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Asymmetric Reactions. VI. Asymmetric Hydrogenation of Atropate Catalyzed by Cyanocobalt-Optically Active Diamine Complex[1]

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In a previous paper,[2] the authors have reported that the asymmetric hydrogenation of atropate by pentacyanocobaltate - optically active α-amino acid system gives only slightly optically active hydratropic acid.

This paper presents the asymmetric hydrogenation catalyzed by a cyanocobalt complex coordinated with optically active *R*(−)-1,2-propanediamine or *S*(+)-*N*, *N'*-dimethyl-1,2-propanediamine.

Results and Discussion

Piringer *et al.*[3] have reported that μ-ethylenediamine-bis[tetracyanocobaltate(II)] has an ability to activate molecular hydrogen.

At first, the catalytic activity of (1,2-propanediamine)-cyanocobalt(II) complex for the reduction of α,β-unsaturated carboxylic acids, using racemic 1,2-propanediamine, was examined under the atmospheric pressure of hydrogen at room temperature. The results (Table 1) show that reactive α,β-unsaturated carboxylic acids,[2,4] itaconic acid and atropic acid, are catalytically reduced to give the corresponding saturated acids almost quantitatively. Subsequently, catalytic asymmetric hydrogenation of atropate using *R*(−)-1,2-propanediamine as a ligand was attempted and gave *S*(+)-hydratropic acid of $[\alpha]_D$ +0.8—+0.9° which corresponds to about 1% optical yield (Table 2). The optical rotation of the product purified by distillation rose to $[\alpha]_D$ +1.1°. No optical activity was, of course, observed in the hydratropic acid recovered after the treatment of the racemic hydratropic acid under the same conditions. From these facts, it is obvious that the catalytic asymmetric hydrogenation gave a little bit higher stereoselectivity than that in the previously studied system.[2]

It was expected that the coordination of *N*-substituted 1,2-propanediamine to metal would cause more selective asymmetric coordination of the substrate, because the former coordination should induce asymmetry on the nitrogen atom[5] which is placed nearer to the reaction center than asymmetric C_2 carbon. For this purpose, *N,N'*-dimethyl-1,2-propanediamine[6] was resolved through L(+)-tartrate salt to give (+)-isomer of $[\alpha]_D$ +53.9° (benzene) in pure state. The configuration was inferred to be *S*(+) from the specific rotation of analogous compound (*R*(−)-N^1-phenyl-N^2-methyl-1,2-propanediamine, $[\alpha]_D$ −29.5°).[7]

The hydrogenation of atropate catalyzed by (*S*(+)-*N,N'*-dimethyl-1,2-propanediamine)cyanocobalt(II)

Table 1. Catalytic hydrogenation of activated olefines with (1,2-propanediamine)cyanocobalt(II) complex

Substrate	Time (days)	Product	Yield
CH_3, CH_3, H, COONa	2	CH_3CH_2CH(CH$_3$)(COOH)	trace
$H_2C=C$(CH_2COONa)(COONa)	3	CH_3CH(CH_2COOH)(COOH)	91%
$H_2C=C$(Ph)(COONa)	2	CH_3CH(Ph)(COOH)	96%

Table 2. Asymmetric hydrogenation of atropate catalyzed by (optically active diamine)cyanocobalt complex

Catalyst: Amine	Mole ratio of Co : CN : Amine	Tb (min)	Tr (days)	Product: Yield	[α]$_D$	Optical yield
Pn	1 : 4 : 3	60	3	95.5%	+0.815°	1.0%
Pn	1 : 2 : 3	25	2	94.5%	+0.905°	1.1%
Pn	1 : 2 : 3	585	2	90.5%	+0.825°	1.0%
diMPn	1 : 4 : 2			50%	+5.73°	7.1%

Tb: Time (min) left standing before the reaction. Tr: Reaction time (days).
Pn: *R*(−)-1,2-propanediamine. diMPn: *S*(+)-*N,N'*-dimethyl-1,2-propanediamine.

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complex was carried out under the same conditions as above. As expected, it was shown that somewhat greater steric control was affected, *i.e.*, the reduction gave hydratropic acid of $[\alpha]_D+5.73°$ (optical yield, 7%). In consequence, *S*(+)-hydratropic acid was predominantly produced either by use of *R*(−)-1,2-propanediamine or *S*(+)-*N,N'*-dimethyl-1,2-propanediamine, despite that these ligands have opposite configurations at C_2 to each other. This discrepancy in appearance may be interpreted as follows, though the asymmetric yields are rather low.

The complex used here showed an absorption spectrum [260 nm (ε, 670); 278 nm (ε, 560); 354 nm (ε, 155); 995 nm (ε, 7.3)] which is closely akin to the spectrum of μ-ethylenediamine-bis(tetracyanocobaltate-(II)) reported by Piringer *et al.*[3] and there is no substantial absorption due to complexes[9,10] produced by disproportionation of the (propanediamine)cyanocobalt complex. These facts indicate that the complex contained in the solution may be such a mixed ligand system as obtained by Piringer *et al.*[3] On the other hand, hydrogenation catalyzed by pentacyanocobaltate-(II) has been reported to proceed with *trans* addition.[8] If this is the case for diamine coordinated cyanocobalt complex described here, coordination models like A and B (Fig. 1) are considered as the transition states of the hydrogenations catalyzed by (*R*(−)-1,2-propanediamine)cyanocobalt(II) and (*S*(+)-*N,N'*-dimethyl-1,2-propanediamine)cyanocobalt(II) complexes, respectively. The alkylcobalt complexes are, then formed by hydride addition to the methylene carbon of olefin, and followed by attack of another hydride complex with inversion to give the same *S*(+)-hydratropic acid. However, there are many sites ineffective to asymmetric control. This may be the main cause of resulting in low optical yield.

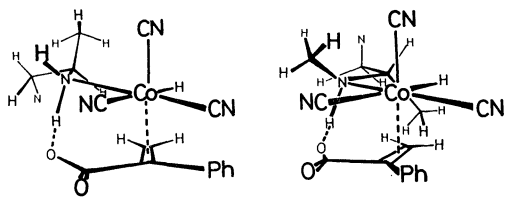

Fig. 1.

It is considered from the results that rigid conformational fixation and proximity of asymmetric groups to the reaction center result in higher optical yield, and that they concurrently prevent, however, coordination of the substrate and therefore the total yield is lowered. This will be an important problem to be overcome in order to design an excellent, homogeneous metal complex catalyst for asymmetric hydrogenation.

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10) The electronic spectrum of $Co(Ph)_3Cl_2$ (prepared under the same condition as the catalyst did): 354 nm (ε, 11.8); 483 nm (ε, 12.0); 1020 nm (ε, 3.4).

Experimental

Reduction of Some α,β-Unsaturated Acids Catalyzed by (1,2-Propanediamine)cyanocobalt(II). To a solution of $CoCl_2 \cdot 6H_2O$ (1 g, 0.0042 mol) in 10 m*l* of water was slowly added a solution of potassium cyanide (1.12 g, 0.017 mol) in water (10 m*l*) with stirring under nitrogen atmosphere to give brown precipitates. The precipitates were dissolved by addition of a solution of 1,2-propanediamine (0.62 g, 0.008 mol) in water (60 m*l*) which had been deoxygenated by bubbling nitrogen gas. To the resulting orange-colored homogeneous solution was added an aqueous solution prepared from 0.6 g (0.004 mol) of atropic acid and sodium hydroxide (0.004 mol). The flask was purged with hydrogen gas and then the reaction mixture was stirred under the atmospheric pressure of hydrogen at room temperature. The solution absorbed the theoretical amount of hydrogen within 2—3 days. The reaction mixture was concentrated and extracted with ether after acidification with conc. hydrochloric acid. The ether layer was washed with water, and concentrated to give a syrup (0.58 g). The product was characterized as hydratropic acid by IR and NMR spectra. Itaconic and tiglic acids were hydrogenated by the same procedure and the results are shown in Table 1.

Asymmetric Reduction by Use of Cyanocobalt Complex Coordinated with Optically Active Diamines (R(−)-1,2-Propanediamine or S(+)-N,N'-Dimethyl-1,2-propanediamine). The asymmetric reduction was carried out by the same procedure as described above, except for using optically active diamines instead of racemic diamine. In the case of the reaction with *R*(−)-1,2-propanediamine the crude product showed only one spot on tlc (silica gel) (R_f, 0.5, ethanol-benzene, 3:1; R_f, 0.65, methanol-water, 3:1). Optical rotation of these crude product was $[\alpha]_D+0.815$—$+0.905$ (see Table 2), and the product was distilled at 90—91°C/0.03 mmHg; $[\alpha]_D+1.1°$ (*c* 10.6, ethanol). The specific rotation corresponds to optical yield of 1.2% [optically pure *S*(+)-hydratropic acid, $[\alpha]_D^{20}$ +81.1° (*c* 3.1, ethanol)]. In the case of the reaction with *S*(+)-*N,N'*-dimethyl-1,2-propanediamine, the product was distilled at 83°C/0.0075 mmHg. The NMR spectrum of the distillate showed that the sample was a mixture of 84.1% of hydratropic acid and 15.9% of atropic acid. The optical rotation, $[\alpha]_D+5.73°$ (*c* 6.1, ethanol), corresponds to optical yield of 7%.

S(+)-N,N'-Dimethyl-1,2-propanediamine. Racemic compound was synthesized by reaction of 1,2-dibromopropane and methylamine according to William's method except for using a mixed solvent of benzene and methanol. A mixture of 1,2-dibromopropane (100 g), methylamine (350 m*l*), benzene (200 m*l*) and methanol (200 m*l*) was shaken in an autoclave at 95—105°C for 5 hours, and left standing overnight at room temperature. To the reaction mixture which was transferred to Erlenmeyer flask was added an excess amount of conc. HCl. The solution was concentrated under diminished pressure to give a solid. The solid was dissolved in a small amount of water, covered with benzene (2000 m*l*) and an excess of sodium hydroxide pellets was added to this solution. During this procedure, excess methylamine was evaporated and *N,N'*-dimethyl-1,2-propanediamine was transferred to benzene layer which was decanted to another vessel. Water layer was extracted with benzene several times. The combined extracts were distilled through a fractionating column. Bp 127—128°C; yield: 15 g (30%). A part of this sample was benzoylated to give crystals of mp 86—88°C whose analytical values were agreed with those of *N,N'*-dimethyl-*N,N'*-dibenzoylpropanediamine. Found: C, 73.76; H, 7.06; N, 9.07%. Calcd for $C_{19}H_{22}N_2O_2$: C, 73.52; H,

7.14; N, 9.03%.

Resolution of *N,N'*-dimethyl-1,2-propanediamine was accomplished by fractional crystallization of its L(+)-tartrate. Racemic *N,N'*-dimethyl-1,2-propanediamine (81 g) was dissolved into a solution of L(+)-tartaric acid (226.8 g) in 153 m*l* of water. The mixture was left standing in a refrigerator. The resulting crystals were separated by filtration. The procedures were repeated, and a part of the crystals obtained in some stage of crystallization was used in order to measure specific rotation; an aqueous solution of the crystals was made alkaline and extracted with benzene. The benzene layer was dried by adding sodium hydroxide pellets. The optical rotation of the dried benzene solution was measured, and the concentration was determined by acid titration. Thus obtained specific rotation in each stage of recrystallization was as follows.

Times of recrystallization	1	4	6	8	12
$[\alpha]_{578}$ of benzene solution (°)	+47.3	+51.25	+52.1	+52.6	+53.9
(*c*)	(0.97)		(0.6)	(0.6)	(1.0)

The sample of $[\alpha]_{578}+53.9°$ was used in the experiment of asymmetric hydrogenation.