

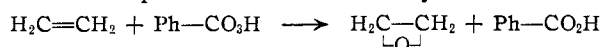
[CONTRIBUTION FROM THE INSTITUTE FOR ENZYME RESEARCH, UNIVERSITY OF WISCONSIN]

The Synthesis of Ethylene Oxide-1,2-C¹⁴ ^{1a}BY ARTHUR J. TOMISEK^{1b} AND HENRY R. MAHLER

Ethylene oxide-1,2-C¹⁴ was isolated in 30% yield from the reaction of ethylene-1,2-C¹⁴ with perbenzoic acid in tetrachloroethane solvent in the presence of iodine catalyst. A procedure was developed for the determination of ethylene oxide in tetrachloroethane solutions.

Only two practical syntheses of ethylene oxide have been reported in the literature, (1) the action of oxygen on ethylene in the presence of various silver catalysts, and (2) the dehydrohalogenation of ethylene halohydrins. The first is in wide use commercially, but its fractionation and recycling procedures did not appear applicable to a small-scale synthesis. The second method involves excessive manipulation, and indeed the best precursor of ethylene chlorohydrin-1,2-C¹⁴ would be the very ethylene oxide-C¹⁴ here sought.

The synthesis chosen was the simple, one-step reaction of perbenzoic acid with ethylene



While syntheses of this type have been used successfully with a wide variety of olefins,² no application to ethylene or any of its low-boiling homologs has been reported. Most olefin oxides prepared by this reaction have been obtained in high yield,² but this efficiency was not realized under any of the reaction conditions studied in this project.

The ethylene oxide determination given below was based upon the method of Nicolet and Poulter.³ The modification was designed to prevent the alkaline hydrolysis of tetrachloroethane which occurs if alcohol is added to obtain a one-phase titration system.

Experimental

Apparatus.—Reaction bulbs were 1.5 cm. in diameter, about 11 cm. long and equipped with 3-mm., slant-bore stopcocks. The stopcocks were lubricated with Cenco Hyvac silicone grease and were fitted with stopcock clamps. Gas-measuring bulbs consisted of round-bottom flasks filled with sufficient mercury to leave the desired volume. The vacuum line was essentially the general-purpose manifold for organic syntheses described by Calvin, *et al.*,⁴ except that the stopcock between the line trap and the remainder of the manifold was eliminated. Vacuum operations were carried out at the residual pressure of 0.05 mm. produced by a mechanical vacuum pump.

Reagents.—*sym*-Tetrachloroethane was obtained as a center cut, b.p. 144.6 to 146.5°, from the careful fractionation of practical grade material (Matheson Co.). *o*-Dichlorobenzene, b.p. 177.0 to 177.4°, was similarly obtained from the practical grade material (Eastman Kodak Co.). Toluene, benzene and ether were of reagent grade. Ethylene (Ohio Chemical Co.) and ethylene oxide (Matheson Co.) were both of 99.5% purity. Ethylene-C¹⁴ (Tracerlab) was supplied in 1-mmole ampoules.

The iodine catalyst was made up as a stock solution containing 5.5×10^{-3} meq. of iodine per ml. of tetrachloroethane.

(1) (a) This research was sponsored in part by the Chemical Corps Biological Laboratories, Camp Detrick, Frederick, Maryland under Contract DA-18-064-CML-452. (b) Present address: Southern Research Institute, Birmingham 5, Alabama.

(2) D. Swern, *Chem. Revs.*, **45**, 16 (1949).

(3) D. Swern, T. W. Findley, G. N. Billen and J. T. Scanlan, *Anal. Chem.*, **19**, 414 (1947).

(4) Calvin, Heidelberger, Reld, Tolbert and Yankwich, "Isotopic Carbon," John Wiley and Sons, Inc., New York, N. Y., 1949, p. 142.

Perbenzoic acid solutions were made by dissolving about 1 g. of perbenzoic acid^{5,6} in 20 ml. of cold tetrachloroethane, and assayed iodimetrically.⁵ The solutions were freshly prepared every day or two, and stored in an ice-box except when aliquots were being removed.

Procedure for Model Runs.—From the above perbenzoic acid solution, 1.05 mmoles was measured into a reaction bulb. This was followed by 1 ml. of the iodine solution and rinsed down by sufficient tetrachloroethane to bring the final volume to 5 ml. By use of liquid air one mmole of ethylene was vacuum transferred from the gas-measuring bulb to the reaction bulb. After closing the stopcock the reaction bulb was removed from the vacuum line and allowed to stand till the tetrachloroethane had melted. The bulb was then shaken to mix the contents and stored in a 3° cold room for 4 to 6 days. The reaction bulb was refrozen in liquid air and evacuated on the vacuum line. The rate of thawing of the frozen reaction mixture was controlled to prevent frothing over during the initial degassing. Vacuum transfer to the line trap was complete in about an hour and a half, leaving a dry residue of benzoic and perbenzoic acids. The vaporizable constituents of the line trap were similarly transferred to a storage bulb. This bulb was closed off and its contents were allowed to melt before being refrozen at about -70° in a Dry Ice-chloroform-bath. Unreacted ethylene was then removed from the bulb by alternately flooding with nitrogen and partially evacuating.

The 5 ml. of solution in the above storage bulb was fractionated as follows. One ml. was removed by vacuum transfer to a calibrated receiver vessel. To the 4-ml. residue was added 1.10 mmoles of ethylene oxide by vacuum transfer from the "1-mmole" gas-measuring bulb. After thawing and mixing the residue, another 1.5 ml. was vacuum transferred to the 1 ml. fraction. The residue was then discarded. The fraction sizes used above had previously been tested on a known mixture and found adequate to ensure that the residue had reached its azeotropic composition of 0.06 mmole of ethylene oxide per ml. of tetrachloroethane.

Almost all preliminary work had been on a sixfold scale. For these larger runs the yields of ethylene oxide as measured in the reaction mixtures on six separate runs were $53 \pm 4\%$ based on the amount of ethylene present at the start of the reaction. Of these yields, recoveries after two vacuum transfers were 75 to 80% (over-all yield 38 to 42%). For runs according to the procedure given (1 mmole scale) yields in the reaction mixtures were not measured, but over-all yields after two vacuum transfers for five separate runs were 30 to 39% based on the amount of ethylene present at the start of the reaction.

Tetrachloroethane solutions of ethylene oxide were found to decompose 4% per month when stored at 3°.

Procedure for Radioactive Runs.—Runs with radioactive ethylene were carried out as above except that the ethylene was vacuum transferred directly from the gas ampoules, and that 1.10 mmoles of ethylene oxide were added as carrier immediately after the reaction period. Specific activities were not measured for either the starting material or the product. However, calculated from data on the model runs the 1.0 mc. of C¹⁴ in the original 1 mmole of ethylene should have led to about 0.35 mc. of C¹⁴ in a total of 3.4 mmoles of ethylene oxide.

To prepare aqueous solutions, the ethylene oxide-C¹⁴ was removed from its 2.5 ml. of tetrachloroethane solvent by aeration with nitrogen (100 ml. of gas per min. for 4 hours). The ethylene oxide was first collected in a trap cooled by

(5) G. Braun, "Org. Syntheses," Coll. Vol. I, John Wiley and Sons, Inc., 1941, p. 431.

(6) In the several batches of perbenzoic acid used, purity variations from 80 to 95% did not appear to affect the reaction.

liquid air, then flushed into a water-containing absorber. Five to ten per cent. of the ethylene oxide remained in the tetrachloroethane, and was removed by adding carrier ethylene oxide.

Analytical Methods.—Perbenzoic acid residual in reaction mixtures was determined by running 2-ml. aliquots into acidified aqueous potassium iodide and titrating with 0.1 *N* sodium thiosulfate.⁶ Titration with sodium arsenite gave equivalent values for perbenzoic acid content.

For the determination of ethylene oxide in any of the reaction solvents, 5-ml. aliquots were run into glass-stoppered (25-ml. iodine titration flasks containing 25 ml. of standardized 0.2 *N* dry hydrogen chloride in anhydrous ether. After three hours, 20 ml. of water, 20 ml. of benzene or toluene and 5 drops of 1% phenolphthalein were added. In titration with *N* sodium hydroxide, 10 to 20 seconds of vigorous shaking were required after each addition of alkali. The ethylene oxide content was taken as the difference in hydrochloric acid content between the titrated mixture and the original ether-hydrogen chloride. To correct for acids in the ethylene oxide samples, blanks were determined by substituting anhydrous ether for the ether-hydrogen chloride. These acidity blanks were of measurable magnitude even in products obtained after two vacuum transfers, since benzoic acid did have some tendency to sublime over during the transfers. For determinations where acidity blanks were very low the addition of 2 g. of solid sodium chloride facilitated the two-phase titrations.

Discussion

Limitations of the Analytical Method for Ethylene Oxide.—Although the above method gave accurate values when applied to known mixtures of ethylene oxide and tetrachloroethane, the exact conditions for its application to solutions containing appreciable amounts of perbenzoic acid could not be worked out.⁷ However, except for reaction mixtures less than one or two days old, the yield of ethylene oxide which could be obtained by fractionation of the reaction mixture was consistently 75 to 80% of that measured in the reaction mixture. Because this recovery appeared reasonable, the procedure for measurement of yields in reaction mixtures was retained as a useful guide.

Factors Influencing the Epoxidation Reaction.—As was expected from Swern's generalization⁸

(7) This difficulty with high values was not avoided by the use of dichlorobenzene, 1,1,2-trichloroethane, toluene or xylene as reaction solvents.

(8) D. Swern, *THIS JOURNAL*, **69**, 1692 (1947). Since these data on ethylene, propylene, etc., concerned oxidation by peracetic acid in glacial acetic acid, the products would be glycol monoacetates. While the over-all reactions are not the same as in this investigation, it is presumed that both proceed through the same rate-determining step.

that only alkyl-substituted ethylenes exhibit rapid epoxidation, prolonged reaction times were found necessary in the ethylene oxide synthesis. This slow rate introduced an unavoidable difficulty, in that perbenzoic acid itself, especially in the presence of iodine, was found to be responsible for the destruction of ethylene oxide.⁹ Using a known mixture of perbenzoic acid, iodine and ethylene oxide in tetrachloroethane, the measured rate of the destructive reaction was found to be the major, though not exclusive, factor in explaining the relatively low yield of ethylene oxide (53% maximum based on initial ethylene).

A few investigators^{10,11,12} have reported that changes of solvent exerted a marked effect on epoxidation rates. In model runs carried out essentially as above, reaction rates¹³ relative to tetrachloroethane as 1.0 were: *o*-dichlorobenzene, 0.5; toluene, 0.4; and di-*n*-butyl ether, 0.1. Incidental to these data, only the dichlorobenzene solutions of perbenzoic acid were found sufficiently stable to be used at room temperature.

The catalytic effect of iodine¹⁰ was confirmed, but in addition it was noted that an excess of iodine could result in a decreased yield of ethylene oxide. In one series of model runs, carried out according to the directions above, the yield of ethylene oxide as measured in the reaction mixture reached 53% (based on initial ethylene) in about four days, then remained constant till at least the eleventh day. In a separate series of runs with double the amount of iodine catalyst the yields reached the 53% in about three days, then gradually decreased to 10%. In both series of runs the 53% yield of ethylene oxide was reached when only 75% of the perbenzoic acid had reacted.

Acknowledgment.—The authors are indebted to Dr. David E. Green for his assistance in the project.

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RECEIVED MAY 7, 1951

(9) Benzoic acid was without effect in this respect.

(10) H. Meerwein, A. Ogait, W. Prang and A. Serini, *J. prakt. Chem.*, **113**, 9 (1926).

(11) S. Medvedev and O. Blokh, *J. Phys. Chem.*, (U. S. S. R.), **4**, 721 (1933).

(12) R. Lagrave, *Ann. Chim.*, [10] **8**, 363 (1927).

(13) These are not true rate constants since they include no correction other than a no-ethylene blank.