$$\frac{\mathrm{d}s}{\mathrm{d}t} = \frac{1}{\mathrm{C^{12}O_2}}\left[\mathrm{d/d}t(\mathrm{C^{14}O_2}) - Rs(1-c) + \frac{Rc}{U} - \frac{\mathrm{d/d}t(\mathrm{C^{14}O_2})}{U}\right]$$
$$= \frac{1}{\mathrm{C^{12}O_2}}\left[\mathrm{d/d}t(\mathrm{C^{14}O_2})\left(\frac{U-1}{U}\right) - Rs(1-c) + \frac{Rc}{U}\right]$$

A family of curves of this function was plotted against time for various values of R and U between times 20 and 150 minutes[33]; the ones which most closely matched the experimental curve corresponded to $U = 0.83 \pm 0.03$ and to respiration in the light, $R = 0.5 \pm 0.1$ times as fast as in the preceding dark period. (These results were roughly confirmed by plotting the rate of gas exchange *vs.* CO_2 pressure and extrapolating to the ordinate.) However, the rate of respiration was by no means constant over the period of illumination; initially, at high CO_2 concentrations, it appeared to be even faster than dark respiration, whereas it dropped well below half the dark rate at subsequent low CO_2 pressures. In judging the significance of these figures one must remember that they were obtained by gas phase measurements alone; it is possible that the observed depression of total respiration was merely due to quick re-assimilation of respiratory carbon before it had a chance to leave the cells. This effect and similar diffusion limitations would be expected to reduce external gas exchange most drastically at low CO_2 pressures; our experimental evidence is in accord with this view.

The reason why little, if any, radioactive carbon dioxide was evolved in the light, and why it did appear in a subsequent dark period may be closely connected with the structure of the cells. Strong light may have inhibited the respiration of newly formed compounds located near the chloroplasts, while in the dark these sources were able to contribute a fairly constant share of total respiration. Independent experiments of a different type[34] also indicate that light inhibits the appearance of newly assimilated carbon in respiratory intermediates. It would thus appear that at least some of the observed gas exchange effects are the result of interference of light in intracellular chemistry.

The authors are indebted to Professor C. Ouellet for some valuable discussions, as well as for his assistance in several experiments.

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[33] This treatment was justified by the fact that $\mathrm{d}s/\mathrm{d}t$ was affected mainly by U at first and by R later on; the value of c was not critical.

[34] A. A. Benson and M. Calvin, *J. Exp. Botany*, **1**, 63 (1950).

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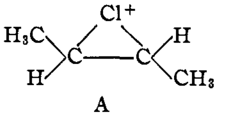
[CONTRIBUTION NO. 1561 FROM THE GATES AND CRELLIN LABORATORIES OF CHEMISTRY, CALIFORNIA INSTITUTE OF TECHNOLOGY]

The Configuration of Optically Active 1,2-Dichloropropane

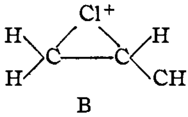
BY W. FICKETT, H. K. GARNER[1] AND H. J. LUCAS

An optically active 1,2-dichloropropane of known configuration, important from the standpoint of absolute configuration, has been obtained from L(+)-*erythro*-3-chloro-2-butanol by reactions not affecting the C–Cl bond. The product, L(−)-1,2-dichloropropane, is believed to have an optical purity exceeding 95%.

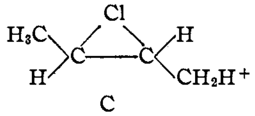
Three substances that lend themselves to the problem of absolute configuration by the theoretical method of Professor J. G. Kirkwood[2] and coworkers are active propylene oxide, 2,3-epoxybutane, and propylene chloride (or bromide) of known configuration. The configurations of propylene oxide[3] and 2,3-epoxybutane[4] are known. The possibility of obtaining propylene bromide of known configuration seems quite remote, in view of the well-known tendency of an adjacent bromine atom to participate in displacement reactions.[5] Moreover, there are fewer physical data available for making the calculations[2c] on the dibromide. The probability that an adjacent chlorine atom might participate in a displacement reaction, as for example, when a propylene chlorohydrin is converted into propylene chloride, is believed to be less than in a similar reaction to form 2,3-dichlorobutane from 3-chloro-2-butanol, because the cyclic chloronium ion, A, is stabilized by resonance more than is B, as a result of hyperconjugation, C, involving two methyl groups in the former and only one in the latter. Thus, B would be less likely to form. It is known that A is not a factor in the reaction of *erythro*-3 chloro-2-butanol with thionyl chloride in the presence of pyridine,[6] although it is a factor in other reactions. The resonance picture that accounts for the relative stabilities of the cyclic intermediates applies also to the activated complexes that precede them, and justifies the conclusions that the activated complex leading to B also is less probable than the activated complex leading to A, and that active 1,2-dichloropropane



A



B



C

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[1] Arthur A. Noyes Research Fellow in Chemistry, 1948–1949.

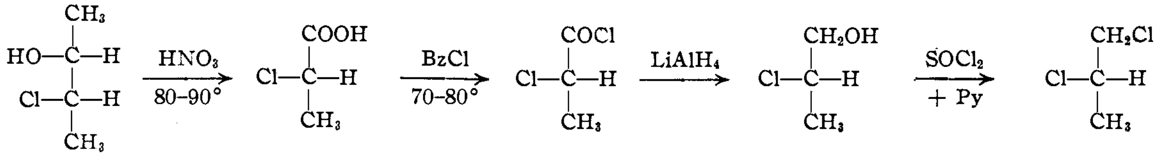
[2] (a) J. G. Kirkwood, *J. Chem. Phys.*, **5**, 479 (1937); (b) W. W. Wood, J. G. Kirkwood and W. Fickett, *J. Chem. Phys.*, in press; (c) W. W. Wood, Thesis, California Institute of Technology, 1951.

[3] P. A. Levene and A. Walti, *J. Biol. Chem.*, **68**, 415 (1926).

[4] H. Lucas and H. K. Garner, THIS JOURNAL, **70**, 990 (1948). The oxide was shown to be related to L(+)-lactic acid through L(−)-α-chloropropionic acid, and the configuration of the latter was established unequivocally. This result is in agreement with the conclusions of a number of other workers (references given) including those of Fregda, who obtained evidence on the basis of the melting points of quasi-racemic compounds; A. Fregda, "The Svedberg," Almquist and Wiksells, Upsala, 1944, p. 261.

[5] (a) S. Winstein and H. J. Lucas, THIS JOURNAL, **61**, 1576, 2845 (1939); (b) S. Winstein, *ibid.*, **64**, 2791, 2792 (1942).

[6] H. J. Lucas and C. W. Gould, Jr., *ibid.*, **63**, 2541 (1941).



I L(+)-*erythro*-3-chloro-2-butanol $[\alpha]^{25}\text{D}$ +8.55°

II L(−)-α-chloropropionic acid $[\alpha]^{25}\text{D}$ −13.98°

III L(+)-α-chloropropionyl chloride $\alpha^{25}\text{D}$ +5.40°

IV L(+)-2-chloro-1-propanol $[\alpha]^{25}\text{D}$ +17.39°

V L(−)-1,2-dichloropropane $[\alpha]^{25}\text{D}$ −5.89°

Fig. 1.—Steps in the conversion of L(+)-*erythro*-3-chloro-2-butanol to L(−)-1,2-dichloropropane.

could be prepared without the intervention of the cyclic intermediate.

If a cyclic intermediate were formed, attack by chloride ion would probably take place at either carbon atom, since the intermediate ion is comparable to the conjugate acid of propylene oxide and this positively charged ion suffers attack at either carbon atom.[7] Complete racemization would be the result if the attack were equal at the primary and secondary carbon atoms; if it took place principally at the primary carbon atom, then partial racemization would be the result. The proportion of isomers produced in the reaction of propylene oxide and hydrochloric acid in the present work indicates a ratio of about 3 to 1 in favor of the primary carbon atom. This agrees with the observations of Forsberg and Smith,[8] who obtained isomers in the ratio of 75 to 25. If the cyclic chloronium ion were an intermediate, the product might have a rotation about half that of an optically pure enantiomorph. Assuming that the cyclic ion does not form, active 2-chloro-1-propanol of known configuration, in a reaction with thionyl chloride in pyridine, would give an active dichloropropane of known configuration. It should be possible to obtain an active dichloride also from 1-chloro-2-propanol of known configuration. In this case, however, it would be necessary to assume that the hydroxyl group is replaced either with or without optical inversion.

The starting point of the synthesis selected is L(+)-3-chloro-2-butanol and the steps are shown in Fig. 1. The configuration of this compound is known,[4] and since, in the various changes, the C-Cl bond is not attacked, the configuration of the asymmetric carbon atom in the desired dichloride is the same as that of C-3 in the chlorobutanol. The changes are: (1) oxidation of the chlorohydrin to L(−)-α-chloropropionic acid with nitric acid; (2) conversion of this to the acid chloride in an exchange reaction with benzoyl chloride; (3) reduction with lithium aluminum hydride to L(+)-2-chloro-1-propanol; and (4) reaction with thionyl chloride in pyridine to give L(−)-1,2-dichloropropane. The configuration of the last is thus unequivocably related to that of L(+)-lactic acid, because the configuration of (−)-α-chloropropionic acid has been established as L.[4]

In the Kirkwood theory[2] the magnitude of rotation as well as the sign can be calculated. The possibility of loss of optical activity should be considered. This includes the optical purity of the starting material and the possibility of racemization at the various steps. The optical purity of L(+)-*erythro*-3-chloro-2-butanol is about 97.5%, judging from the rotation of the distilled material (Table I). The rotation of the glycol from which it was prepared was about 1.3% low, compared with the glycol from another source.[4] The longer reaction time of the diacetate with hydrochloric acid (three weeks, instead of two) probably caused slight con-

Table I

Physical Constants

	Yield, %	B.p., °C.	Pressure, mm.	$n^{25}\text{D}$	d^{25}_4	$\alpha^{25}\text{D}$ obsd. undil.	$\alpha]^{25}\text{D}$
L(+)-*erythro*-3-Chloro-2-butanol[a]	53	55.9–56.1	30	1.4392		+ 9.22	+ 8.69
L(−)-α-Chloropropionic acid	41	80.7–80.9[b]	10	1.4335		−17.56	−13.98
L(+)-α-Chloropropionyl chloride	72	69.1–70.1	200	1.4369		+ 5.40[c]	+ 4.3
L(+)-2-Chloro-1-propanol	67	70.3–70.5	75	1.4365	1.1025	+19.17	+17.39
L(−)-1,2-Dichloropropane	25	96.0–96.1	747	1.4368	1.1478	− 6.76	− 5.89
L(−)-2,3-Dichlorobutane[d]	22	53.2–53.3	80	1.4406	1.1048	−28.43	−25.66
DL-1-Chloro-2-propanol[e]	80	64.5	75	1.4366	1.1075		
DL-1-Chloro-2-propanol[f,g]	*ca.* 66	64.7	75	1.4368			
DL-2-Chloro-1-propanol[f,h]	*ca.* 24	70.3	75	1.4367			
DL-2-Chloro-1-propanol[i]	23	70.3	75	1.4360	1.1020		
DL-1,2-Dichloropropane[j]		96.3–96.4	747	1.4368			

[a] Previous values[4]: b.p. 56.0° (30 mm.), $n^{25}\text{D}$ 1.4397, $\alpha^{25}\text{D}$ +9.47°. [b] Constants of a redistilled part; b.p. of main portion, 67.0-69.5° (5 mm.). [c] Previous values[9]: α_{5780} +5.2°, $[\alpha]_{5780}$ +4.1°. [d] Previous values[6]: b.p. (80 mm.): *meso*, 49.52°, DL 53.16°; $n^{25}\text{D}$: *meso*, 1.4386; DL 1.4409; d^{25}_4: *meso*, 1.1023; DL, 1.1063. [e] From allyl chloride. [f] From propylene oxide and hydrochloric acid. [g] Previous values[8]: b.p. 58° (52 mm.), $n^{20}\text{D}$ 1.4387, d^{20}_4 1.1120. [h] Previous values[8]: b.p. 62° (52 mm.), $n^{20}\text{D}$ 1.4390, d^{20}_4 1.1092. [i] Purified through the 3,5-dinitrobenzoate. [j] Previous values: b.p. 96.20°, $n^{25}\text{D}$ 1.43638, d^{25}_4 1.14929 [R. R. Dreisbach and R. A. Martin, *Ind. Eng. Chem.*, 41, 2875 (1949)]; b.p. 96.4° [O. A. Nelson and H. D. Young, This Journal, **55**, 2429 (1933)].

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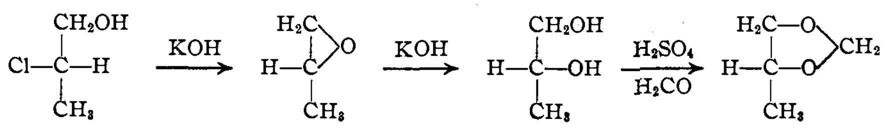
(7) S. Winstein and R. B. Henderson, "Heterocyclic Compounds," Vol. I, edited by R. C. Elderfield, John Wiley and Sons, Inc., New York, N. Y., 1950, p. 37.

(8) G. Forsberg and L. Smith, *Acta Chem. Scand.*, **1**, 577 (1947). This result is somewhat different from that reported earlier, H. Nilsson and L. Smith, *Z. physik. Chem.*, **166A**, 136 (1933).

version to the *threo* isomer, with consequent loss in activity.



IV
L(+)-2-chloro-1-propanol
[α]^{25}D +17.16°

VI
D-1,2-epoxypropane

VII
D-1,2-propanediol

VIII
D(−)-4-methyl-1,3-dioxolane
[α]^{25}D −51.1°

Fig. 2.—Proof of the optical purity of L(+)-2-chloro-1-propanol.

The optical purity of 2-chloro-1-propanol (IV) was established by converting this to the formal through the steps: IV, propylene oxide, VI, propylene glycol, VII, and propylene formal, VIII, without isolation of any of the intermediate products (Fig. 2). This was accomplished with an over-all yield of 33%, to give a formal having a rotation 97.4% of that of the formal obtained from fermentation propylene glycol.[9] Thus the 97.4% optical purity of VIII, and thus of IV is essentially identical with the 97.5% optical purity of I. This leads to the conclusion that there is no loss of optical activity in the three steps, butylene chlorohydrin (I) to propylene chlorohydrin (IV).[10]

The optical purity of 2-chloro-1-propanol is superior to that prepared by the action of nitrous acid on 2-chloro-1-aminopropane,[11] for which α^{18}D was +9.26°. It is evident that some rearrangement accompanied the reaction with nitrous acid, in agreement with the results of Smith and Platon, who found that this reaction, when applied to the DL-chloroamine, leads to a mixture of 2-chloro-1-propanol and 1-chloro-2-propanol.[12]

For checking the constants of the two inactive propylene chlorohydrins, the products of the reaction of hydrogen chloride and DL-propylene oxide were subjected to careful fractional distillation. The lower boiling isomer, 1-chloro-2-propanol, constituted about 73% and the higher boiling, 2-chloro-1-propanol, about 27%. The latter was purified by conversion to the 3,5-dinitrobenzoate and was regenerated in 38% yield from this by an exchange reaction with diethylene glycol catalyzed with *p*-toluenesulfonic acid. The over-all yield from the high boiling fractions of the crude chlorohydrin was 23%. The proportion of isomers formed agreed roughly with that observed by Forsberg and Smith,[3] and there is general correlation of properties, except that the conditions were different (see Table I).

In the final reaction of 2-chloro-1-propanol (IV) with thionyl chloride in pyridine, the possibility of racemization through an intermediate cyclic chloronium ion has already been ruled out, on the basis of similarity of reaction with that of 3-chloro-2-butanol.[6] Thionyl chloride in pyridine was shown to give (−)-2,3-dichlorobutane, essentially free of *meso*-2,3-dichlorobutane, from *erythro*-3-chloro-2-butanol. This stereochemical result is confirmed by a repetition of the experiment with optically pure L(+)-*erythro*-3-chloro-2-butanol. The optically active L(−)-2,3-dichlorobutane possessed boiling point and refractive index close to those of the DL-isomer and quite different from those of the *meso* isomer. There could not have been any significant racemization as a result of an exchange reaction with chloride ion, otherwise the resulting racemization at one carbon atom would have led to the formation of the *meso* isomer. For the same reason there could have been little contribution from a cyclic chloronium intermediate.

The optical purity of L(−)-1,2-dichloropropane is believed to be reasonably high, probably above 95%. If it were assumed to be 97% optically pure, on the basis that no racemization took place at the last step, [α]^{25}D would be −6.07°. Attempts to obtain oxide directly from dichloride were unsuccessful, consequently it was not possible to confirm the optical purity of the final product.

The authors take this opportunity to express their thanks to Dr. G. A. Ledingham, Director, and to Drs. A. C. Neish and J. A. Wheat, of the National Research Council of Canada, for the optically active 2,3-butanediol, the starting material for these researches.

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[9] H. J. Lucas, F. W. Mitchell, Jr., and C. N. Scully, THIS JOURNAL, **72**, 5491 (1950).

[10] A reasonably pure IV was expected and predicted on the basis of the following statements. The optical purity of α-chloropropionic acid, II, is believed to be high because the observed rotation, α^{25}D −17.56°, corresponds roughly to that previously recorded at a different wave length *viz.*, α_{5780} −19.30° (K. Freudenberg, W. Kuhn and I. Bumann, *Ber.*, **63**, 2380 (1930)). If the rotatory dispersion of α-chloropropionic acid were the same as that of α-bromopropionic acid, α_{5780} of −19.30° would correspond to α^{25}D −18.5°.

Although α-bromopropionic acid is known to racemize (K. Freudenberg, "Stereochemie," F. Deuticke, Leipzig, 1933, p. 854), α-chloropropionyl chloride (III) is stable under conditions that cause racemization of α-bromopropionyl bromide (P. Walden, *Ber.*, **28**, 1292 (1895)). It has been reported (Freudenberg, Kuhn and Bumann) that no loss of optical activity takes place when the acid chloride is prepared with thionyl chloride. In the present work it was found that when the acid chloride was prepared separately with thionyl chloride and benzoyl chloride from a partially active acid, the one prepared with benzoyl chloride had a somewhat higher rotation.

Reduction of the acid chloride with lithium aluminum hydride would not be expected to produce racemization except for the effect of chloride ion on the active chlorohydrin, IV, or on any propylene oxide that might conceivably be formed by the action of the bases present on IV. The chlorohydrin would have little chance to undergo an exchange reaction with chloride ion because it immediately separated from solution in the form of a lithium or aluminum salt. If any oxide reacted with chloride ion, attack would be mainly at the primary carbon atom (reference 7, p. 32), with formation of D-1-chloro-2-propanol. The oxide would have the D-configuration because the asymmetric carbon atom is inverted when the ring is formed, and the chlorohydrin also would have the D-configuration because reaction is taking place on the primary carbon atom. When D-1-chloro-2-propanol reacts with thionyl chloride and pyridine, the asymmetric carbon atom would be inverted when the chloro replaces the hydroxyl group, giving L-1,2-dichloropropane, the desired product. Even if some ring opening of the epoxide took place in the opposite direction, the final result would be the same. There is evidence that 1-chloro-2-propanol was not formed to any appreciable extent, because no lower-boiling fraction corresponding to it was encountered during careful fractional distillation of 2-chloro-1-propanol. Also, the physical properties checked with those of DL-2-chloro-1-propanol. Moreover two separate preparations of active propylene chlorohydrin had closely agreeing rotations, *viz.*, +19.17° and +18.92°, respectively.

[11] E. Abderhalden and E. Eichwald, *Ber.*, **51**, 1312 (1918).

[12] L. Smith and E. Platon, *ibid.*, **55B**, 3143 (1922).

Experimental[13,14]

L(+)-*erythro*-**3-Chloro-2-butanol.**—This compound was prepared as previously described[4] from redistilled D(−)-2,3-butanediol (α^{25}D −12.83°). From 360 g. (4.0 moles) of active glycol were obtained 218 g. (53% over-all yield) of chlorohydrin, α^{25}D +9.07. Redistillation of a portion at 30 mm. gave b.p. 55.9–56.1°, n^{25}D 1.4392, α^{25}D +9.22°. In addition, after fractionally distilling the higher boiling material through a 60-cm. column filled with glass helices, there were obtained 78.9 g., 15% yield, of 3-chloro-2-acetoxybutane, b.p. 69.5–69.9° (30 mm.), and 19.1 g. of an intermediate fraction.

L(−)-α-**Chloropropionic Acid.**—This was prepared in several batches, in order to maintain more precise control over the reaction. A typical run is described. In a three-necked 500-ml. flask fitted with reflux condenser, dropping funnel, and stirrer were placed 60 ml. (1.3 moles) of concentrated nitric acid and 15 ml. of water. The nitric acid solution was heated to 85°, a few crystals of sodium nitrite were added, and 32.4 g. (30.4 ml., 0.30 mole) of L(+)-*erythro*-3-chloro-2-butanol were added with slow stirring. At the start only a few drops were added until the reaction had started, as evidenced by the evolution of nitrogen dioxide. The addition was then begun, very slowly at first and then more rapidly as the reaction progressed. It was found that the desirable temperature range, 85–90°, could be maintained with slight cooling if addition of the chlorohydrin was at a rate of about 1 ml. per minute. Toward the last the reaction slowed and it was necessary to add the chlorohydrin more rapidly to maintain the temperature. The addition required about 20 minutes. The mixture was kept at about 85° for 20 minutes after the addition.[15] Anhydrous sodium sulfate was added slowly, with stirring, to the cooled reaction mixture until some solid remained. This served a double purpose in reducing acidity and salting out the crude product, which separated as a light green upper layer. The phases were separated, and the aqueous phase was extracted twice with ether. The ether extracts were combined with the crude product and dried over magnesium sulfate. The material from the separate runs was combined and distilled in one batch. From a total of 130 g. (1.20 moles) of chlorohydrin were obtained 53 g. (41% yield) of α-chloropropionic acid, b.p. 67.0–69.5° (5 mm.). This material may have been slightly impure but was found to give a pure acid chloride and was used directly. About five ml. was refractionated through a small Vigreux column of ten theoretical plates. The main fraction had b.p. 80.7–80.9° (10 mm.) n^{25}D 1.4335, α^{25}D −17.56°, $[\alpha]^{25}$D −13.98°.

L(+)-α-**Chloropropionyl Chloride.**—A number of modifications of the thionyl chloride method were attempted, but the yield could not be made to exceed about 35%. Carefully purified thionyl chloride[16] was found to give lower yields. A partially active acid, 4.54 g. of inactive acid plus 1.46 g. of active acid, α^{25}D −2.95°, equivalent to 6.0 g. (0.055 mole) of α-chloropropionic acid α^{25}D −0.72° (calcd.), 4.1% active, was refluxed 45 minutes with 10 ml. (16.5 g., 0.14 mole) of purified thionyl chloride. Distillation gave 1.9 g., 29% yield, b.p. 98–99°, α^{25}D +0.20°, 3.7% active on basis that the acid chloride, α^{25}D +5.40°, is optically pure.

Benzoyl chloride gave yields of 70–80% in an exchange reaction and was thus much superior. The preparation was carried out as described,[17] using 158 g. (1.13 moles) of benzoyl chloride for 48.3 g. (0.45 mole) of α-chloropropionic acid. The material obtained by direct distillation from the reaction mixture boiled at 60–65° (180 mm.) and was redistilled; weight, 37.4 g., 72% yield, b.p. 69.1–70.1° (200 mm.), n^{25}D 1.4369, α^{25}D +5.40°, $[\alpha]^{25}$D +4.3°.

A partially active acid, 53.4 g. (0.49 mole), α^{25}D −1.13° (6.4% active), was converted to the acid chloride by the benzoyl chloride method, yield, 50.7 g., 82%, b.p. 68.8–70.0° (195 mm.), n^{25}D 1.4369, α^{25}D +0.38°, 7.0% active on the basis that the acid chloride, α^{25}D +5.40°, is optically pure. The exchange reaction would seem, on the basis of the approximate results with partially active materials, to give better optical results than does thionyl chloride.

L(+)-**2-Chloro-1-propanol.**—The procedure used was adapted from that previously described for the reduction of chloroacetic acids.[18] In a three-necked 500-ml. flask fitted with reflux condenser, stirrer and dropping funnel were placed 3.42 g. (0.09 mole, 20% excess) of lithium aluminum hydride and 125 ml. of dry ether. The mixture was refluxed for three hours to effect solution. In the dropping funnel was placed 18.8 g. (0.15 mole) of α-chloropropionyl chloride. When a few drops of the acid chloride was added to the ether solution with vigorous stirring a white precipitate appeared. The reaction mixture was then cooled to 0° for the remainder of the addition, which was completed in 20 minutes. The mixture was stirred for 15 minutes, and then a few ml. of water was added carefully but as rapidly as consistent with the avoidance of a violent reaction. This was followed, again rapidly, with an excess of 10% sulfuric acid.[19] The upper phase was separated and the aqueous portion extracted twice with isopropyl ether. The extracts were combined with the crude chlorohydrin and dried over magnesium sulfate, and finally with drierite. Distillation through the small Vigreux column at 75 mm. gave 9.58 g., 67% yield, of 2-chloro-1-propanol, b.p. 70.3–70.5°, n^{25}D 1.4365, d^{25}_{4} 1.1025, α^{25}D +19.17°, $[\alpha]^{25}$D +17.39°. The smallness of the fore-run, approximately 0.4 g., b.p. 69.9–70.3°, n^{25}D 1.4345, indicated the absence of any appreciable amount of the isomeric 1-chloro-2-propanol. A second preparation from 18.4 g. of acid chloride gave 10.24 g., 72% yield, of chlorohydrin, α^{25}D +18.92°, $[\alpha]^{25}$D +17.16°.

L(−)-**1,2-Dichloropropane.**—The procedure used was that described for 2,3-dichlorobutane.[6] The thionyl chloride had been carefully purified.[16] The pyridine was Merck reagent grade, freshly distilled. In a 200-ml. three-necked flask fitted with reflux condenser, dropping funnel, and stirrer were placed 9.45 g. (8.5 ml., 0.10 mole) of L(+)-2-chloro-1-propanol and 17.5 g. (0.22 mole) of pyridine. From the dropping funnel were added with vigorous stirring 19.6 g. (11.6 ml., 0.20 mole) of thionyl chloride over a period of about 40 minutes. During the addition the flask was kept in a water-bath at room temperature. The stirring was continued for 20 minutes after the addition. The flask was then placed on a steam-bath for two hours, during which time the volume of the upper dichloride layer increased and the lower layer became quite dark. The flask was then allowed to cool to room temperature, and the upper light yellow layer was poured off. The lower black layer was diluted with about half its volume of water and extracted twice with ether. It was found necessary to extract small portions at a time with large volumes of ether to avoid emulsion formation. The ether extracts were combined with the crude product, and extracted four times with 6 *N* hydrochloric acid, twice with water, and dried over potassium carbonate. Distillation was made through the small Vigreux column; weight, 4.52 g., 25% yield. The main fraction had b.p. 94.3–94.4° (747 mm.), n^{25}D 1.4368, d^{25}_{4} 1.1478, α^{25}D −6.76°, $[\alpha]^{25}$D −5.87°.

L(−)-**2,3-Dichlorobutane.**—This was prepared as previously described.[6] From 11.85 g. (0.10 mole) of L(+)-*erythro*-3-chloro-2-butanol was obtained 2.74 g., 21.7% yield, of dichloride, b.p. 53.2–53.3° (80 mm.), n^{25}D 1.4406, d^{25}_{4} 1.1048, α^{25}D −28.43°, $[\alpha]^{25}$D −26.65°. The physical constants check closely those of DL-2,3-dichlorobutane, not those of the *meso* isomer.[6]

1-Chloro-2-propanol by Hydration of Allyl Chloride.—The method of preparation followed that of Dewael.[20] From 336 g. (4.4 moles) of allyl chloride was obtained 334 g., 80.5% yield, of 1-chloro-2-propanol. The product was fractionated twice through a 110-cm. column filled with glass helices. The final main fraction had b.p. 64.5° (75 mm.), n^{25}D 1.4366, d^{25}_{4} 1.1075.

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(13) Analyses by A. Elek.

(14) The individual steps in the preparation of 1,2-dichloropropane were worked out using inactive materials. Then a complete preliminary run starting with α-chloropropionic acid having 6% activity was carried out before working with the optically pure material. In general the rotations of the optically pure compounds were found to be in agreement with those predicted on the basis of these preliminary experiments.

(15) Separate experiments showed that chloropropionic acid was reasonably stable toward hot nitric acid of this concentration containing nitrogen oxides. Longer heating after the addition, to complete the oxidation of intermediate products, might be desirable.

(16) "Organic Syntheses," Coll. Vol. II, John Wiley and Sons, Inc., New York, N. Y., 1944, p. 570.

(17) H. C. Brown, THIS JOURNAL, **60**, 1325 (1938).

(18) C. E. Sroog, C. M. Chih, F. A. Short and H. M. Woodburn, *ibid.*, **71**, 1719 (1949).

(19) The operation were carried out rapidly to minimize the possibility of oxide formation.

(20) A. Dewael, *Bull. soc. chim. Belges*, **39**, 87 (1930).

2-Chloro-1-propanol and 1-Chloro-2-propanol from Propylene Oxide and Hydrochloric Acid.—The method of preparation was essentially that used previously for the butylene chlorohydrins.[6] From 290 g. (5.0 moles) of propylene oxide were obtained 421.5 g., 89.7% yield, of mixed chlorohydrins. Two distillations through a 110-cm. column filled with glass helices gave small fractions of the relatively pure isomers, having constant boiling points when refractionated through the small Vigreux column. The lower-boiling fraction, 1-chloro-2-propanol, b.p. 64.7° (75 mm.), had $n^{25}\text{D}$ 1.4368; the higher boiling fraction, 2-chloro-1-propanol, b.p. 70.3° (75 mm.), had $n^{25}\text{D}$ 1.4367.

3,5-Dinitrobenzoate of 2-Chloro-1-propanol.—In a 500-ml. flask were mixed 138 g. (0.60 mole) of freshly prepared 3,5-dinitrobenzoyl chloride and 57.5 g. (0.61 mole) of 2-chloro-1-propanol (several of the higher boiling fractions from the above separation). The reaction mixture was heated gradually to about 120° over a period of about 45 minutes, then to 140° for another 10 minutes. The mixture was cooled and poured into 500 ml. of dilute potassium carbonate solution, stirred until the mass solidified, collected by suction filtration and washed; weight, 167 g. (96% yield), m.p. 67–73°. Three recrystallizations from ethanol gave 100 g., m.p. 78.0–78.3°.

Anal. Calcd. for $C_{10}H_9O_6N_2Cl$: C, 41.59; H, 3.14; N, 9.70; Cl, 12.30. Found: C, 41.66; H, 3.19; N, 9.77; Cl, 12.30.

Recovery of 2-Chloro-1-propanol from the Ester.—In a 1-liter flask fitted with reflux condenser with a Dry Ice trap at the condenser outlet were placed 400 ml. (445 g., 4.2 moles) of diethylene glycol and 50 g. (0.25 mole) of *p*-toluenesulfonic acid. The system was evacuated to 3 mm. and the mixture was refluxed to remove water. To the cooled mixture was then added 100 g. (0.35 mole) of the 3,5-dinitrobenzoate ester. When 55 g. of liquid had been collected in the trap the material coming over was apparently largely dioxane, although it gave a positive chlorine test. Calcium chloride was added and the mixture was extracted with ether. The ether extracts were dried with calcium chloride and fractionated. The first fraction, 17.2 g., had b.p. 40–68° at 75 mm. The final fraction, 14.1 g., had b.p. 70.4–70.5° at 75 mm., $n^{25}\text{D}$ 1.4363. The final and intermediate fractions were then refractionated, giving 13.5 g., 38% yield on the recovery from the ester and 23% yield for the over-all purification starting with the high-boiling fractions from the mixture. The main fraction, b.p. 70.3°, had $n^{25}\text{D}$ 1.4360, d^{25}_4 1.1020.

Optical Purity of IV.—This was converted to the formal of D(−)-1,2-propanediol, without isolation of any intermediates (Fig. 2). Action of base would almost certainly produce first D(+)-1,2-epoxypropane, which would then hydrate (without loss of optical activity if the solution remains basic) to D(−)-1,2-propanediol.[21] The formal can be prepared directly from this dilute solution of glycol according to the method of Lucas, Mitchell and Scully.[9]

To a solution of 7.8 g. (0.14 mole) of sodium hydroxide in 300 ml. of water was added 6.6 g. (0.07 mole) of IV, $[\alpha]^{25}\text{D}$ +17.16°. The solution was sealed in an ampoule and kept at about 50° for 48 hours. The ampoule was opened and the solution was neutralized and made approximately 0.05 *f* in sulfuric acid. Then 4.5 g. of paraformaldehyde (0.15 mole as formaldehyde) was added. The solution was refluxed under a 60-cm. column filled with glass helices so that the formal could be removed as it was formed. About six hours of refluxing with intermittent take-off of the formal were required to complete the reaction. The collected VIII was dried over potassium carbonate and redistilled; yield 1.8 g., 33%, b.p. 84–85° (745 mm.), $n^{25}\text{D}$ 1.3971, $\alpha^{25}\text{D}$ −50.06°, $[\alpha]^{25}\text{D}$ −51.1°. The same formal previously obtained from optically pure 1,2-propanediol[9] had b.p. 84.2° (745 mm.), $n^{25}\text{D}$ 1.3971, $\alpha^{25}\text{D}$ −51.33°, $[\alpha]^{25}\text{D}$ −52.4°. The optical purity of the present product was thus about 97.4%. Since the optical purity of the original I was estimated to be 97.5%, it is evident that there is no loss of optical activity in the conversion of I to IV, Fig. 1, or of IV to VIII, Fig. 2. The results of Fig. 2 have a parallel in the butane series, for in the steps D(−)-2,3-butanediol → butanediol formal → D(−)-2,3-butanediol the recovered diol has 99.9% of the activity of the initial diol.[22]

Assuming that the hydrolysis of IV is complete, the yield of formal, VIII, is less than that previously reported.[9] Experiments with inactive material indicated that yields of about 70% could be obtained with much less refluxing of the reaction mixture if the hydrolysis and conversion to formal were carried out in more concentrated solutions.

Attempted Hydrolysis of 1,2-Dichloropropane.—The hydrolysis was attempted under different conditions. Basic hydrolysis was used, since the basic hydrolysis of the epoxide has been found to give 1,2-propanediol of higher optical purity than acid hydrolysis.[21] In a typical run 2 g. (0.02 mole) of 1,2-dichloropropane, 2 g. (0.06 mole) of potassium hydroxide and 50 ml. of water were sealed in an ampoule. After three days at 50° the ampoule was cooled and opened. There was considerable pressure within; the issuing inflammable gas had an olefinic odor. The recovery of the glycol was attempted through its formal.[9] The solution was made acid and the methanol removed by fractionation. Water was added to make the volume about 50 ml., the solution was made 0.05 *f* in sulfuric acid, and 1 g. of paraformaldehyde (0.04 mole of formaldehyde) was added to convert any glycol to the corresponding formal. Fractionation of the resulting solution through a 60-cm. column filled with glass helices, however, failed to give any material boiling lower than 99°. The boiling point of the formal is 84°. The hydrolysis was repeated several times, using about the same concentrations of base and dichloride, with water alone, aqueous dioxane and aqueous methanol as solvents and with heating periods up to ten days, and temperatures as high as 80°. In no case was any formal obtained. Analogous results have been reported by Goudet and Schenker[23] with alcoholic potassium hydroxide, the products being largely chloropropenes. The glycol has been obtained from the dichloride at higher temperatures and pressures.[24] but hydrolysis under such drastic conditions would be quite likely to result in racemization.

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