[CONTRIBUTION FROM THE RESEARCH AND DEVELOPMENT DEPARTMENT OF THE CARBIDE AND CARBON CHEMICALS CORPORATION]

The Reaction of Propylene Oxide with Alcohols

BY H. C. CHITWOOD AND B. T. FREURE

The alcoholysis of propylene oxide may take one of two courses, yielding either a primary or a secondary monoalkyl ether of propylene glycol. The literature contains a number of reactions of this type, but the available information is unspecific and sometimes contradictory. In a series of seven uncatalyzed alcoholyses Davidson[1] believed he obtained primary ethers, although the structures were not established, whereas Cox, Nelson and Cretcher[2] obtained both possible *n*-propyl ethers in the absence of catalysts. Acid catalyzed alcoholysis has been assumed to yield the primary ethers[3,4]; basic catalysts for the alcoholysis of olefin oxides have been mentioned in a number of patents,[5,6,7,8,9] but no mention is made of any directive influence of the catalyst used, and only one of them[9] contains an example with propylene oxide.

We have studied the reaction of propylene oxide with ethanol without catalyst and with acidic and basic catalysts. The results are summarized in Table I. Sulfuric acid at a concentration of 1.3% led to the formation of both isomers in approximately equal amounts, together with a small amount of 1,2-diethoxypropane, a product of dehydration. A decrease in the acid concentration caused increased formation of the primary ether. Similar mixtures were encountered when boron trifluoride was used as a catalyst, or when the reaction was carried out without added substances at elevated temperatures. In contrast, sodium hydroxide, sodium ethoxide and tributylamine directed the reaction almost quantitatively to the formation of the primary ether. This pronounced difference in the directive influence of acidic and basic catalysts was found not only with ethanol but also with isopropyl alcohol, *n*-butanol and 2-ethylhexanol. We also found that the reaction of excess propylene glycol with diethyl sulfate yielded almost exclusively the primary monoethyl ether.

Attempted identification of the primary ethyl ether by synthesis from 1-chloro-2-propanol and sodium ethoxide was unsuccessful because of indications of the presence of propylene oxide in the reaction mixture, which vitiated the validity of the structure proof. Lucas's hydrochloric acid method[10] could not be used for a differentiation of the isomers, but the cleavage method described by Wohl[11] could be used as a suitable criterion. Following Wohl's procedure, the low-boiling isomer was treated with a small amount of sulfuric acid in acetic anhydride solution, and 1-ethoxy-2-acetoxypropane was formed, while the high-boiling isomer, under similar conditions, underwent cleavage to yield ethyl acetate and 1,2-propanediol diacetate. Thus the low-boiling isomer was identified as the primary ether.

All of the primary alcohols studied reacted at about the same rate, but isopropyl alcohol reacted much more slowly under both acidic and basic conditions. In the case of sulfuric acid catalysis, small amounts of diisopropyl ether and of 1,2-diisopropoxypropane were formed by dehydration.

It seems that bases selectively catalyze the rupture of the bond between the oxygen atom and the

TABLE I

REACTION OF PROPYLENE OXIDE WITH ETHANOL

Catalyst (concentration based on ethanol)	None	0.82% H_2SO_4	1.3% H_2SO_4	0.1% BF_3	0.7% $NaOC_2H_5$	0.3% NaOH	1.0% $(C_4H_9)_3N$
Mole ratio, ethanol to propylene oxide	5.0	2.85	5.0	5.1	5.1	5.0	5.0
Reaction time, hr.	15[a]	3.5	3.2	2.1	5	6	10
Yields, % based on propylene oxide							
1-Ethoxy-2-propanol	55.9	41.0[b]	25.0[c]	45.1	83.2	81.4	65.5
2-Ethoxy-1-propanol	16.2	23.6	31.2	29.0	16.5	1.9	8.4
Ethyl ether of dipropylene glycol	17.5	18.2	22.8	20.4		8.3	
Higher boiling						0.5	
Number of runs averaged	1	3	2	1	2	2	1

[a] Reaction in a bomb to 245°. [b] 16% of the propylene oxide unreacted. [c] 18% oxide unreacted. The diethyl ether of propylene glycol was obtained in 2.5% yield.

---

[1] Davidson, British Patent 255,406 (1927), and U. S. Patent 1,730,061 (1929), to Carbide and Carbon Chemicals Corporation.

[2] Cox, Nelson and Cretcher, THIS JOURNAL, **49**, 1080–1083 (1927).

[3] Dewael, *Bull. soc. chim. Belg.*, **39**, 395–401 (1930).

[4] British Patent 354,357 (1931), and French Patent 610,282 (1932), to I. G. Farbenindustrie A. G.

[5] British Patent 271,169 (1927), to I. G. Farbenindustrie A. G.

[6] British Patent 467,228 (1937), to The Distillers Co., Ltd.

[7] British Patent 530,230 (1940), to The Distillers Co., Ltd.

[8] U. S. Patent 2,053,708 (1936) to Union Carbide and Carbon Corporation.

[9] German Patent 542,765 (1932) to I. G. Farbenindustrie A. G.

[10] Lucas, THIS JOURNAL, **52**, 802–804 (1930).

[11] Wohl and Berthold, *Ber.*, **43**, 2177 (1910).

primary carbon atom, while in neutral or acidic media either one of the oxygen–carbon bonds is broken. This interpretation agrees with the experiments of Levene and Walti,[12] who found that basic hydrolysis of optically active propylene oxide proceeded with retention of configuration, while acidic hydrolysis caused a certain amount of inversion. While their data do not permit of differentiation between the effect of high or low hydrogen ion concentration on the acid side, the fact stands out that all of their acidic hydrolyses gave more than 50% inversion, *i. e.*, in all of these cases the secondary carbon atom was attacked preferentially. In the alcoholyses described above, preferential attack of the secondary carbon atom took place only at the higher acid concentrations.

The base-catalyzed reaction probably involves a nucleophilic attack of alkoxyl ion, preferentially at the primary carbon atom, which has the lower electron density. The primary carbon–oxygen bond is broken while the secondary bond is left intact, and the product is a 1-alkoxy-2-propanol. A similar mechanism accounts for the results of the non-catalytic reaction, but in this case the nucleophilic attack is by the alcohol molecule rather than an ion and the reaction is much slower. The non-catalytic reaction is less specific in its course, possibly because the higher temperature needed to give a suitable reaction rate lessens the directive effect of electron density.

In the acid-catalyzed reaction a proton presumably adds to the oxygen bridge, weakening the carbon–oxygen bonds. Attack by an alcohol molecule then occurs readily at either the primary or secondary carbon atom. The bond between the oxygen and the carbon atom to which the alcohol molecule attaches itself is broken, and a proton is expelled simultaneously. To the extent that the secondary carbon is attacked inversion occurs (though not measurable optically in the present case because of optically inactive starting material). The 2-alkoxy-1-propanol formed affords a measure of the inversion for the alcoholysis which is analogous to the inversion in the hydrolysis described by Levene and Walti.

Experimental

Materials.—Commercial propylene oxide and alcohols were used without any further purification. Commercial propylene chlorohydrin was carefully fractionated to obtain 1-chloro-2-propanol (b. p. 57–58° at 50 mm.) substantially free from its higher boiling isomer.

Apparatus and Procedure.—The catalytic reactions were conducted in a round-bottom flask equipped with a mercury-sealed stirrer, a reflux condenser, a thermometer and a graduated dropping funnel with a delivery tube extending below the level of the liquid. The alcohol containing the catalyst was heated to the reaction temperature and propylene oxide was added as fast as the rate of reflux would permit. Heating was continued after the addition until the temperature of the boiling liquid had become constant, indicating that the olefin oxide had been consumed. This was generally the case within two hours after completion of the addition; in the case of isopropyl alcohol heating was continued for eight hours.

The catalyst was neutralized with sulfuric acid or sodium hydroxide and the product was fractionated through a 4-foot column of glass helices, employing a reflux ratio of about 10:1. The main fractions were redistilled to obtain nearly constant-boiling samples for determination of the physical properties, which are listed in Table II.

TABLE II

PHYSICAL PROPERTIES OF THE ISOMERIC MONO-ETHERS OF PROPYLENE GLYCOL

Alkyl group	Hydroxyl group etherified	B. p., °C.	B. p., Mm.	$d^{20}_{15.5}$	$n^{20}D$
Ethyl	Primary	130–130.8		0.896	1.4058
	Secondary	137.5–138		.908	1.4100
Isopropyl	Primary	137–138		.879	1.4070
	Secondary	143–144		.885	1.4094
n-Butyl	Primary	74–74.5	20	.880	1.4170
	Secondary	78–78.5	20	.888	1.4192
2-Ethylhexyl	Primary	101.5–102	10	.871	1.4327
	Mixed[a]	91–93	5	.873	1.4336

[a] An unresolved mixture of isomers from BF_3 catalysis.

The yields of all products were estimated from the distillation curves of the crude reaction products, supplemented by redistillations of mid-fractions and residues. Typical distillation curves are shown in Fig. 1.

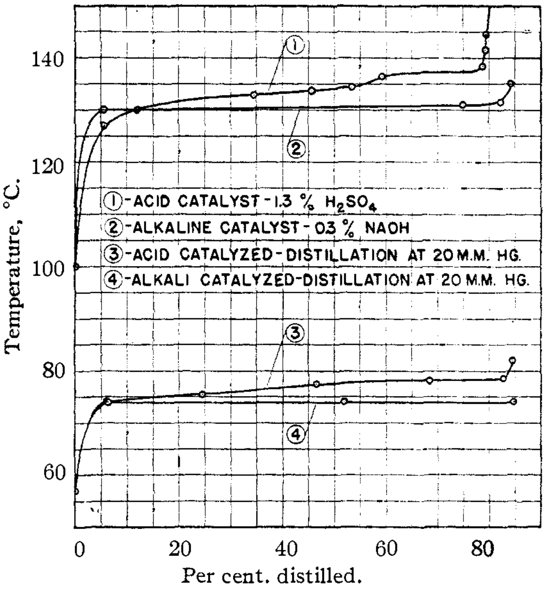

Fig. 1.—Distillation of products from acid- and alkali-catalyzed reaction of propylene oxide with ethanol 1 and 2, and with butanol 3 and 4.

For the non-catalytic alcoholysis, the reactants were heated in an Adkins bomb.

Base-Catalyzed Alcoholyses

Sodium Hydroxide.—During the course of four hours 638 g. (11 moles) of propylene oxide was added to 2560 g. (55.5 moles) of absolute ethanol containing 10 g. of sodium hydroxide, while the liquid was kept at 76–77°. After two additional hours of boiling, the temperature had become constant at 80°. The mixture yielded 770 g. of 1-ethoxy-2-propanol, b. p. 130–130.5°; estimated yield, 81.4%.

---

(12) Levene and Walti, *J. Biol. Chem.*, **73**, 263–274 (1927).

The combined residues from several runs were fractionated, and it was found that 1.9% of the propylene oxide had been converted into 2-ethoxy-1-propanol, 8.3% into dipropylene glycol monoethyl ether and 0.5% into higher boiling products. About 6% of the oxide was not accounted for, probably because of mechanical loss.

Reactions conducted with sodium ethylate as the catalyst gave almost identical results.

Essentially the same procedure as described for ethanol was used with isopropyl, *n*-butyl and 2-ethylhexyl alcohols. In all cases five moles of the alcohol to one of the oxide were used. The temperature in the reaction flask was 76–78° in the case of isopropyl alcohol; the other compounds were prepared at 110–115°.

The reaction with isopropyl alcohol was slow, and a yield of only 53% of the desired ether was obtained after nineteen hours of heating, the ether of dipropylene glycol being obtained simultaneously in 26% yield. The higher primary alcohols reacted nearly as readily as ethanol. Whenever yields below 80% were obtained, some unreacted propylene oxide was recovered. The physical properties of the products obtained are listed in Table II.

Tributylamine.—The same quantities of ethanol and propylene oxide as used in the preceding section were brought together in the presence of 26 g. of tributylamine. The addition of the oxide to the boiling liquid required eight hours, and after two additional hours the mixture was worked up. The 1-ethoxy-2-propanol fraction weighed 704 g., b. p. 130–131°; estimated yield 65.5%. A considerable amount of propylene oxide was lost in this experiment, and only 74% of the starting material could be accounted for.

Acid-catalyzed Alcoholyses

Sulfuric Acid.—The general procedure described above was followed. In the case of the isopropyl derivative a considerable amount of propylene oxide was recovered, and diisopropyl ether and 1,2-diisopropoxypropane were found among the by-products. The yields of mixed monoethers obtained are listed in Table III.

TABLE III

COMBINED YIELDS OF THE ISOMERIC MONO-ETHERS OF PROPYLENE GLYCOL

Catalyst		NaOH	H_2SO_4	BF_3	None
Alcohol used	Ethyl	83.5%	65%	74%	72%
	Isopropyl	53	23.5	64	..
	n-Butyl	80	70	..	..
	2-Ethylhexyl	60	..	70	..

Boron Trifluoride.—These reactions were run at 50–60° and were completed in four to six hours. As may be seen from Table I, this catalyst has about the same directive influence as sulfuric acid, but under the conditions employed gives somewhat better yields.

Non-catalytic Reaction

A mixture of 765 g. (16.7 moles) of absolute ethanol and 193 g. (3.3 moles) of propylene oxide was gradually heated to 245° over a period of fifteen hours in a rocking bomb. Upon distillation, 190 g. of the isomeric monoethyl ethers was obtained, b. p. 130–136°; estimated yield 72%. The distillation curve and the refractive indices of the principal product fractions indicate a 3.5:1 ratio of primary to secondary ether produced.

Ethylation of Propylene Glycol.—A mixture of 2280 g. (30 moles) of dry propylene glycol and 260 g. (6.5 moles) of sodium hydroxide was stirred at 75° in a three-necked round-bottomed flask. After the solid had dissolved 924 g. (6 moles) of diethyl sulfate was added over a period of five hours. The temperature was kept at 90–100° during the addition, and stirring at 100° was continued for thirty minutes. The ethyl hydrogen sulfate was then hydrolyzed by addition of a solution of 240 g. (6 moles) of sodium hydroxide in 1200 cc. of water. The mixture was filtered and distilled. The 1-ethoxy-2-propanol distilled as an azeotropic mixture with water boiling at 94–95°. The organic matter in the distillate was salted out with potassium carbonate. Upon redistillation 424 g. of the primary ether was obtained, b. p. 130–130.5°; estimated yield 98%.

Reaction of 1-Chloro-2-propanol with Sodium Ethylate.—A solution of sodium ethylate (1750 cc.) containing 96.5 g. of sodium (4.2 moles) was added over a period of two and one-half hours to a mixture of 374 g. (4 moles) of 1-chloro-2-propanol and 375 cc. of dry ethanol, which had been heated to 60°. The temperature gradually rose to 66°, where the mixture boiled gently under reflux without the application of heat. After boiling for another hour the mixture was filtered and distilled. The 1-ethoxy-2-propanol fraction amounted to 278 g. (66.8%) and of this fraction 228 g. boiled within the narrow range of 130–131°. About 30% of the chlorohydrin had been converted into higher boiling products.

The low temperature at which the reaction mixture boiled indicated that propylene oxide was being formed. Eventually the oxide disappeared indicating that a part of the ether, or possibly all of it, may have been formed by alcoholysis of this oxide. Thus the reaction could not be used for a proof of structure.

Identification of 1-Ethoxy-2-propanol and of 2-Ethoxy-1-propanol.—Each of the isomeric ethers was redistilled until it boiled over a narrow range. Then a mixture of 312 g. (3 moles) of each of the ethoxypropanols with 1224 g. (12 moles) of acetic anhydride and 3 cc. of concentrated sulfuric acid was boiled under reflux in a still until the temperature at the head of the column had become constant.

With the low-boiling isomer, the temperature became constant at 99° after two hours of boiling. After addition of 10 g. of anhydrous sodium acetate the mixture was distilled, and 1-ethoxy-2-acetoxypropane was obtained in 78% yield, b. p. 77–78° (50 mm.). On redistillation it boiled at 156–157° (746 mm.); sp. gr. $d^{20}_{15.6}$ 0.9425; n^{20}_D 1.4025; *MR* 37.80 (obs.), 37.83 (calcd.); saponification equivalent 146.4 (obs.), 146.2 (theoret.). These physical properties do not agree with those reported by Dewael[3]; this is understandable, as Dewael acetylated the product of an acid-catalyzed alcoholysis of propylene oxide, and thus probably was dealing with a mixture of isomers.

In the case of the high-boiling isomer the vapor temperature dropped to 78° within thirty minutes and remained at that point during twenty-one hours of distillation. The distillate contained 211 g. of ethyl acetate. The residue in the still flask was treated with 10 g. of anhydrous sodium acetate and fractionated. No 2-ethoxy-1-acetoxypropane was encountered, but a 62.5% yield of 1,2-propanediol diacetate was obtained, b. p. 88° (20 mm.). On redistillation it boiled at 189–191° (746 mm.), $d^{20}_{15.6}$ 1.058, n^{20}_D 1.4148, *MR* 37.85 (obs.), 37.84 (calcd.). These values agree well with Pukirev's reported data[13] of d^{20}_4 1.0562, n^{20}_D 1.4146, *MR* 37.93 (obs.).

Summary

1. Base-catalyzed alcoholysis of propylene oxide yields almost exclusively the primary monoethers of propylene glycol.

2. Non-catalytic or acid-catalyzed alcoholysis of propylene oxide yields mixtures of the isomeric ethers.

3. The isomeric ethyl, isopropyl, butyl and 2-ethylhexyl monoethers of propylene glycol were prepared and characterized.

4. 1-Ethoxy-2-propanol was also prepared

---

[13] A. G. Pukirev, *Trans. Inst. Pure Chem. Reagents U. S. S. R.*, **15**, 45–50 (1937).

from 1-chloro-2-propanol and sodium ethoxide, and from propylene glycol and diethyl sulfate.

5. The monoethyl ethers were differentiated by the selective cleavage of the secondary ether group with sulfuric acid and acetic anhydride.

SOUTH CHARLESTON, WEST VIRGINIA

RECEIVED[14] JANUARY 28, 1946

---

[14] Original manuscript received November 4, 1944.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, STANFORD UNIVERSITY]

Isotropic and Anisotropic Liquid Phases in the System Hexanolamine Oleate–Water

BY EMANUEL GONICK AND JAMES W. MCBAIN

Hexanolamine oleate (4-methyl-4-amino-pentanol-2 oleate) is soluble in water in almost all proportions. The anhydrous soap is a yellowish waxy solid melting to an isotropic liquid at 58°.[1] At room temperature, as little as 3 or 4% of water is sufficient to convert it into an *isotropic* liquid. However, anisotropic liquid phases intervene between these concentrated solutions and the ordinary more dilute isotropic solutions.

Between 0 and 30% of soap in water, the solutions are isotropic, and are those of a typical colloidal electrolyte. However, it is remarkable that with increasing concentration these solutions become more and more jelly-like, reaching a maximum stiffness at approximately 12% soap, and upon further *concentration* become fluid again—all without change of phase. Between 30 and 85% soap at room temperature the solutions are birefringent, viscous liquids. Indeed a few of these anisotropic liquids are remarkable in being as free-flowing as an oil. This is a very unusual degree of fluidity for liquid crystals.

At sufficiently high temperatures, above 183°, all the systems of hexanolamine oleate and water are isotropic liquids, miscible in all proportions. It is again remarkable that even where the soap itself has so low a melting point, and while both concentrated and dilute solutions are isotropic solutions at room temperature, the intervening anisotropic solutions require such extreme elevations of temperature before they "melt" to become isotropic. In general, however, the transition temperatures between liquid crystals and isotropic phase are much lower than in the case of ordinary soaps. It had been hoped that there might be a maximum in the temperature boundary of one or other of the anisotropic phases at a temperature low enough to permit a direct study in ordinary apparatus open to the atmosphere. Then the change in conductivity and other properties accompanying the change from a single homogeneous isotropic phase to an anisotropic phase of the same composition and of almost the same temperature could be easily and directly measured. However, the two maxima lie at 156 and 183°, very much above the boiling point of the solutions.

The outlines of the phase diagram are here described, together with a number of physical properties of certain of the phases.

Experimental

The hexanolamine oleate was made by mixing equivalent amounts of Kahlbaum "purest" oleic acid and redistilled hexanolamine[2] (b. p. 60.2° at 6 mm. pressure, mol. wt. 117.3).

Phase Relations.—Solutions for phase studies were made by weighing the soap and conductivity water into Pyrex tubes, which were evacuated and sealed while the contents were frozen in a bath of Dry Ice and acetone. Compositions are expressed in true per cent. by weight. The tubes were then heated to the temperature of isotropy and tilted back and forth until the contents became homogeneous. The tubes were then observed between crossed polaroids while heated in a transparent furnace, made by wrapping nichrome wire around a piece of large-bore Pyrex tubing, stoppered at both ends and lagged with asbestos through which slits were cut on opposite sides to permit observation. Temperature was controlled by means of a rheostat. Thermometer readings were corrected for stem-exposure. Transition temperatures from isotropic phases were determined by the first appearance of birefringent specks upon slow cooling, these showing up as bright spots in the dark field of the crossed polaroids. Transitions were strictly reversible, the final disappearance of birefringent material on heating and its appearance on cooling occurring at the same temperature.

The results of these observations are tabulated in Table I and the phase diagram is graphed in Fig. 1.

TABLE I

VALUES OF T_i, THE TEMPERATURE AT WHICH ON SLOW COOLING THE FIRST DROP OF ANISOTROPIC LIQUID PHASE FORMS FROM THE HOMOGENEOUS ISOTROPIC LIQUID PHASE IN THE SYSTEM HEXANOLAMINE OLEATE–WATER

% Soap	T_i, °C.		% Soap	T_i, °C.
21.5	180		55.3	122
22.3	183		63.7	100
25.0	181		74.3	71
30.0	177	2 phases at room temp.	78.5	54
35.5	164		83.7	22
37.5	159		85.5	16.5
39.3	143		86.8	9
39.6	153		87.3	8
40.2	156		88.0	7
41.4	154		91.8	14
45.7	143		94.5	27
49.8	135		97.6	43

---

[1] A sample of the oleate, recrystallized from acetone, turned from opaque solid crystals to anisotropic jelly at 54–58°, and finally to isotropic liquid at 68°. On cooling below 52°, this liquid froze to an opaque solid without passing through the anisotropic phase observed above. On reheating, the solidified soap melted directly to an isotropic liquid at 58°. The unrecrystallized soap also melted to isotropic liquid at 58°.

[2] Kindly supplied by the Shell Development Co., Emeryville, Calif.