-*t*-butyl-1,2-propanediol, white needles, 0.06 g. (23%), m.p. 77.5–78.5°, identical with the previously isolated *threo*-1-*t*-butyl-1,2-propanediol by mixed m.p., infrared spectrum and V.P.C. criteria.

Ethyl Methylisopropylcyanoacetate.—Following the published method for the synthesis of ethyl ethylisopropylcyanoacetate,[25] ethyl isopropylcyanoacetate[26] (80 g., 0.516 mole) was added to a solution of sodium (12.5 g., 0.543 mole) in absolute ethanol (150 ml.). To the resulting red solution was added 10% excess methyl iodide (87 g., 0.6 mole) at a rate sufficient to control the exothermic reaction (30 min.) The reaction was run in a closed system under a

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[21] C. E. Wilson and H. J. Lucas, THIS JOURNAL, **58**, 2400 (1936).

[22] H. J. Lucas, M. J. Schlatter and R. C. Jones, *ibid.*, **63**, 22 (1941).

[23] E. D. Bergmann, *J. Appl. Chem.*, **1**, 380 (1951), reported a mixture of these isomers.

[24] P. L. Cramer and V. A. Miller, THIS JOURNAL, **62**, 1452 (1940).

[25] E. Fischer, H. Rohde and F. Browns, *Ann.*, **402**, 364 (1914).

[26] E. Fischer and F. Flateau, *Ber.*, **42**, 2983 (1909).

condenser fitted at its top with a balloon to minimize the loss of volatile methyl iodide. After addition was complete, the reaction was refluxed for 15 hours and allowed to stand at room temperature for an additional 24 hours. At this time an aliquot of the reaction mixture tested neutral to *p*H paper. The mixture was distilled (finally at the water-pump) to remove ethanol. The residue was thinned with water to dissolve the sodium iodide, and extracted several times with a total of 500 ml. of ether. The ether was dried over sodium sulfate and distilled at atmospheric pressure to remove the solvent. The residue was distilled to give ethyl methylisopropylcyanoacetate, 73.2 g., 85% pure (67% yield), b.p. 98–102° (17 mm.), $n^{25}\mathrm{D}$ 1.4222.

Methylisopropylacetonitrile.—Ethyl methylisopropylcyanoacetate (61 g., 85% pure, 0.0306 mole) was added to a solution of 126 ml. of 50% potassium hydroxide (0.92 mole) in methanol (total volume 930 ml. before addition of ester and 995 ml. after addition). After 12 hours at room temperature, titration of an aliquot of the solution showed the hydrolysis was complete. The reaction was worked-up after an additional 12 hours (no change in titer) by adding water (150 ml.) and removing the methanol at the water-pump without heat. The residue was extracted with ether (100 ml.) to remove organic impurities. The water layer was acidified with 50% sulfuric acid and extracted with three 300-ml. portions of ether. The ether was dried over sodium sulfate and removed at the water-pump. Methylisopropylcyanoacetic acid was obtained as a crude oily residue and decarboxylated at 190° for 4 hours, during which time methylisopropylacetonitrile was collected as an impure distillate. The product was taken up in ether, washed with potassium carbonate solution, and dried over sodium sulfate. The ether was removed at atmospheric pressure and the residue was distilled to give methylisopropylacetonitrile, 19.6 g., 92% pure (61% yield), b.p. 55–65° (28 mm.), $n^{25}\mathrm{D}$ 1.3992.

Methylisopropylacetaldehyde.—Lithium aluminum hydride reduction was carried out after the procedure of Smith and Rogier.[27] The lithium aluminum hydride solution was standardized by the method of Felkin.[28] A solution of lithium aluminum hydride (0.0267 mole) in ether (55 ml.) was added dropwise to a well-stirred solution of methylpropylacetonitrile (8 g., 92% pure, 0.076 mole) in ether (30 ml.), cooled in a Dry Ice–acetone-bath. After addition was complete (40 min.) the reaction was stirred for 15 min. in the cold and for 30 min. at room temperature. It was decomposed by adding a slight excess of 10% sulfuric acid. The ether layer was separated and the aqueous layer was extracted with two 75-ml. portions of ether. The combined ether extract was dried over sodium sulfate and distilled through a 46 × 0.6 cm. Podbielniak column to remove the ether. The residue was distilled through a 10 × 0.25 cm. Podbielniak column to give methylisopropylacetaldehyde, 2.35 g., 75% pure (23% yield), (contaminated with *ca.* 25% of the nitrile), b.p. 115–120°; 2,4-dinitrophenylhydrazone, m.p. 118–120° (reported[29] b.p. 112–114°; 2,4-dinitrophenylhydrazone, m.p. 119–121°).

Independent Synthesis of *threo*- and *erythro*-3,4-Dimethyl-2-pentanols.—Methylisopropylacetaldehyde (0.28 g., 80% pure, 0.0224 mole) dissolved in 5 ml. of ether was added to a Grignard reagent prepared from methyl iodide (3.6 g., 0.025 mole), magnesium (0.6 g., 0.025 mole) and ether (20 ml.). After being stirred overnight at room temperature, the reaction mixture was incompletely neutralized with cold ammonium sulfate solution and extracted with 100 ml. of ether. The ether was dried over sodium sulfate and distilled at atmospheric pressure to remove the solvent. The residue was distilled in a small Claisen flask to give a stereoisomeric mixture of 3,4-dimethyl-2-pentanols, 0.14 g., 78% pure (42% yield), b.p. 75–80° (49 mm.), containing 67% of one isomer and 33% of a less-rapidly eluted isomer by V.P.C. analysis (105° Ucon polar). The major component was assigned the *erythro* configuration after Cram's rule. An analytical sample of the *erythro* isomer was obtained by V.P.C.

Anal. Calcd. for $C_7H_{16}O$: C, 72.35; H, 13.88. Found: C, 72.20; H, 13.95.

3,4-Dimethylpentene-1.—To an ether solution (40 ml.) of redistilled methylisopropylacetaldehyde (1.5 g., 95% pure, 0.0143 mole) was added slowly the Wittig reagent, prepared by the modification of Bergmann and Dusza[10] from triphenylphosphine methyl bromide (7.14 g., 0.02 mole), ether (75 ml.) and butyllithium (12.5 ml. of 1.39 *N* solution, 0.0175 mole). After addition of the aldehyde, more ether was added to the reaction vessel (pressure flask) to facilitate the magnetic stirring of the heavy suspension. After 1 hour at room temperature and 3 hours at 65° (capped pressure flask) the reaction mixture was decomposed by the addition of wet ether. The triphenylphosphine oxide precipitate was filtered off and washed with ether. The combined filtrate and wash ether solution was dried over sodium sulfate and carefully fractionated, first through a 46 × 0.6 cm. Podbielniak column, and then through a 10 × 0.25 cm. Podbielniak column to give 1 g. of a mixture of ether, benzene and 3,4-dimethylpentene-1, b.p. 75–80° (760 mm.). the composition of which was determined by V.P.C. and infrared to be 11.5% ether, 48.9% olefin (35% yield) and 39.7% benzene. An analytical sample of pure olefin, collected by V.P.C., showed $n^{25}\mathrm{D}$ 1.3978, infrared 10.99 μ (strong), (reported[30] b.p. 80.8° (760 mm.), $n^{25}\mathrm{D}$ 1.3995, no analysis given).

Anal. Calcd. for C_7H_{14}: C, 85.63; H, 14.37. Found: C, 85.76; H, 14.37.

***threo*- and *erythro*-1,2-Epoxy-3,4-dimethylpentanes *via* Peroxidation of 3,4-Dimethylpentene-1.**—An ether–benzene–olefin mixture containing 0.372 g. (0.00397 mole) of 3,4-dimethylpentene-1 was dissolved in 6 ml. of ether and added to monoperphthalic acid (0.00535 mole) in ether (16 ml.). The reaction mixture was stored at room temperature for 94 hours. Titration of aliquots of the mixture showed the following consumption of peracid: 9.5 hours, 0.22 equiv.; 22.5 hours, 0.39 equiv.; 48.5 hours, 0.59 equiv.; 70 hours, 0.65 equiv.; 94 hours, 0.787 equiv. The reaction was worked-up in the standard manner. The ether extract was dried over sodium sulfate and distilled through a 46 × 0.6 cm. Podbielniak column, leaving a residue which was distilled in a small Claisen flask to give 0.343 g. of a distillate. The composition of this distillate, as determined by infrared and V.P.C. was 32% ether, 45% benzene plus 3,4-dimethylpentene-1 and 23% of a stereoisomeric mixture of 1,2-epoxy-3,4-dimethylpentanes. Based upon unrecovered olefin, the yield of the epoxide mixture was 26%. The infrared spectrum of the V.P.C. peak attributed to 1,2-epoxy-3,4-dimethylpentanes had no band at 10.99 μ, but did show several medium bands in the 10.75–12 μ region. The epoxide mixture was not further characterized, but was used directly in the next experiment.

Lithium Aluminum Hydride Reduction of the Mixture of Stereoisomeric 1,2-Epoxy-3,4-dimethylpentanes.—The 1,2-epoxy-3,4-dimethylpentane mixture obtained above (0.150 g., containing 0.035 g. of stereoisomeric epoxides, 0.000306 mole) was added to a stirred supension of lithium aluminum hydride (0.2 g., 0.0053 mole) in ether (3 ml.). After being stirred for 24 hours at room temperature, the reaction mixture was decomposed and worked up in the usual manner. The ether extract was dried over sodium sulfate and most of the solvent was removed by distillation through a 10 × 0.25 cm. Podbielniak column, leaving 0.187 g. of residue which was analyzed by V.P.C. without further purification. This residue contained 13% (70% yield) of a mixture of *threo*- and *erythro*-3,4-dimethyl-2-pentanols consisting of 52% *erythro*- and 48% *threo*-alcohols. These compounds were shown to be identical with the authentic alcohols described above, by V.P.C. and infrared comparisons.

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[27] L. I. Smith and E. R. Rogier, THIS JOURNAL, **73**, 4047 (1951).

[28] H. Felkin, *Bull. soc. chim. France*, 347 (1951).

[29] R. A. Barnes and W. M. Budde, THIS JOURNAL, **68**, 2339 (1946).

[30] A. I. M. Keulemans, *Rec. trav chim.*, **67**, 298 (1948), partially characterized this olefin.