Asymmetric Induction in Friedel-Crafts Reaction with (+)-1,2-Epoxybutane and (−)-2-Chloro-1-butanol

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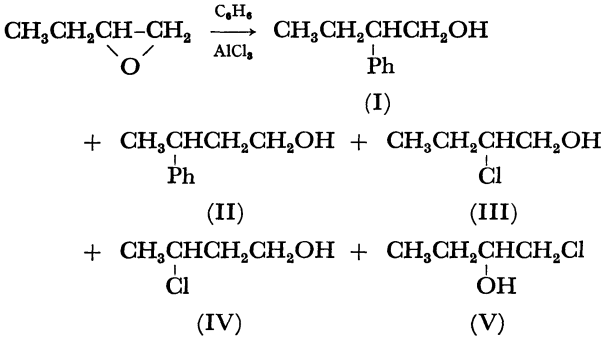
The alkylation of benzene with (+)-1,2-epoxybutane in the presence of Lewis acid gave a mixture of optically active 2-phenyl-1-butanol (I) and 3-phenyl-1-butanol (II) together with a mixture of optically active 2-chloro-1-butanol (III), 3-chloro-1-butanol (IV) and 1-chloro-2-butanol (V). The formation of (−)-I and (−)-III suggests that the ring opening of the epoxide proceeds with an inversion of configuration, while that of optically active II and IV suggests an asymmetric induction at the carbon adjacent to the terminal methyl group of the epoxide. The reactions with aluminum chloride at 20 °C and with stannic chloride at −20 °C gave (+)-II in 10% and (−)-IV in 56% optical yield, respectively. In the reaction of (−)-III with benzene, such an asymmetric induction was also found to give (+)-II in 21—24% optical yield. The probable mechanism of this induction was discussed on the basis of the stability of the transition state conformations.

The Friedel-Crafts alkylation of aromatic hydrocarbon with 1,2-epoxyalkane is known to give 2-aryl-1-alkanol by fission of the secondary C–O bond in the epoxide.[1,2] A similar reaction of 1,2-epoxybutane with benzene was found to give 2-phenyl-1-butanol (I), 2-chloro-1-butanol (III), and 1-chloro-2-butanol (V) together with 3-phenyl-1-butanol (II) and 3-chloro-1-butanol (IV) as products of the isomerized type.[3]



Friedel-Crafts reactions in the presence of Lewis acid are accompanied by isomerization, *e.g.*, the reaction of hex-2-enoic acid, and pent-2-enoic acid with benzene in the presence of aluminum chloride gives a mixture of 3-, 4-, and 5-phenylhexanoic acid,[4] and 3-, and 4-phenyl pentanoic acid,[5] respectively. These results are rationalized on the basis of the mechanism involving the initial carbonium ion formation followed by a series of 1,2-hydride ion shifts. Hata *et al.* reported a similar isomerization in the reaction of 1,2-epoxyoctane with benzene by a Lewis acid catalyst, and concluded that it proceeds through a phenonium ion intermediate.[6] However, the reaction of (+)-propylene oxide in the presence of Lewis acid proceeded with complete inversion of configuration at the secondary carbon atom in the epoxide. Thus the mechanism involving a free carbonium ion should be ruled out in the reaction of epoxide in the presence of Lewis acid.[7]

These studies prompted us to investigate the stereochemistry of the reaction of (+)-1,2-epoxybutane with benzene in the presence of Lewis acid. 3-Phenyl-1-butanol (II) and 3-chloro-1-butanol (IV) were obtained in the reaction in an optically active form, besides (−)-2-phenyl-1-butanol (I) and (−)-2-chloro-1-butanol (III). The formation of optically active II and IV indicates the asymmetric induction at the carbon adjacent to the terminal methyl group of the epoxide. Such an induction in the presence of Lewis acid has not been reported. Its mechanism was discussed on the basis of the stability of the transition state conformations. The stereochemistry of conversion of 2-chloro-1-butanol (III) into 3-phenyl-1-butanol (II) was also investigated.

Results

The reaction of (+)-1,2-epoxybutane with benzene in the presence of Lewis acid was carried out in carbon disulfide at −20—+30 °C. After three hours, the resulting mixture was worked up as reported previously,[3] a mixture of I and II together with a mixture of III, IV, and V being obtained. The structures of these products were identified by comparison of IR and NMR spectra and retention time in gas chromatogram with those of authentic samples. The isomers were separated by means of preparative glpc or recrystallization of the α-naphthylurethane derivatives. The isomer composition in the products was determined by glpc. The results are given in Table 1.

The total yield of the phenylbutanols (I and II) and the relative amount of II to I increased with an increase in temperature, while that of the chlorobutanols (III, IV, and V) decreased with a rise of temperature. The chlorobutanols were scarcely formed at 20—30 °C.

Treatment of III with benzene in the presence of aluminum chloride gave II.[3] In carbon disulfide, the reaction of III with aluminum chloride and bromide gave IV and a mixture of 2-bromo-1-butanol and 3-bromo-1-butanol, respectively (see Experimental). However, no conversion of I into II occurred under these conditions.[3] Thus, if the conversion of III into IV is possible in the reaction of the epoxide with benzene at a higher temperature (0—30 °C), IV formed should react immediately with benzene to afford II, IV thus being scarcely formed.

Stereochemistry. (−)-I and (−)-III, formed by fission of the secondary C–O bond in the (+)-1,2-epoxybutane, were obtained in almost 100% and 55—56% optical yields, respectively (Table 2). The absolute configuration of (+)-1,2-epoxybutane, (−)-I, and (−)-

Table 1. Reaction of (+)-1,2-epoxybutane with benzene in the presence of Lewis acid[a,b] —isomer compositions—

Run	Lewis acid	Temp. (°C)	Phenylbutanol Yield[c] (%)	Phenylbutanol Isomer % I	Phenylbutanol Isomer % II	Chlorobutanol Yield[c] (%)	Chlorobutanol Isomer % III	Chlorobutanol Isomer % IV	Chlorobutanol Isomer % V
1	$AlCl_3$	30	61	13	87	2	trace	0	100
2	$AlCl_3$	20	50	28	72	4	1	trace	99
3	$AlCl_3$	10	25	31	69	38	71	3	26
4	$AlCl_3$	0	33	43	57	35	79	1	20
5	$AlCl_3$	−10	40	51	49	29	81	2	17
6	$AlCl_3$	−30	33	86	14	49	72	17	11
7	$SnCl_4$	−10	41	98	2	34	59	37	4
8	$SnCl_4$	−20	38	98	2	36	61	36	3

a) Mole ratio: (+)-1,2-epoxybutane: Lewis acid: C_6H_6: CS_2=1: 1.2: 20: 10 b) Reaction time, 3 hr.
c) Based on (+)-1,2-epoxybutane used.

Table 2. Stereochemical results of 2-phenyl-1-butanol (I) and 2-chloro-1-butanol (III)[a]

Run	Lewis acid	Temp. (°C)	I $[\alpha]_D^{26}$ [b]	I Optical yield (%)[c]	III $[\alpha]_D^{26}$	III Optical yield (%)[d]
1	$AlCl_3$	30	−11.3° (*c* 4.6, C_6H_6)	76		
2	$AlCl_3$	20	−12.6° (*c* 11, C_6H_6)	83		
3	$AlCl_3$	10	−13.5° (*c* 8.7, C_6H_6)	90	−13.0° (neat)	55
4	$AlCl_3$	0	−18.2° (neat)	100		
5	$AlCl_3$	−10	−14.3° (*c* 18, C_6H_6)	96	−13.3° (neat)	56
7	$SnCl_4$	−10	−15.0° (neat)	83	−18.1° (*c* 4.1, C_6H_6)	
8	$SnCl_4$	−20	−15.6° (neat)	87	−14.5° (*c* 28, C_6H_6)[e]	

a) Starting (+)-1,2-epoxybutane: $[\alpha]_D^{26}$ +8.3° (neat), 93% optical purity.[8b] b) Rotations were taken on the samples which contain II in the following percentage; 7, 9, 3, 4, and 4% in run 1, 2, 3, 7, and 8, respectively. c) Calculated from the reported rotation[9] $[\alpha]_D$ −19.5° (neat) or $[\alpha]_D$ −13.8° (*c* 5.9, C_6H_6) of (−)-II, and the optical purity of (+)-1,2-epoxybutane used. These values were uncorrected for the optical rotation due to II contained. d) Calculated from the reported rotation $[\alpha]_D^{25}$ +23.9° (neat)[9] of (+)-III and the optical purity of (+)-1,2-epoxybutane used. e) This fraction contains 4% of V and 2% of IV.

III has been established as *R*,[8] *R*,[9] and *S*,[10] respectively. It is apparent that the formation of (−)-I and (−)-III from (+)-1,2-epoxybutane proceeds with inversion of configuration in analogy with the reaction of (+)-propylene oxide. The lower optical yield of (−)-III obtained can be interpreted by the exchange of chlorine atom. The secondary halohydrin (V) formed by fission of the primary C–O bond in the epoxide was obtained in too low an yield to permit polarimetric measurement. However, V might be optically pure since the asymmetric center of the starting epoxide remains unchanged.

Table 3. Stereochemical results of 3-phenyl-1-butanol (II) and 3-chloro-1-butanol (IV).

Run	Lewis acid	Temp. (°C)	II $[\alpha]_D^{26}$ [a]	α-Naphthylurethane $[\alpha]_D^{26}$ (*c* 10, $(CH_3)_2CO$)	α-Naphthylurethane Optical yield (%)[b]	IV $[\alpha]_D^{26}$ (*c* 7, C_6H_6)	IV Optical yield (%)[c]
1	$AlCl_3$	30	+2.3° (neat)	+3.1°	6.9		
2	$AlCl_3$	20	+2.3° (neat)	+4.6°	10.2		
3	$AlCl_3$	10	−0.05° (*c* 14, C_6H_6)	+1.5°	3.3		
4	$AlCl_3$	0	−0.5° (neat)	+1.5°	3.3		
5	$AlCl_3$	−10	−2.2° (*c* 14, C_6H_6)	−0.5°	1.1		
6	$AlCl_3$	−30				+14.6°	21.0
7	$SnCl_4$	−10				+38.8°	51.9
8	$SnCl_4$	−20				+41.8°	55.9

a) Rotations were taken on samples containing (−)-I in the following percentage; 8, 4, 4 and 5% in runs 2, 3, 4, and 5, respectively. b) Calculated from the rotation $[\alpha]_D^{26}$ +8.4° (*c* 10, $(CH_3)_2CO$) of α-naphthylurethane of (+)-II (optical purity 17.2%)[12] and the optical purity of (+)-1,2-epoxybutane used. c) Calculated from the rotation $[\alpha]_D^{25}$ +38.2° (*c* 7, C_6H_6) of (+)-IV (optical purity 51%).

TABLE 4. REACTION OF (−)-2-CHLORO-1-BUTANOL (III) WITH BENZENE IN THE PRESENCE OF ALUMINUM CHLORIDE

Run	(−)-III $[\alpha]_D^{26}$ (neat)	Temp. (°C)	Phenylbutanol Yield (%)	Isomer % I	Isomer % II	α-Naphthylurethane of II $[\alpha]_D^{26}$ (c 10, $(CH_3)_2CO$)	α-Naphthylurethane of II Optical yield (%)[c]
10[a]	−17.1°	10	70	trace	100	+8.4°	24.1
11[a]	−12.7°	20	75	10	90	+6.2°	23.7
12[b]	−13.3°	30	74	10	90	+5.5°	21.0

a) Mole ratio; (−)-III: $AlCl_3$: C_6H_6=1: 1.2: 100. b) Reaction was carried out in 1,2-dichloroethane. Mole ratio; (−)-III: $AlCl_3$: C_6H_6: $Cl(CH_2)_2Cl$=1: 1.2: 100: 20. c) See Table 3, footnote c.

Both II and IV were obtained in optically active form (Table 3). The glpc fraction corresponding to II was treated with α-naphthyl isocyanate to give its urethane, since a pure sample of II could not be isolated by means of preparative glpc. After repeated recrystallization of the urethane, the optical rotation was measured to determine the optical yield of II.

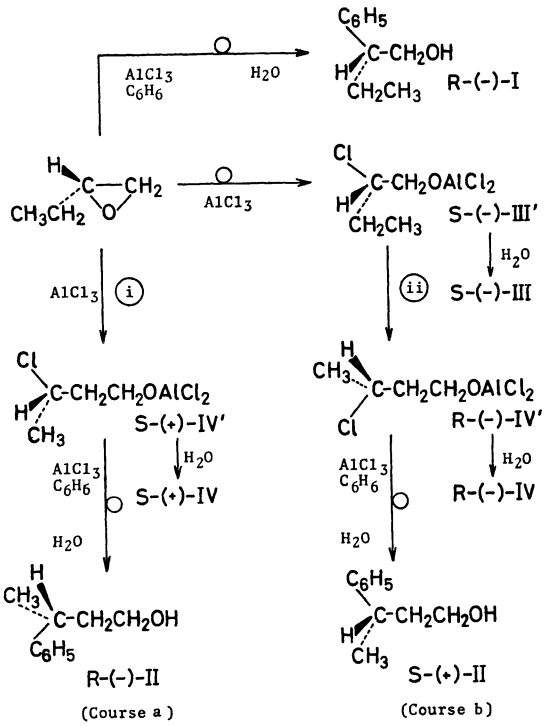
In the presence of aluminum chloride at 20 °C, (+)-II was obtained in 10.2% optical yield, while the reaction at −10 °C gave (−)-enantiomer of II in excess (1.1%) and (+)-IV in 20% optical yield. On the other hand, the reaction with stannic chloride gave (+)-IV in 56% optical yield at −20 °C and hardly any II even at elevated temperature. The results suggest that a new chiral center was formed in the carbon adjacent to the terminal methyl group in the epoxide.

In order to ascertain the possibility of asymmetric induction in the reaction of III to II, (−)-III was allowed to react with benzene in the presence of aluminum chloride. (+)-II was obtained in reasonable optical yield (24—25%) (Table 4). When (+)-II was treated with aluminum chloride in benzene under the same conditions, the specific rotation of (+)-II remained unchanged before and after the reaction. Thus successive racemization of (+)-II should not occur in the reaction with (−)-III.

Discussion

The reaction of optically active IV with benzene by an aluminum chloride catalyst proceeded with inversion of configuration to give II in 20% optical yield.[11] The absolute configurations of (+)-II and (+)-IV have been established as *S*.[10,12] Thus the aluminum chloride salt of III or IV (III′ or IV′) would play an important role as an intermediate in the reaction of *R*-(+)-1,2-epoxybutane to optically active II.

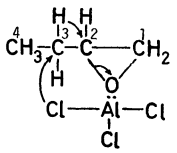
In the overall reaction, two competing courses for the formation of II would be possible (Scheme 1). In course **a**, the ring opening reaction of *R*-(+)-1,2-epoxybutane yields directly *S*-(+)-IV′ (path i) which alkylates benzene with the inversion of configuration to give *R*-(−)-II. In course **b**, *S*-(−)-III′ was initially formed by the fission of the secondary C–O bond of epoxide, and then converted into *R*-(−)-IV′ (path ii) which reacts with benzene to give *S*-(+)-II. Paths i and ii should involve asymmetric induction at the carbon adjacent to the terminal methyl group of the



Scheme 1.

epoxide. The other pathways, *R*-(+)-1,2-epoxybutane →*R*-IV′ and *S*-III′→*S*-IV′, should be excluded.

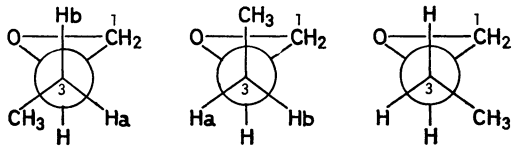
Formation of S-(+)-*IV from* R-(+)-*1,2-Epoxybutane.* The free carbonium ion mechanism was ruled out in the ring opening reaction of epoxide by the Lewis acid catalyst. This asymmetric induction may be rationalized as follows. The epoxide reacts initially with aluminum chloride to give a complex in which the secondary C–O bond is released and either of the hydrogens on C_3 migrates to C_2 from the back of the C_2–O bond to form a hydrogen bridge. Thus, the rotation about the C_2–C_3 bond would be restricted, and the chlorine atom of the complexing aluminum chloride would then attack intramolecularly C_3 from the back of the migrating hydrogen. If the C_2–O bond and the



migrating hydrogen are in one plane and *trans* to each

other, the hydrogen on C_3 would migrate easily to C_2 as in the case of E_2 elimination.[13]

The Newman projections **A**, **B**, and **C** show the possible conformations of *R*-(+)-1,2-epoxybutane in the ground state. The conformational stability of **A**



and **C** seems to be nearly equal, while **B** is less stable because of *gauche* interaction between three bulky groups (CH_3–, –O–, and $-CH_2$). However, the conformation **C**, in which the methyl group is *trans* to the C_2–O bond, should not participate in the asymmetric induction since the formation of the hydrogen bridge between C_2 and C_3 is unfavorable. The preferred conformation of epifluorohydrin has also been found to be type **A** by NMR spectroscopy.[14]

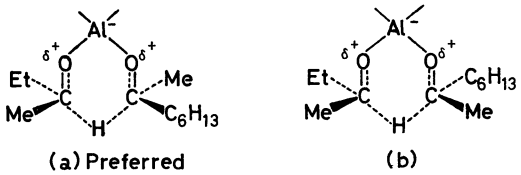
Thus the reaction from the stable **A** involves the bond breaking of C_2–O and the hydrogen bridging of Ha between C_2 and C_3, accompanied by an attack of chloride anion at C_3 from the back of Ha to give *S*-(+)-IV′, while the reaction from **B** should form *R*-(−)-IV′ by displacement of Hb from C_3 to C_2.

The enantiomeric product ratio (*S*/*R*) calculated from the optical yield of IV depends on the free energy difference between the two transition states:

$$\Delta\Delta G^{\ddagger} = \Delta G_S^{\ddagger} - \Delta G_R^{\ddagger} = -RT\ln(S/R)$$

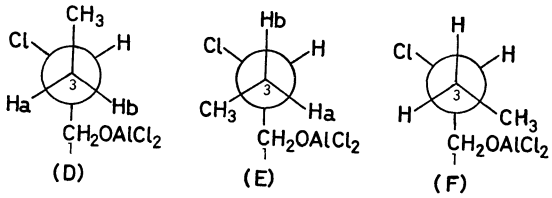
where $\Delta G_S^{\ddagger}$ and $\Delta G_R^{\ddagger}$ are the activation free energy for the formation of *S* and *R* enantiomer, respectively. For example, the optical yield (21%) of *S*-(+)-IV in run 6 corresponds to 0.22 kcal/mol of free energy difference. The value implies the difference of steric interaction of the substituents on C_2 and C_3. Since the conformation in the transition state seems to reflect that in the ground state of the epoxide, the reaction from **A** should preferentially proceed to give *S*-(+)-IV in excess.

In the Meerwein-Ponndorf-Verley reduction of methyl isohexyl ketone with (+)-2-butanol to (+)-methylisohexylcarbinol in the presence of aluminum 2-butoxide, the asymmetric induction has been rationalized in terms of an optimal steric fit of the reagents involved, and the free energy difference between the two possible transition states, (a) and (b), have been reported to be 0.2 kcal/mol.[15] Thus, the above value of $\Delta\Delta G^{\ddagger}$ is reasonable.



When stannic chloride was used as a catalyst, *S*-(+)-IV was obtained in 56% optical yield ($\Delta\Delta G^{\ddagger}$=0.64 kcal/mol). This might be interpreted in terms of the enhanced steric hindrance in the transition state due to the bulkiness of stannic chloride as compared with the case of aluminum chloride.

Formation of S-*(+)-II from* S-*(−)-III′ (or III).* The Lewis acid salt of *S*-(−)-III (III′) also has three conformations of *gauche* type, **D**, **E**, and **F**, in the ground state. In **D** and **E**, the C_2–Cl bond and the migrating



hydrogen are in one plane and *trans* to each other, while the C_2–Cl bond and the methyl group in **F** are *trans* to each other. Thus, the conformation **D** is more stable than **E** because of *gauche* interaction between three bulky groups (Cl–, CH_3–, and $-CH_2OAlCl_2$), and **F** should be ruled out in this asymmetric induction for the same reason as that in the case of conformation **C**.

The first step of the reaction from the stable **D** involves the bond breaking of C_2–Cl and the hydrogen bridging of Hb between C_2 and C_3, accompanied by the attack of chloride anion at C_3 from the back of Hb to give *R*-(−)-IV′. The intermediate then alkylates benzene with inversion of configuration in the presence of aluminum chloride to produce *S*-(+)-II. A similar reaction from **E**, which affords *S*-(+)-IV′ and then *R*-(−)-II, can be ruled out because of its unstable conformation.

On the other hand, *R*-(−)-II could be formed also from *S*-(+)-IV′ in course **a**. The final optical yield of II obtained should therefore be determined by difference of the reaction rate between courses **a** and **b**. Taking into account the preferential formation of *S*-(+)-II in this experiment, the reaction through course **b** would proceed in preference to that through course **a** except at low temperature.

In contrast, at low temperature (run 5, −10 °C) *R*-(−)-II was obtained in 1.1% optical yield. This can be rationalized by considerating that the ability of the catalyst to polarize the C_2–Cl bond of III′ so weakened that the rate of conversion of III′ into IV′ slowed down as compared with the above case.

The reaction with stannic chloride catalyst at low temperature gave two chlorobutanol isomers (III and IV) and 2-phenyl-1-butanol (I), but scarcely any 3-phenyl-1-butanol (II). This might be due to the minor catalytic ability of stannic chloride in the alkylation of benzene with IV (or IV′).

Experimental

All the melting points and boiling points are uncorrected. The optical rotations were taken on a REX photoelectric polarimeter with use of 0.5 and 1 dm tubes. The NMR spectra were determined on a JEOL JNM PS-100 spectrometer operating at a frequency of 100 MHz. Chemical shifts are given in ppm down field from internal TMS. The IR spectra were determined on a JASCO DS-301 spectrometer. Glpc analyses were carried out on a 3 m column of

10% Carbowax 20 M on Diasolid L with a Shimadzu GC-3A instrument. Preparative glpc was carried out on a 3 m column of 25% Carbowax on C-22 with a Yanagimoto GCG-5DH instrument.

Materials. Benzene was washed with concentrated sulfuric acid and distilled after drying on sodium ribbon. Carbon disulfide was distilled over phosphorus pentachloride. Anhydrous aluminum chloride was prepared from high purity aluminum and dry hydrogen chloride. Commercial GR grade stannic chloride was used without further purification.

(+)-1,2-Epoxybutane was prepared by the method of Levene and Walti[8b] and Price and Spector[16] as follows: 1-hydroxy-2-butanone prepared from 1-chloro-2-butanone and potassium formate in methanol, was reduced microbiologically by the reductase of baking yeast to (+)-1,2-butanediol (bp 98—100 °C/18 mmHg, $[\alpha]_D^{26}$ +14.1° (*c* 10, EtOH), lit,[8b] $[\alpha]_D^{25}$ +12.6° (*c* 11, EtOH), 67% yield). The 1,2-butanediol was converted into (−)-1-bromo-2-butanol with dry hydrogen bromide at 0 °C (bp 75—78 °C/20 mmHg, α_D^{26} −8.3° (neat, 1 dm), lit,[8b] α_D^{22} −11.8° (neat, 1 dm), 40% yield). The bromobutanol containing 17% 2-bromo-1-butanol was treated with 50% aqueous solution of potassium hydroxide for conversion into (+)-1,2-epoxybutane. After being dried over anhydrous calcium sulfate (Drierite) and redistillation, the epoxybutane indicated bp 61 °C and α_D^{26} +8.40° (neat, 1 dm) (lit,[8b] α_D^{24} +8.75° (neat, 1 dm)).

Typical Reaction Procedure and Product Indentification. To a stirred mixture of benzene (39 g, 0.5 mol) containing aluminum chloride (8.0 g, 60 mmol) and carbon disulfide (39 g, 0.5 mol) was added a solution of (+)-1,2-epoxybutane (3.6 g, 50 mmol) in benzene (39 g, 0.5 mol). The reaction temperature was maintained at −10 °C throughout the course of addition, which required 1 hr. After the addition the resulting mixture was allowed to stand at −10 °C for 2 hr with stirring and was then poured onto a mixture of crushed ice and 20 ml of concentrated hydrochloric acid. The benzene layer was separated, washed with 6 M hydrochloric acid and then water, and dried over anhydrous sodium sulfate. After removal of solvent, the residue was distilled *in vacuo* to give 0.5 g of a chlorobutanols fraction (bp 82—85 °C/90 mmHg) and 3.9 g of a phenylbutanols fraction (bp 108—115 °C/20 mmHg). After purification by boric ester method,[17] the phenylbutanols fraction showed bp 75—79 °C/4 mmHg. The water layer was extracted five times with 50 ml portions of ether. The combined extracts were dried over anhydrous sodium sulfate. After careful removal of ether, the residue was distilled *in vacuo* to give 0.8 g of a mixture of chlorobutanols (bp 83—95 °C/71 mmHg). The chlorobutanols obtained from benzene and water layer were combined.

Determination of isomer percentages and separation of each isomer by glcp were carried out on a 10% Carbowax column (temperature: 210 °C for the phenylbutanols and 150 °C for the chlorobutanols) and a 25% Carbowax column (temperature: 230 °C for the phenylbutanols and 180 °C for the chlorobutanols), respectively. The isomer percentages and the optical rotations of each isomer are given in Tables 1, 2, and 3.

(−)-2-Phenyl-1-butanol (I): IR(neat); 3340 (νOH), 1050 (νC–OH), 700 and 760 cm^{-1} (δCH, mono-substituted phenyl). NMR ($CDCl_3$, 5%); δ 0.81 (triplet, 3H, $-CH_3$), 1.71 (quintet, 2H, $-CH_2-$), 1.56 (singlet, 1H, –OH), 2.68 (quintet, 1H, –CH=), 3.72 (doublet, 2H, $-CH_2O$), 7.22 (5H, phenyl). α-Naphthylurethane of (−)-I; mp 72 °C; $[\alpha]_D^{26}$ +29° (*c* 1.4, C_6H_6), (Found: C, 78.10; H, 6.70; N, 4.14%).

(+)-3-Phenyl-1-butanol (II): IR(neat); 3340 (νOH), 1050 (νC–OH), 700 and 760 cm^{-1} (δCH, mono-substituted phenyl). NMR ($CDCl_3$, 5%); δ 1.26 (doublet, 3H, $-CH_3$), 1.50 (singlet, 1H, –OH), 1.84 (quartet, 2H, $-CH_2-$), 2.88 (sextet, 1H, –CH=), 3.54 (triplet, 2H, $-CH_2O-$), and 7.20 (5H, phenyl). α-Naphthylurethane of (+)-II; mp 86—87 °C; $[\alpha]_D^{26}$ +4.6 (*c* 10, CH_3COCH_3), (Found: C, 78.47; H, 6.62; N, 4.53%).

(−)-2-Chloro-1-butanol (III): The glpc retention time and IR were identical with those of an authentic sample prepared by the method of Markownikoff[18] and Freudenberg and Lwowski.[10] NMR ($CDCl_3$, 7%); δ 1.06 (triplet, 3H, $-CH_3$), 1.64—1.96 (multiplet, 3H, $-CH_2-$), 2.29 (singlet, 1H, –OH), and 3.56—4.08 (multiplet, 3H, $-CH_2O-$ and –CH=).

(+)-3-Chloro-1-butanol (IV): The glpc retention time and IR were identical with those of an authentic sample prepared by the lithium aluminum hydride reduction of 3-chlorobutanoic acid.[19,20] NMR ($CDCl_3$, 7%); δ 1.56 (doublet, 3H, $-CH_3$), 1.84—2.06 (multiplet, 2H, $-CH_2-$), 2.24 (singlet, 1H, –OH), 3.81 (triplet, 2H, $-CH_2O-$), and 4.25 (sextet, 1H, –CH=).

1-Chloro-2-butanol (V): The glpc retention time and IR were identical with those of an authentic sample prepared by the lithium aluminum hydride reduction of 1-chloro-2-butanone. NMR ($CDCl_3$, 7%); δ 0.98 (triplet, 3H, $-CH_3$), 1.59 (quintet, 2H, $-CH_2-$), 2.27 (singlet, 1H, –OH), and 3.37—3.85 (multiplet, 3H, $-CH_2Cl$ and –CH=).

Reaction of (−)-2-Chloro-1-butanol (III) with Benzene. To a stirred mixture of benzene (29 g, 0.38 mol) containing aluminum chloride (1.81 g, 14 mmol) and carbon disulfide (21 g, 0.28 mol) was slowly added a solution of (−)-III (1.23 g, 11.3 mmol, $[\alpha]_D^{26}$ −12.7——17.1° (neat)) in benzene (15 g, 0.09 mol). The reaction mixture was maintained at 10—20 °C throughout the course of addition. The resulting mixture was worked up as mentioned above. The results are given in Table 4.

Reaction of a Mixture of 2-Chloro-1-butanol (III) and 1-Chloro-2-butanol (V) with Aluminum Chloride. To a stirred mixture of carbon disulfide (42 g, 0.56 mol) containing aluminum chloride (1.6 g, 12 mmol) was added a solution of III and V (III: V=66: 34, 1.1 g, 10 mmol) in carbon disulfide (10 g, 0.13 mol) at 5 °C. After the resulting mixture was treated as mentioned above, a mixture of III, IV and V was obtained (0.44 g, bp 80—90 °C/70 mmHg, III: IV: V= 1: 58: 41).

Reaction of a Mixture of 2-Chloro-1-butanol (III) and 3-Chloro-1-butanol (IV) with Aluminum Bromide. To a stirred solution of carbon disulfide (42 g, 0.56 mol) containing aluminum bromide (3.2 g, 12 mmol) was added a solution of III and IV (III: IV=58: 42, 1.1 g, 10 mmol) in carbon disulfide (10 g, 0.13 mol) at 5 °C. After the resulting mixture was treated as mentioned above, a mixture of 2-bromo-1-butanol (VI) and 3-bromo-1-butanol (VII) was obtained (1.2 g, bp 90—100 °C/40 mmHg, VI: VII=25: 75).

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