

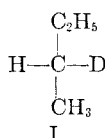
Optically Active Butane-2-*d*¹

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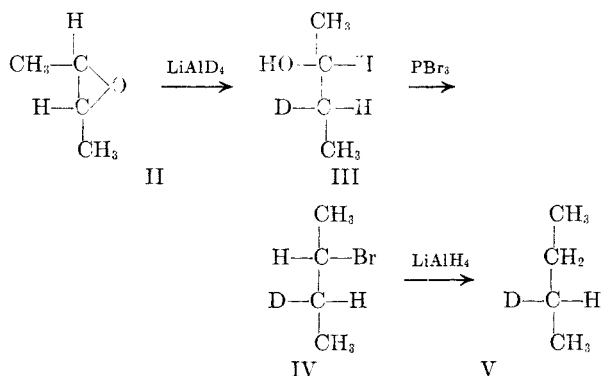
Optically active butane-2-*d* has been prepared by lithium aluminum deuteride reduction of *D*-2,3-epoxybutane followed by conversion of the resulting deuterio alcohol to the deuterio bromide and reduction of the bromide with lithium aluminum hydride. If the assumption is made that inversion accompanies opening of the epoxide ring, the specific rotation exhibited by pure liquid *D*-butane-2-*d* corresponds in sign but not in magnitude to the value predicted by Fickett using Kirkwood's theory of optical activity.

Recently Kirkwood's theory of optical rotatory power² was applied by Fickett³ for the calculation of the specific rotation of butane-2-*d*. For the stereoisomer illustrated (I),



the calculated value of $[\alpha]_{\text{D}}^{25}$ was 1.1° for a medium of refractive index 1.33. It was proposed⁴ that this simple hydrocarbon might be obtained by appropriate reduction of *D*-2,3-epoxybutane.

In a study of the stereochemistry accompanying this synthesis, active butane-2-*d* has been synthesized by the following route, and a concurrent sequence has been carried out using lithium aluminum hydride in the first step instead of lithium aluminum deuteride.



In all of the steps between *D*(+)-2,3-epoxybutane (II) and *D*-butane-2-*d* (V), each synthetic intermediate exhibited a sign of rotation opposite to that of its precursor. This eliminated the possibility that the optical activity of the levorotatory butane-2-*d* was due to the precursor, particularly

in view of the fact that the parallel sequence yielded *n*-butane which exhibited no optical activity.

The configuration of all the deuterium compounds is based on the assumption that inversion accompanies the opening of the epoxide ring with lithium aluminum deuteride, as demonstrated for bicyclic epoxides^{5,6} with lithium aluminum hydride. If the absolute configuration of the butane-2-*d* is *D*, the sign agrees with the theoretical calculation³ but the magnitude, $[\alpha]_{\text{D}}^{25} -0.56 \pm 0.02^\circ$, is only about one-half the predicted value, $[\alpha]_{\text{D}}^{25} 1.1^\circ$. Approximately the same observations had been made for α -deuteroethylbenzene³ in which agreement of sign was noted, but the calculated rotation, $[\alpha]_{\text{D}}^{25} 0.41^\circ$, was considerably higher than the observed rotation for the pure liquid enantiomorph, $[\alpha]_{\text{D}}^{25} -0.30^\circ$.⁷

Racemization during reduction of 2,3-epoxybutane is negligible, for the specific rotation of *L*-2-butanol is within 99.0% of the maximum reported values, $[\alpha]_{\text{D}}^{25} -13.63^\circ$, interpolated for resolved material,⁸ and $[\alpha]_{\text{D}}^{25} -13.51^\circ$ for material prepared by the indicated route.⁹ In addition, the magnitude of rotations of the 2-bromobutane, $[\alpha]_{\text{D}}^{25} 28.45^\circ$, and 3-bromobutane-2-*d*,¹⁰ $[\alpha]_{\text{D}}^{25} 29.34^\circ$, is essentially the same as empirically calculated maximum values, $[\alpha]_{\text{D}}^{25} 28.6^\circ$ ¹¹ and 26.1° .¹² Potentially, racemization or hydrogen exchange might have taken place during contact of butane-2-*d* or its precursors with phosphoric acid, lithium aluminum deuteride, or lithium aluminum hydride. However it has been demonstrated that *n*-butane does not undergo noticeable hydrogen exchange reactions or isomerization

(1) This investigation was supported by a Frederick Gardner Cottrell Grant from the Research Corporation.

(2) Kirkwood, *J. Chem. Phys.*, **5**, 479 (1937).

(3) Fickett, *J. Am. Chem. Soc.*, **74**, 4204 (1952).

(4) Fickett, Ph.D. Dissertation, California Institute of Technology, 1951.

(5) Plattner, Heusser, and Feurer, *Helv. Chim. Acta*, **32**, 587 (1949).

(6) Trevo and Brown, *J. Am. Chem. Soc.*, **71**, 1675 (1949).

(7) Eliel, *J. Am. Chem. Soc.*, **71**, 3972 (1949).

(8) Pickard and Kenyon, *J. Chem. Soc.*, **99**, 45 (1911).

(9) Leroux and Lucas, *J. Am. Chem. Soc.*, **73**, 41 (1951).

(10) The deuterio alcohols and bromides are named with the deuterium atom in the 2-position. The family is determined by the configuration about the 3-position according to the method described in *Report of the Committee on Carbohydrate Nomenclature*, *Chem. Eng. News*, **26**, 1623 (1948).

(11) Levene and Marker, *J. Biol. Chem.*, **91**, 405 (1931).

(12) Letzinger, *J. Am. Chem. Soc.*, **70**, 406 (1948).

during short periods of time in contact with sulfuric acid at 25°¹³ or with barium hydride at 300°.¹⁴ Furthermore, lithium aluminum hydride did not racemize adjacent asymmetric centers during reduction of 2-methylbutanoic acid or *l*-menthone.¹⁵

On the basis of these observations, namely, that (a) only inversion accompanies epoxide-ring opening, (b) subsequent reactions induce no racemization of the adjacent center, and (c) observed rotation cannot be due to impurities, the stereoisomer *D*-butane-2-*d* has been obtained with a high degree of optical purity. The specific rotation, $[\alpha]_D^{25} -0.56^\circ$, of this simplest monodeutero hydrocarbon in the liquid state is somewhat higher than that reported for α -deuteroethylbenzene,⁷ $[\alpha]_D^{25} -0.30^\circ$, but the molecular rotations, -0.33° and -0.32° respectively, are comparable.

EXPERIMENTAL¹⁶

D(+)-2,3-Epoxybutane. The epoxide was prepared from *L*(-)-2,3-butanediol¹⁷ by a previously described procedure.^{18, 19} Its optical purity, $[\alpha]_D^{25} 57.10^\circ$, was about 97%, based on the best previous value, 59.05°.¹⁹

L(-)-2-Butanol. This was prepared by the method of Leroux and Lucas⁹ by reduction of *D*-2,3-epoxybutane with lithium aluminum hydride;^{6, 20} $[\alpha]_D^{25} -13.49^\circ$ (lit.,⁹ $[\alpha]_D^{25} -13.51^\circ$).

D(-)-erythro-3-Butanol-2-*d*. From the reduction of 20.6 g. (0.285 mole) of *D*(+)-2,3-epoxybutane with 3.5 g. (0.0835 mole, 0.334 equiv.) of lithium aluminum deuteride in ether was obtained 18.3 g., 86% yield, of the deuterio alcohol, b.p. 96.5–98.0° (730 mm.). The material was redistilled through a spinning band column; b.p. 98.9° (734 mm.); $n_D^{25} 1.3948$; $\alpha_D^{25} -11.05^\circ$; $d_4^{25} 0.8134$; $[\alpha]_D^{25} -13.59^\circ$.

Anal. Calc'd for C₄H₉DO: C, 63.95; H + D, 14.76; apparent H, as reported in microanalysis, 13.56. Found: C, 63.92; H, 13.65.

D(+)-2-Bromobutane. A modification of the method of Noller and Adams²¹ was used to convert *L*-2-butanol to the bromide with phosphorus tribromide. The crude reaction mixture was washed with water and 5% sodium bicarbonate, isolated by azeotropic distillation with water, dried over calcium chloride, and redistilled. The optical purity of the product, $[\alpha]_D^{25} 28.45^\circ$, was considerably higher than that of previously reported preparations, -13.79° ¹¹ and

(13) Otvos, Stevenson, Wagner, and Beeck, *J. Am. Chem. Soc.*, **73**, 5741 (1951).

(14) Wright and Weller, *J. Am. Chem. Soc.*, **76**, 5948 (1954).

(15) Noyce and Denney, *J. Am. Chem. Soc.*, **72**, 5743 (1950).

(16) Microanalyses by A. Elek, 4763 West Adams Blvd., Los Angeles, California.

(17) The authors are indebted to Dr. H. J. Lucas of the California Institute of Technology for a generous sample of *D*-2,3-butanediol used as the starting material.

(18) Lucas and Gould, *J. Am. Chem. Soc.*, **63**, 2541 (1941).

(19) Lucas and Garner, *J. Am. Chem. Soc.*, **70**, 990 (1948).

(20) Nystrom and Brown, *J. Am. Chem. Soc.*, **70**, 3738 (1948).

(21) Noller and Adams, *J. Am. Chem. Soc.*, **48**, 1084 (1926).

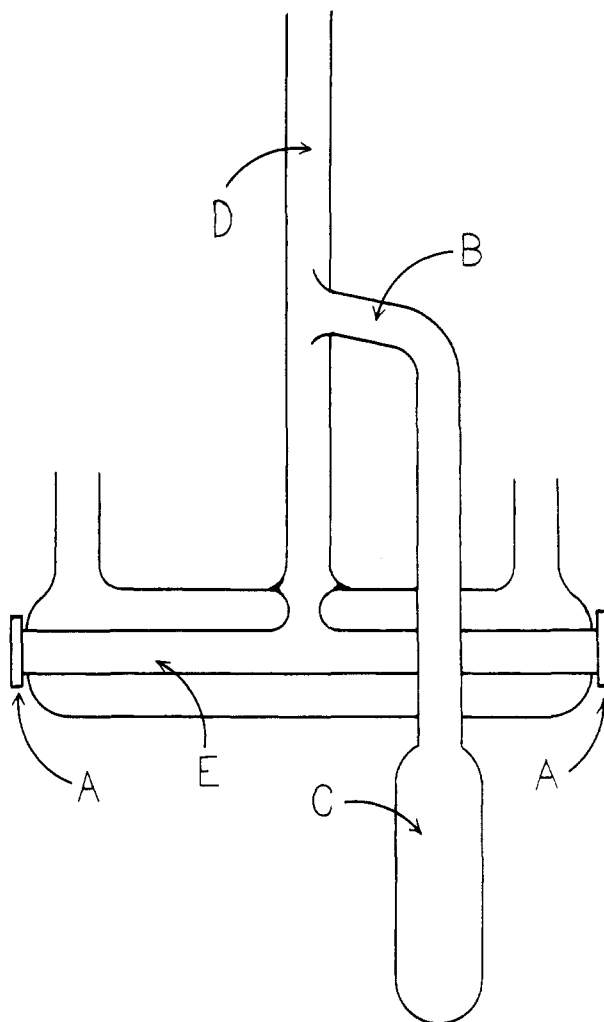


FIGURE 1. POLARIMETER TUBE FOR LIQUID BUTANE.

-13.66° ¹² from partially resolved *D*-2-butanol, and -13.52° for *L*-2-bromobutane from the von Braun reaction.²²

L(+)-threo-3-Bromobutane-2-*d*. This was prepared by the procedure used for *D*-2-bromobutane. From 16.0 g. (0.213 mole) of *D*(-)-erythro-3-butanol-2-*d* and 25 g. (0.092 mole) of phosphorus tribromide there was obtained 23.0 g., 75% yield, of the corresponding bromide: b.p. 90.2–90.3° (735 mm.); $n_D^{25} 1.4337$; $\alpha_D^{25} 37.00^\circ$; $d_4^{25} 1.2614$; $[\alpha]_D^{25} 29.34^\circ$.

Anal. Calc'd for C₄H₉BrD: C, 34.80; H + D, 7.29; apparent H, as reported in microanalysis, 6.65; Br, 57.90. Found: C, 34.68; H, 6.64; Br, 58.00.

n-Butane and *D*(-)-butane-2-*d*. The butanes were prepared by the reduction of the corresponding secondary bromo compounds with lithium aluminum hydride and lithium hydride in tetrahydrofuran.²³ The apparatus was an integral system consisting of solvent distilling column, reaction flask with stirrer and condenser, gas washing units, and collection ampoule. For the preparation of butane-2-*d*, about 35 g. of solvent was introduced to the thoroughly dry reaction flask by distillation from lithium aluminum hydride. After addition of 1.6 g. (0.042 mole) of lithium aluminum hydride and 1.5 g. (0.19 mole) of lithium hydride, 11.6 g. (0.084 mole) of 3-bromobutane-2-*d* was added dropwise to

(22) Leonard and Nommensen, *J. Am. Chem. Soc.*, **71**, 2808 (1949).

(23) Johnson, Blizzard, and Carhart, *J. Am. Chem. Soc.*, **70**, 3664 (1948).

the refluxing solvent and this temperature was maintained for one hour. The butane-2-*d* which formed was passed through two scrubbers containing 85% phosphoric acid, through sodium hydroxide pellets, and into an ampoule at -80° ; residual material was flushed into the ampoule with nitrogen; yield, 4.0 g., 81%. The product was distilled through a 100-cm. Podbielniak Heligrad column. Successive redistillations had no noticeable effect on the optical rotatory powers of either butane-2-*d* or butane prepared by the same procedure. The polarimeter tube, Figure 1, was of an all-glass, water-jacketed construction, with windows, A, sealed on the ends with an epoxy cement.²⁴ The tube contained a side arm, B, and bulb, C, for freezing out butane from a gas handling system. After the tube was sealed at D, liquid butane could readily be transferred from the freeze-out bulb to the measuring tube, E. The polarimeter was an O. C. Rudolph & Sons Model 70 with a changeable

image-field diaphragm, and verniers to read directly to 0.01° arc. All optical rotation measurements were made in the liquid state because theoretical calculations were based on a pure liquid with refractive index 1.33, but also because measurement involving a comparable number of gas molecules at standard conditions would require a polarimeter tube length of over 200 dm. *n*-Butane: α_D^{25} $0.00 \pm 0.01^{\circ}$; d_4^{25} 0.5731 (lit.,²⁵ d_4^{25} 0.5733, calculated from $d_4^{26.5}$ and $d_4^{23.3}$). *n*(-)-Butane-2-*d*: b.p. -1.5° to -1.0° (740 mm.) (lit.,²⁶ $-1 \frac{1}{2}^{\circ}$ to $\frac{1}{2}^{\circ}$); α_D^{25} $-0.32 \pm 0.01^{\circ}$ (*l*, 0.985 dm.); d_4^{25} 0.5829; $[\alpha]_D^{25}$ $-0.56 \pm 0.01^{\circ}$ (four observations in two different polarimeter tubes).

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(24) Armstrong's A-6 adhesive, Armstrong Products Company, Warsaw, Indiana.

(25) Coffin and Maass, *J. Am. Chem. Soc.*, **50**, 1427 (1928).

(26) Wagner and Stevenson, *J. Am. Chem. Soc.*, **72**, 5785 (1950).