Tetrahedron Vol. 36, pp. 3391 to 3398
Pergamon Press Ltd., 1980. Printed in Great Britain

0040-4020/80/1201 3391/$02.00/0

ASYMMETRIC CYCLIZATIONS OF SOME CHLOROHYDRINS CATALYZED BY OPTICALLY ACTIVE COBALT (SALEN) TYPE COMPLEXES

TSUTOMU TAKEICHI, MOTOJI ARIHARA, MICHIHIRO ISHIMORI and TEIJI TSURUTA

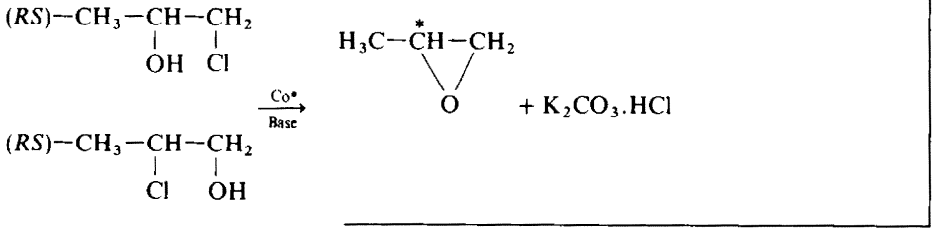
Department of Synthetic Chemistry, Faculty of Engineering, University of Tokyo, Bunkyo-ku, Tokyo 113, Japan

(*Received in Japan 28 January* 1980)

Abstract—Optically active chloromethyloxirane was obtained from 1,3-dichloro-2-propanol by a process of asymmetric synthesis. The highest enantiomeric excess (e.e.) of chloromethyloxirane that could be obtained was 67%, using Co(II) (3,5-Cl,Cl-sal)$_2$(*S*-CHXDA) and K_2CO_3 as the catalyst and base, respectively. For purpose of comparison, asymmetric cyclizations of racemic 2,3-dichloro-1-propanol and 2-chloro-1-propanol were examined; optically active chloromethyloxirane and methyloxirane were obtained according to kinetic resolution mechanisms, although the optical purities of oxiranes formed were not so high. The mechanisms for the asymmetric reactions were investigated by circular dichroism and absorption spectroscopies. It was found that the cobalt (salen) type complex forms a new complex with alkali metal carbonate, similarly to the function of crown ether. The substrate interacts with the newly formed chiral complex, followed by cyclization to give optically active oxiranes.

Several studies have been carried out on the asymmetric epoxidations of olefins with various peracids.[1] Of particular interest is the highly asymmetric induction in the epoxidation of olefins with alkyl hydroperoxide catalyzed by optically active transition metal (Mo or V) complexes, as reported by Yamada *et al.*[2] and Sharpless *et al.*[3] The substrates used for the asymmetric reactions, however, have rather complicated structures, as is the case for most asymmetric reactions[4] giving rise to highly asymmetric values.

Recently, we[5,6] succeeded in a one-step synthesis of optically active methyloxirane by the cyclization of propylene chlorohydrin with base, where an optically active cobalt(salen) type complex, N,N′-disalicylidene-1(*R*),2(*R*)-1,2-cyclohexanediaminatocobalt(II), Co(II)(sal)$_2$(*R*-CHXDA), was used as the catalyst.



As a continuation of our study, we report here the synthesis of optically active chloromethyloxirane from the prochiral substrate, 1,3-dichloro-2-propanol, by the mechanism of asymmetric synthesis. The syntheses of optically active chloromethyloxirane and methyloxirane from racemic 2,3-dichloro-1-propanol and 2-chloro-1-propanol, respectively, are also reported in terms of elucidated stereochemistry for the asymmetric cyclizations. The mechanisms of the asymmetric reactions will be discussed in connection with the rigid chiral structure of the asymmetric cobalt complex.

EXPERIMENTAL

Measurements. CD spectra were measured using a JASCO Model J-20 spectrometer. Optical rotations were observed using a Perkin–Elmer Polarimeter Model 241. Glc analyses were carried out with a Hitachi Model K-53 Gas Chromatograph equipped with a column containing PEG.

Reagents. 1-Chloro-2-propanol and 2-chloro-1-propanol were synthesized according to methods described.[7] 1,3-Dichloro-2-propanol and 2,3-dichloro-1-propanol (Tokyo Kasei Co.) were dried over drierite and distilled in a dry N_2 atmosphere. Other reagents used were purified by standard methods described elsewhere.[8]

Co(II)(sal)$_2$(*R*-CHXDA). The Co(II)(sal)$_2$(*R*-CHXDA) complex was prepared by methods described previously.[9] *R*-CHXDA (1(*R*),2(*R*)-1,2-cyclohexane-diamine) was prepared according to the procedure reported by Asperger *et al.*[10] $[\alpha]_D^{24} = -44.1°$ (free diamine; 3% methanolic soln), $[\alpha]_D^{24} = -15.8°$ (dihydrochloride salt; 20% aqueous soln), lit.,[10] $[\alpha]_D^{25} = -15.8°$ (dihydrochloride salt; 20% aqueous soln).

Co(II)(4-OH-sal)$_2$(*S*-CHXDA). The enantiomeric excess(e.e.) of (*S*)-1,2-cyclohexanediamine (*S*-CHXDA) used was 34.2%, $[\alpha]_D^{24} = +15.1°$ (free diamine; 3% methanolic soln). *S*-CHXDA (10.33 g, 0.0905 mol) and 2,4-dihydroxybenzaldehyde (25.0 g, 0.1810 mol) was allowed to react in 60 ml EtOH for 30 min at 60° to give Schiff-base as an orange-red powder in 69% yield (22.0 g). The Schiff-base (5.73 g, 0.0162 mol) was allowed to react with anhyd cobalt acetate (2.87 g, 0.0162 mol) in hot 1-propanol. The resulting crude Co- complex was suspended in 1-propanol and purified by filtration. N,N′-bis(4-hydroxysalicylidene)-1(*S*),2(*S*)-1,2-cyclohexanediaminatocobalt(II), Co(II)(4-OH-sal)$_2$(*S*-

CHXDA), was obtained as brown powder in 95% yield. (Found: C, 56.40; H, 6.06; N, 5.69%. Calc. for $CoC_{20}H_{20}N_2O_4$: C, 58.40; H, 4.90; N, 6.81%). IR(KBr) 3250 (broad), 2920, 1605, 1540, 1450, 1360, 1230, 1130, 990, 845 cm^{-1}.

The complexes described hereafter were prepared analogously. Co(II) (3-MeO-sal)$_2$(*S*-CHXDA). The Schiff-base (1.99 g, 0.00521 mol), obtained from 2-hydroxy-3-methoxybenzaldehyde and *S*-CHXDA (e.e. 34.2%) as a yellow powder, was allowed to react with anhydrous cobalt acetate (0.922 g, 0.00521 mol) in 100 ml of 1-propanol at 60° for 1 hr with stirring. The brown precipitate was filtered off and then suspended in 1-propanol for purification. N,N'-bis(3-methoxysalicylidene)-1(*S*),2(*S*)-1,2-cyclohexanediaminatocobalt(II), Co(II)(3-MeO-sal)$_2$(*S*-CHXDA), was obtained in 50% yield. (Found: C, 57.07; H, 5.48; N, 5.78%. Calc. for $CoC_{22}H_{24}N_2O_4$: C, 60.14; H, 5.51; N, 6.38%). IR (KBr) 3400, 2920, 1605, 1545, 1472, 1450, 1325, 1250, 1230, 1085, 983, 740, 570 cm^{-1}.

Co(II)(3,5-Cl,Cl-sal)$_2$(*R*-CHXDA). The Schiff-base (7.45 g, 0.0162 mol), obtained from 3,5-dichlorosalicylaldehyde and *F*-CHXDA (e.e. 100%) as an orange resin-like solid, was suspended in 80 ml of hot 1-propanol, and anhyd cobalt acetate (2.87 g, 0.0162 mol) was added, and the mixture was stirred at 60° for 1 hr. The brown precipitate was filtered off and then suspended in 60 ml of 1-propanol for purification. N,N'-bis(3,5-dichlorosalicylidene-1(*R*),2(*R*)-1,2-cyclohexanediaminatocobalt(II), Co(II)(3,5-Cl,Cl-sal)$_2$(*R*-CHXDA), was obtained in 81% yield. (Found: C, 46.92; H, 3.00; N, 5.49; Cl, 27.33%. Calc. for $CoC_{20}H_{16}N_2O_2Cl_4$: C, 46.45; H, 3.12; N, 5.42; Cl, 27.43%). IR (KBr) 2930, 1610, 1440, 1330, 1215, 1180, 870, 770, 760 cm^{-1}.

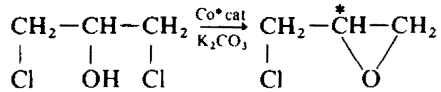
Ni(II)(sal)$_2$(*S*-CHXDA). The e.e. of the Schiff-base, (salH)$_2$(*S*-CHXDA), used was 34.2%. The green powder of $Ni(CH_3COO)_2.4H_2O$ (4.98 g, 0.02 mol) was added to 50 ml of the hot 1-propanol soln of the Schiff-base (6.45 g, 0.02 mol) to give a red-brown suspended soln. The precipitate was filtered off and then suspended in 50 ml of 1-propanol for purification. N,N'-disalicylidene-1(*S*),2(*S*)-1,2-cyclohexanediaminatonickel(II), Ni(II)(sal)$_2$(*S*-CHXDA), was obtained in 93% yield. (Found: C, 63.79; H, 5.25; N, 7.65%. Calc. for $NiC_{20}H_{20}N_2O_2$: C, 63.38; H, 5.31; N, 7.38%). IR (KBr) 2920 1620, 1536, 1470, 1450, 1350, 1330, 1150, 910, 755, 740 cm^{-1}.

Asymmetric cyclization of chlorohydrins. A representative procedure is as follows. Co(II)(sal)$_2$(*R*-CHXDA) (0.1895 g, 0.5 mmol) and K_2CO_3 (8.292 g, 60 mmol) were placed in a 50 ml-flask. The mixture was dried at 130 ~ 150° for 3 hr *in vacuo*. After cooling, 40 ml of solvent was added under a dry nitrogen. To the suspended solution, 120 mmol of chlorohydrin was added and stirred at 25°. After an appropriate reaction time, the product and non-reacted substrate were analyzed by gas chromatography. The oxirane formed and non-reacted chlorohydrin were isolated by fractional distillation and their optical rotations were measured.

RESULTS AND DISCUSSION

Synthesis of optically active chloromethyloxirane by asymmetric synthesis. In Fig. 1 is shown the optically active Co(salen) type complex, N,N'-disalicylidene-1(*R*),2(*R*)-1,2-cyclohexanediaminatocobalt(II), Co(II)(sal)$_2$(*R*-CHXDA), and its analogues having various substituted benzene rings: Co(II) (4-OH-sal)$_2$(*S*-CHXDA), Co(II)(3-MeO-sal)$_2$(*S*-CHXDA), Co(II)(3,5-Cl,Cl-sal)$_2$(*R*-CHXDA) and Ni(II)(sal)$_2$(*S*-CHXDA) (Experimental). The structure of the Co(II)(sal)$_2$(*R*-CHXDA) was established[9] as a low-spin square-planar tetradentate complex having a λ-conformation for the central chelate ring around the cobalt atom.

By using the above optically active Co(salen) type complexes as catalysts, asymmetric cyclizations of 1,3-dichloro-2-propanol were examined. The reaction involves asymmetric elimination of hydrogen chloride from 1,3-dichloro-2-propanol with base, potassium carbonate being found to be the most favorable among several mild bases in the preliminary examination.



(1)

1,3-dichloro-2-propanol (prochiral) — chloromethyloxirane (optically active)

The results of cyclization of 1,3-dichloro-2-propanol catalyzed by the optically active cobalt (salen) type complexes are summarized in Table 1. Chloromethyloxirane was obtained selectively from most reaction systems. When Co(II)(sal)$_2$(*R*-CHXDA), which has no substituent in the benzene ring, was used, chloromethyloxirane (configuration *S*[11]) of 34.8% e.e. was obtained in high (or theoretical) yield (50%, see initial condition: K_2CO_3/substrate = 1/2 (mol/mol)).

It should be noted that (*S*)(+)-chloromethyloxirane having a high e.e. value (59.5%) was obtained by using Co(II) (3,5-Cl,Cl-sal)$_2$(*R*-CHXDA) as the catalyst. In the experiment using an equimolar amount of K_2CO_3 (100 mmol) for the substrate, chloromethyloxirane of 54% e.e. was obtained in 65% yield. When Co(II) (3,5-Cl,Cl-sal)$_2$(*S*-CHXDA) (e.e. 34.2%) was used, (R)(−)-chloromethyloxirane of 22.9% e.e. was obtained. This value for chloromethyloxirane corresponds to 67.0%

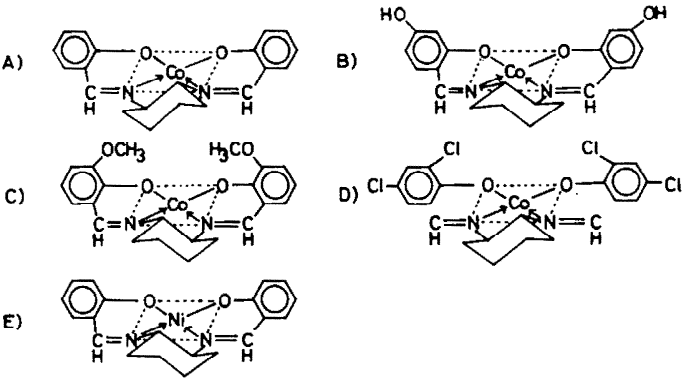


Fig. 1. The structure of complexes. (A) Co(II)(sal)$_2$(*R*-CHXDA), (B) Co(II)(4-OH-sal)$_2$(*S*-CHXDA), (C) Co(II)(3-MeO-sal)$_2$(*S*-CHXDA), (D) Co(II)(3,5-Cl,Cl-sal)$_2$(*R*-CHXDA), (E) Ni(II)(sal)$_2$(*S*-CHXDA).

Table 1. Asymmetric cyclization of 1,3-dichloro-2-propanol[a)]

Complex	Substrate (mmol)	K_2CO_3 (mmol)	Time (day)	Conv.[b)] (%)	CMO/Sub[c)] (%)	CMO d) yield (%)	CMO e) $[\alpha]_D^{20}$ (°)	CMO f) e.e. (%)
Co(II)(sal)$_2$(R-CHXDA)	100	50	6	87.5	57	49.9	+ 8.90	34.8
Co(II)(3,5-Cl,Cl-sal)$_2$(R-CHXDA)	100	50	4	53.3	95	50.6	+15.16	59.2
Co(II)(3,5-Cl,Cl-sal)$_2$(R-CHXDA)[g)]	100	50	4	54.5	97	52.9	+15.23	59.5
Co(II)(3,5-Cl,Cl-sal)$_2$(R-CHXDA)	100	100	4	84.1	77	64.8	+13.69	53.5
Co(II)(3,5-Cl,Cl-sal)$_2$(R-CHXDA)	50	50	19[h)]	49.3	96	47.3	+11.40	44.5
Co(II)(3,5-Cl,Cl-sal)$_2$(S-CHXDA)	100	50	6	59.8	82	49.0	- 5.87	22.9(67.0)[i)]
Co(II)(3-MeO-sal)$_2$(S-CHXDA)	100	50	6	48.7	97	47.2	- 0.32	1.3(3.7)[i)]
Co(II)(4-OH-sal)$_2$(S-CHXDA)	100	50	6	52.4	93	48.7	- 3.96	15.5(45.2)[i)]
Ni(II)(sal)$_2$(S-CHXDA)	100	50	6	51.2	74	37.9	- 0.00	0.0(0.0)[i)]
----------	100	50	6	50.3	99	49.8	0	0

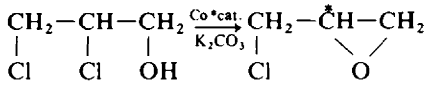
a) Complex 0.1 mmol, solvent CH_2Cl_2 40 ml, 25°C, under a nitrogen atmosphere.
b) Conversion of substrate. c) (Chloromethyloxirane formed)/(substrate converted) (mol/mol)x100.
d) Chemical yield of chloromethyloxirane. e) Specific rotation of CMO formed.
f) Optical purity of CMO formed; $[\alpha]_D^{18}$=-25.61°(Ref.11) for optically pure CMO.
g) Complex (0.3 mmol) was used. h) 0~5°C for 11 days and then 10~15°C for 8 days.
i) Estimated e.e. values considering e.e.(34.2%) for catalysts by the eq :(e.e. for CMO)/(34.2)x100.

e.e. when corrected by the equation: (e.e. % for chloromethyloxirane)/(e.e. % for catalyst) × 100.

The effectiveness of a series of cobalt (salen) type complexes as catalysts for this asymmetric reaction is in the following order: Co(II)(3,5-Cl,Cl-sal)$_2$(*R*-CHXDA) > Co(II)(sal)$_2$(*R*-CHXDA) ≃ Co(II)(4-OH-sal)$_2$(*S*-CHXDA) > Co(II)(3-MeO-sal)$_2$(*S*-CHXDA) > Ni(II)(sal)$_2$(*S*-CHXDA). In the reaction system involving Ni(II)(sal)$_2$(*S*-CHXDA), no sign of asymmetric cyclization was observed. The turn-over number of these complexes as catalysts were found to be very high (chloromethyloxirane(mol)/cobalt complex (mol) ≃ 500), the highest one being observed to be 840.

The time-conversion curve for the reaction using Co(II)(3,5-Cl,Cl-sal)$_2$(*R*-CHXDA) as the catalyst is shown in Fig. 2. The rate of the reaction does not change significantly when the concentration of base is altered. The high e.e. value for the product is considered to come about because potassium carbonate, sparingly soluble in dichloroethane solvent, is solubilized by the addition of the cobalt complex; thus, most substrate molecules are cyclized under the asymmetric influence of optically active cobalt complex (see *Mechanism of asymmetric cyclization*).

Synthesis of optically active chloromethyloxirane by kinetic resolution. In comparison with the reaction of 1,3-dichloro-2-propanol, which proceeds by the mechanism of asymmetric synthesis (eqn 1), the asymmetric cyclization of racemic 2,3-dichloro-1-propanol (eqn 2) was examined under similar conditions; the optically active chloromethyloxirane is expected to be formed by a mechanism of kinetic resolution, where the e.e. of oxirane formed should decrease with conversion.



(2)

2,3-dichloro-1-propanol (racemic) — chloromethyloxirane (optically active)

The results of cyclization of 2,3-dichloro-1-propanol by using Co(II)(sal)$_2$(*R*-CHXDA) as a catalyst are given in Table 2. (*R*)(−)-chloromethyloxirane having a low e.e. value (16%) was obtained in low yield (10%);

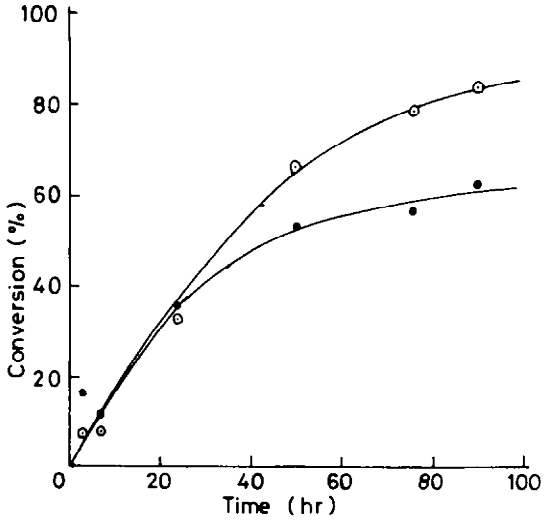


Fig. 2. Curves for the conversions of 1,3-dichloro-2-propanol with time in the systems of 50 mmol (●) and 100 mmol (○) of K_2CO_3 used. Other conditions: Co(II)(3,5-Cl,Cl-sal)$_2$(*R*-CHXDA) 0.1 mmol, CH_2Cl_2(solvent) 40 ml.

Table 2. Asymmetric cyclization of 2,3-dichloro-1-propanol[a)]

Complex	Substrate (mmol)	K_2CO_3 (mmol)	Time (day)	Conv.[b)] (%)	CMO/Sub[c)] (%)	CMO yield[d)] (%)	CMO $[\alpha]_D^{20}$[e)] (°)	CMO e.e.[f)] (%)
Co(II)(sal)$_2$(R-CHXDA)	100	50	6	15.0	69	10.4	-4.12[g)]	16.1
----------	100	50	6	3.8	60	2.3	0	0

a)~f) As in Table 1. g) The specific rotation of the non-reacted substrate recovered: $[\alpha]_D^{20}$ = +0.21°(neat) (unkown configuration).

cf chloromethyloxirane obtained with the same catalyst by eqn (1): 34.8% e.e. and 49.9% yield.

The results of cyclization of 2-chloro-1-propanol to be described later suggest that (*S*)(−)-2,3-dichloro-1-propanol is preferentially cyclized to give (*R*)(−)-chloromethyloxirane with an inversion of configuration at the asymmetric carbon.

Synthesis of optically active methyloxirane by kinetic resolution. Asymmetric cyclization of racemic 2-chloro-1-propanol was studied in detail. Since the configurations and optical activities of optically pure 2-chloro-1-propanol[12] and methyloxirane[13] are well known, this investigation provided some information on the stereochemistry of the above two asymmetric cyclizations which gave optically active chloromethyloxirane.

The results of the asymmetric cyclization of 2-chloro-1-propanol using the cobalt(salen) type complexes (Fig. 1) as catalysts are summarized in Table 3. The asymmetric reaction using Co(II)(sal)$_2$(*R*-CHXDA) gave (*S*)(−)-methyloxirane while the non-reacted substrate showed (+) optical rotation. The fact indicates that (*R*)(−)-2-chloro-1-propanol is preferentially bound to the optically active cobalt complex and is converted to (*S*)(−)-methyloxirane with an inversion of the configuration at the asymmetric carbon. Most of the e.e. values of methyloxirane formed are in approximate agreement with the $e.e._{calcd}$ values obtained by assuming that the reaction proceeds by a complete kinetic resolution mechanism (see note g) in Table 3).

The effects of substituents of the complexes on the cyclizations were remarkable in a similar way to the asymmetric reactions of 1,3-dichloro-2-propanol, although the order of the effectiveness of the complexes as asymmetric catalysts was different. The highest e.e. of methyloxirane was observed in the reaction using Co(II)(sal)$_2$(*R*-CHXDA). When Co(II)(4-OH-sal)$_2$(*S*-CHXDA) was used, the roughly estimated optical yield of methyloxirane formed (see note h) in Table 3) was similar to the e.e. value of methyloxirane obtained in the Co(II)(sal)$_2$(*R*-CHXDA)-catalyzed reaction, though the conversion was very low. A poor optical yield of methyloxirane observed in the Co(II)(3-MeO-sal)$_2$(*S*-CHXDA)-catalyzed reaction may be attributed to the bulky methoxy substituent. In the reaction with Co(II) (3,5-Cl,Cl-sal)$_2$(*S*-CHXDA) and Ni(II)(sal)$_2$(*S*-CHXDA) as catalysts, the results were

Table 3. Synthesis of methyloxirane (MO) by the asymmetric cyclization of 2-chloro-1-propanol (2-Cl-1-PrOH) using various chiral complexes[a)]

Catalyst	Conv.[b)] (%)	MO/2-Cl-1-PrOH[c)] (%)	MO $[\alpha]_D^{20}$[d)] (°)	MO e.e.[e)] (%)	2-Cl-1-PrOH $[\alpha]_D^{20}$[f)] (°)	2-Cl-1-PrOH e.e.[g)] $_{calcd}$ (%)
Co(II)(sal)$_2$(R-CHXDA)	40.3	88	-3.34	26.6	+3.25	27.7
Co(II)(4-OH-sal)$_2$(S-CHXDA)	9.5	90	+1.25	10.0(29.2)[h)]	-0.25	13.4(39.2)[h)]
Co(II)(3-MeO-sal)$_2$(S-CHXDA)	39.2	84	+0.04	0.3(0.9)[h)]	-0.07	0.7(1.9)[h)]
Co(II)(3,5-Cl,Cl-sal)$_2$(S-CHXDA)	21.2	91	+0.35	2.8(8.2)[h)]	-0.14	2.9(8.5)[h)]
Ni(II)(sal)$_2$(S-CHXDA)	23.4	85	-0.01	0.1(0.2)[h)]	+0.00	0.1(0.2)[h)]
----------	17.8	82	0	0	0	0

a) Co(II)(sal)$_2$(R-CHXDA) 0.5 mmol, other Co^{II} and Ni^{II} catalysts 0.2 mmol, K_2CO_3 60 mmol, 2-Cl-1-PrOH 120 mmol, 1,2-dichloroethane (solv.) 40 ml, 25°C, 5 days.
b) Conversion of 2-chloro-1-propanol. c) MO formed / 2-Cl-1-PrOH converted (mol/mol)x100.
d) Specific rotation of MO formed. e) Optical purity of MO formed; $[\alpha]_D$=+12.53°(Ref. 13) for optically pure (R)(+)-MO. f) Specific rotation of non-reacted 2-Cl-1-PrOH recovered.
g) Optical purity of MO evaluated from the optical purity of non-reacted 2-Cl-1-PrOH; $e.e._{calcd}=[\alpha]/[\alpha_o]\{(100-conv.)/conv.\}x100$; $[\alpha_o]_D^{25}$=17.37°(neat)(Ref.12) for pure (S)(+)-2-Cl-1-PrOH. h) Estimated e.e. values considering e.e.(34.2%) for catalysts by the eq : (e.e. for MO)/(34.2)x100.

Table 4. Synthesis of methyloxirane (MO) by the asymmetric cyclization of 2-chloro-1-propanol (2-Cl-1-PrOH) by using various metal carbonates[a]

Co^{II}[b]	Base	Solv.[c]	Time (day)	Conv.[d] (%)	MO[e] / 2-Cl-1-PrOH (%)	MO $[\alpha]_D^{20}$[f] (°)	MO e.e.[g] (%)	2-Cl-1-PrOH $[\alpha]_D^{20}$[h] (°)	2-Cl-1-PrOH e.e.[i] (%) calcd
yes	Na_2CO_3	Diox	6	6.1	61	-3.29	26.3	+0.60	54.0
yes	K_2CO_3	Diox	5	8.8	84	-4.39	35.0	+0.64	38.3
---	K_2CO_3	Diox	5	trace	--	0	0	0	0
yes	Li_2CO_3	DCE	6	3.1	--	----	----	----	----
---	Li_2CO_3	DCE	6	0.6	--	0	0	0	0
yes	Na_2CO_3	DCE	5	10.1	80	----	----	+0.69	35.1
---	Na_2CO_3	DCE	5	1.0	--	0	0	0	0
yes	K_2CO_3	DCE	5	40.3	88	-3.34	26.6	+3.25	27.7
---	K_2CO_3	DCE	5	17.8	82	0	0	0	0
yes	Rb_2CO_3	DCE	4	39.1	91	-2.44	19.5	+1.88	16.8
---	Rb_2CO_3	DCE	4	35.9	88	0	0	0	0
yes	Cs_2CO_3	DCE	5	40.8	94	-0.92	7.3	+0.79	6.6
---	Cs_2CO_3	DCE	5	39.8	85	0	0	0	0
yes	$NaHCO_3$	DCE	5	7.9	90	-1.60[j]	----	+0.76	50.6
yes	$CaCO_3$	DCE	6	0.0	--	----	----	----	----
yes	$BaCO_3$	DCE	6	0.0	--	----	----	----	----

a) Co(II)(sal)$_2$(R-CHXDA) 0.5 mmol, Base 60 mmol, 2-Cl-1-PrOH 120 mmol, solv. 40 ml, 25°C. b) Co(II)(sal)$_2$(R-CHXDA).
c) Diox : dioxane, DCE : 1,2-dichloroethane. d)~i) As in Table 1.
j) Measured in 1,2-dichloroethane solution.

very unfavorable with regard to both conversion and optical yield of methyloxirane.

Next, asymmetric cyclizations of 2-chloro-1-propanol with a series of alkali metal carbonates were carried out, using Co(II) (sal)$_2$(*R*-CHXDA) as the catalyst. The results are summarized in Table 4. The highest enantiomeric excess of methyloxirane formed was 35%, achieved in the cyclization of 2-chloro-1-propanol with potassium carbonate in dioxane.

The reaction rate in 1,2-dichloroethane was observed to increase in the following order: $Li_2CO_3 \ll Na_2CO_3 < K_2CO_3 < Rb_2CO_3 < Cs_2CO_3$, although weaker bases such as Na_2CO_3 and K_2CO_3 were much more favorable in view of asymmetric selectivity.

It is considered that the reaction proceeds by the following two parallel pathways: the cobalt-catalyzed reaction (eqn 3) and the non-catalyzed reaction (eqn 4).

$$\text{2-chloro-1-propanol} \xrightarrow[\text{Base}]{\text{Co* cat.}} \text{methyloxirane (optically active)} \quad (3)$$

$$\text{2-chloro-1-propanol} \xrightarrow[\text{Base}]{} \text{methyloxirane (racemic)} \quad (4)$$

With stronger bases such as Rb_2CO_3 and Cs_2CO_3, 2-chloro-1-propanol was cyclized easily even in the absence of the cobalt catalyst (Table 4). On the other hand, cyclization with weaker bases such as Na_2CO_3 and K_2CO_3 could proceed significantly only with the cobalt catalyst, thus resulting in a highly asymmetric selective reaction. The ratio of the cobalt-catalyzed reaction (eqn 3) to a non-catalyzed reaction (eqn 4) seems to be the decisive factor in the asymmetric selectivity for the above cyclizations with metal carbonates.

Mechanism of asymmetric cyclization. In order to obtain insight into the feature of the asymmetric reactions, binary systems of Co(II)(sal)$_2$(*R*-CHXDA) with a series of alkali metal carbonates were investigated by absorption and CD spectroscopies, as shown in Fig. 3.

The absorption spectra of the binary systems of Co(II)(sal)$_2$(*R*-CHXDA) and M_2CO_3(M=Li, Na, K, Rb, and Cs) are similar to that of the cobalt(II) complex itself but completely different from those of such cobalt(I) complexes as Li^+[Co(I)(sal)$_2$(*R*-CHXDA)]$^-$[9] and Na^+[Co(I)(salen)]$^-$[14], indicating that the cobalt species in the binary systems remain as the Co^{II} state. On the other hand, the CD spectrum of each binary system is completely different from that of Co(II) (sal)$_2$(*R*-CHXDA) itself. The results suggest the formation, in reference to certain related systems,[15] of a new complex, [Co(II)(sal)$_2$(*R*-CHXDA).M_2CO_3] depicted in Fig. 4.

The rate of change of the CD spectra from Co(II)(sal)$_2$(*R*-CHXDA) itself to the [Co^{II}.M_2CO_3] complexes increased in the following order: $Li_2CO_3 \simeq Na_2CO_3 < K_2CO_3 < Rb_2CO_3 < Cs_2CO_3$.

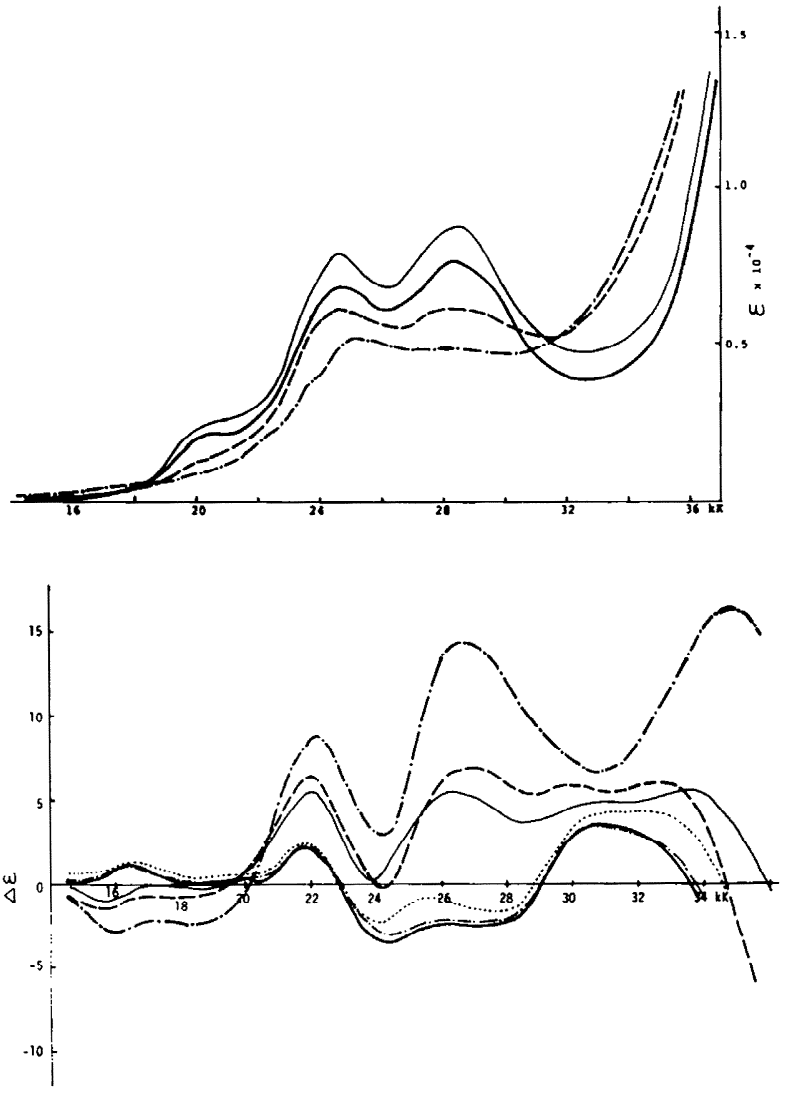


Fig. 3. The absorption and associated CD spectra of Co(II)(sal)$_2$(*R*-CHXDA)/metal carbonate systems (in dioxane). Co^{II} —, Co^{II}/Li_2CO_3 —·—·—, Co^{II}/Na_2CO_3 ·····, Co^{II}/K_2CO_3 ——, Co^{II}/Rb_2CO_3 – – –, Co^{II}/Cs_2CO_3 –·–·–·–.

The typical bands for the complexes (Fig. 4) were observed around 22×10^3 cm^{-1} and 26.5×10^3 cm^{-1}. The complex shown in Fig. 4 is a kind of host-guest complex, and thus the enhancement of basicity of metal carbonates by Co(II)(sal)$_2$(*R*-CHXDA) can be explained in terms of a similar function performed by crown ether.[16]

It is considered that the asymmetric cyclizations of 1,3-dichloro-2-propanol, 2,3-dichloro-1-propanol, and propylene chlorohydrins proceed by the mechanism depicted in Scheme 1. The Co atom of the [Co*.M_2CO_3] complex is considered to interact with the chlorine atom of the coordinated chlorohydrin.[6,17]

In the cyclizations of 1-chloro-2-propanol,[6] 2-chloro-1-propanol and 2,3-dichloro-1-propanol, which proceed by kinetic resolution mechanisms, asymmetric selection of (*R*)- or (*S*)-substrate should take place at the stage of coordination of the substrate to the chiral cobalt complex in Scheme 1. The cyclization of 1,3-dichloro-2-propanol proceeds by the mechanism of asymmetric synthesis. The conformation of the coordinated 1,3-dichloro-2-propanol

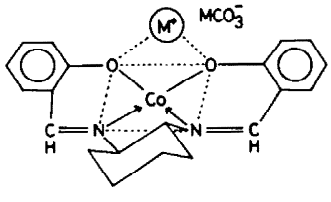
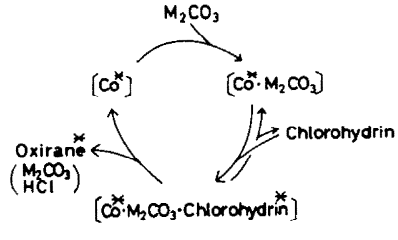


Fig. 4. The suggested structure of the [Co(II)(sal)$_2$(*R*-CHXDA).M_2CO_3] complex.



Scheme 1.

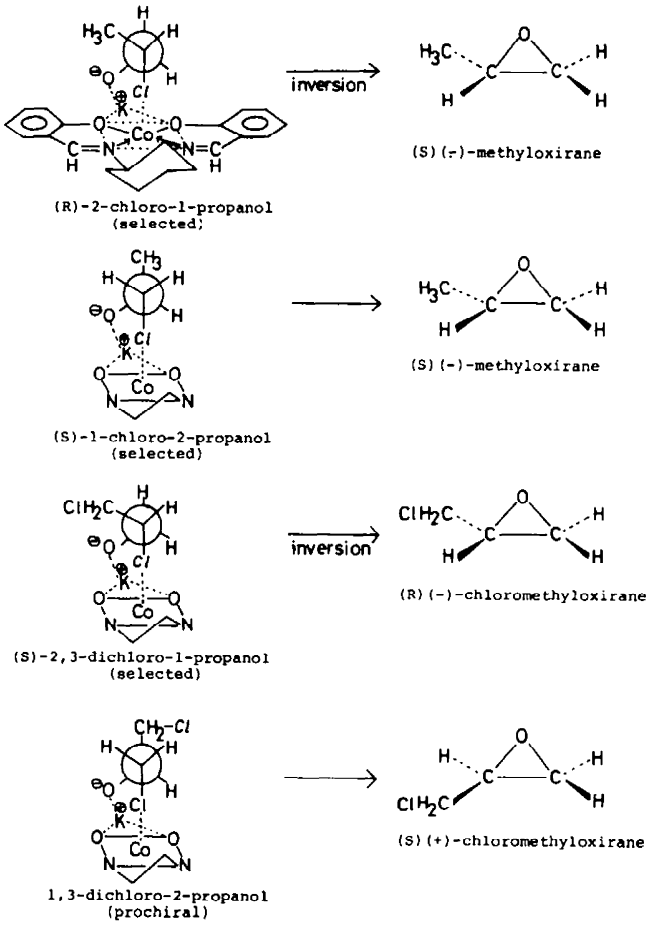


Fig. 5. A probable stereochemistry of the four types of asymmetric cyclizations with the [Co(II)(sal)$_2$(*R*-CHXDA).K_2CO_3] complex as a representative; the leaving chlorine atom is shown by *Cl*. The bulky groups of the coordinated substrate molecules are assumed to be present in the left side of the complexes due to the λ-conformation fixed by the (*R*)-1,2-cyclohexanediamine part.

molecule should be determined at the stage of [Co*.M_2CO_3.chlorohydrin] as well.

A probable stereochemistry in the asymmetric reactions with [Co(II)(sal)$_2$(*R*-CHXDA).K_2CO_3] may be depicted in Fig. 5, where the bulky methyl and chloromethyl groups of the substrates are far apart from the cyclohexanediamine chelate rings. The chiral steric circumstance around the active site, established by the λ-conformation of the central chelate ring, should restrict the mode of incoming substrates. As shown in Fig. 5, the four types of asymmetric reactions seem to be explained reasonably in terms of the orientation of the coordinated substrate involving the chiral (steric and electronic) effects of the λ-conformation of the optically active cobalt complex.

The alkoxy-part ($C-O^-$) of the coordinated chlorohydrin in Fig. 5 probably revolves around the central C–C bond as a free anion and attacks the carbon bearing Cl atom by an S_N2 mechanism. The presence of the interaction between the Co and Cl atoms at the stage of the back-side attack of the alkoxy anion can be demonstrated by the asymmetric cyclization of prochiral substrate, 1,3-dichloro-2-propanol. The optically active chloromethyloxirane could not be formed except by interaction between the Co and Cl atoms.

The stereochemistry for the cyclization of 1,3-dichloro-2-propanol in Fig. 5 indicates that the cobalt-free Cl atom, rather than the cobalt-bound Cl atom is eliminated; this fact may be reasonably explained by the steric and electronic ease with which the Co-free Cl atom leaves in the form of potassium chloride.

REFERENCES

[1]R. M. Bowman and M. F. Grundon, *J. Chem. Soc.* C, 1967, 2368; R. C. Ewins, H. B. Henbest and M. A. Mckervey, *Chem. Commun.* 1085 (1967); F. Montanari, I. Moretti and G. Tore, *Ibid.* 135, (1969); D. R. Boyd, D. M. Jerina and J. W. Daly, *J. Org. Chem.* **35**, 3170 (1970).

[2]S. Yamada, T. Mashiko and S. Terashima, *J. Am. Chem. Soc.* **99**, 1988 (1977).

[3]R. C. Michaelson, R. E. Palermo and K. B. Sharpless, *Ibid.* **99**, 1990 (1977).

[4]J. D. Morrison and H. S. Mosher, *Asymmetric Organic Reactions*. Prentice-Hall, Englewood Cliffs, New Jersey (1971).

[5]M. Ishimori, H. Aoi, T. Takeichi and T. Tsuruta, *Chem. Lett.* 645 (1976).

[6]T. Takeichi, M. Ishimori and T. Tsuruta, *Bull. Chem. Soc. Jpn.* **52**, 2614 (1979).

[7]C. A. Stewart and C. A. Vanderwerf, *J. Am. Chem. Soc.* **76**, 1259 (1954).

[8]J. A. Riddick and W. B. Bunger, *Technique of Organic Chemistry*, (Edited by A. Weissberger) Vol. II. Wiley, New York (1970).
[9]H. Aoi, M. Ishimori, S. Yoshikawa and T. Tsuruta, *J. Organometal. Chem.* **85,** 241 (1975); H. Aoi, M. Ishimori and T. Tsuruta, *Bull. Chem. Soc. Jpn.* **48,** 1897 (1975).
[10]R. G. Asperger and C. F. Liu, *Inorg. Chem.* **4,** 1492 (1965).
[11]E. Abderhalden and E. Eichwald, *Ber. Dtsch. Chem. Ces.* **48,** 1847 (1915); J. J. Baldwin, A. W. Raab, K. Mensler, B. H. Arison and D. E. McClure, *J. Org. Chem.* **43,** 4876 (1978).
[12]W. Fickett, H. K. Garner and H. J. Lucas, *J. Am. Chem. Soc.* **73,** 5063 (1951).
[13]Y. Kumata, J. Furukawa and T. Fueno, *Bull. Chem. Soc. Jpn.* **43,** 3920 (1970); B. T. Golding, D. R. Hall and S. Sakrikar, *J. Chem. Soc.* Perkin I, 1214 (1973).
[14]F. Calderazzo and C. Floriani, *Ibid.* Chem. Commun. 139 (1967).
[15]N. F. Curtius, E. N. Barker, D. Hall and T. N. Waters, *Chem. Commun.* 675 (1966); S. J. Gruber, C. M. Harris and E. Sinn, *Inorg. Chem.* **7,** 268 (1968); G. H. W. Milburn, M. R. Truter and B. L. Vickery, *Chem. Commun.* 1188 (1968); C. Floriani, F. Calderazzo and L. Randaccio, *J. Chem. Soc.* Chem. Commun 384 (1973); H. Milburn, M. R. Truter and B. L. Vickery, *Ibid.*, Dalton 841 (1974).
[16]C. J. Pedersen, *J. Am. Chem. Soc.* **92,** 386 (1970); D. J. Sam and H. E. Simmons, *Ibid.* **94,** 4024 (1972).
[17]P. W. Schneider, P. F. Phelan and J. Halpern, *J. Am. Chem. Soc.* **91,** 77 (1969); L. G. Marzilli, P. A. Marzilli and J. Halpern, *Ibid.* **93,** 1374 (1971).