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Isomerization of the (D-Aspartato)(L-2,4-diaminobutyrato)-cobalt(III) Complex

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The isomerization of two of the three possible geometrical isomers for the (D-aspartato)(L-2,4-diaminobutyrato)cobalt(III) complex afforded the residual third isomer which has not here to fore been obtained. The equilibrium mole fractions of these isomers in water in the presence of activated carbon were found for D-*cis*O_5*cis*N_5, D-*trans*O_5*trans*N_5, D-*fac* to 0.68, 0.11, 0.21, respectively. As the two ligands coordinated are considered to involve no intermolecular hydrogen bonding or steric hindrance, the relative positions of the six coordinated atoms around a cobalt atom may cause these unequal isomer ratios. These isomerisms are dealt with by means of a network of first-order reversible reactions and the relative values of the rate constants are determined.

The preparation and absorption and PMR spectra of [Co(L- or D-asp)(L-2,4-dba)] (asp=aspartate ion and dba=diaminobutyrate ion) have already been reported.[1] Though three possible isomers of [Co(L-asp)(L-dba)] could be obtained, only two isomers of [Co(D-asp)(L-dba)] could be obtained (Figs. 1-a and c). The residual isomer (Fig. 1-b) could not be obtained though several preparative methods were attempted. The two ligands coordinated are considered to involve no intermolecular hydrogen bonding or steric hindrance. It is interesting to study the difficulty encountered in obtaining the third isomer of [Co(D-asp)(L-2,4-dba)]. In the work reported here, the present authors studied whether the third isomer of [Co(D-asp)(L-2,4-dba)] could be obtained by equilibrating the complex obtained earlier in the presence of activated carbon.

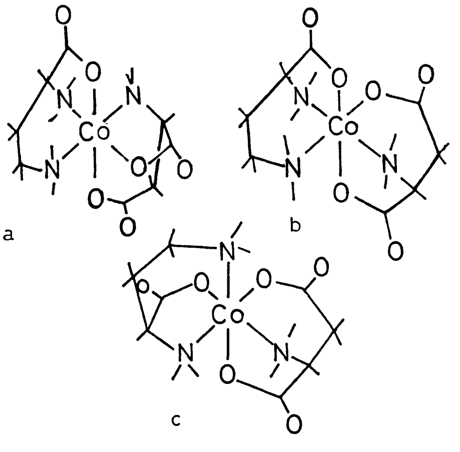

Fig. 1. The three possible geometrical isomers of the [Co(D-asp)(L-2,4-dba)] a: *cis*O_5*cis*N_5, b: *trans*O_5*trans*-N_5, c: *fac*. The isomers are named by considering 5-membered N and O atoms.

Experimental

The [Co(D-asp)(L-2,4-dba)] was prepared as described in a previous paper.[1] Two isomers were obtained and named D1 and D2 in their order of elution using a cation exchange column (Dowex 50 w X8, Na form). Activated carbon was purchased from Takeda-Yakuhin, Ltd, which was "Shirasagi," and dried at 100 °C before use.

The isomerization of D1 (D-*cis*O_5*cis*N_5) and D2 (D-*fac*) isomers using the activated carbon as a catalyst afforded the third isomer D3 (D-*trans*O_5*trans*N_5). When the resulting mixture was loaded on a cation exchange column (Dowex 50 w X8, 100—200 mesh Na form) the D3 isomer was found to closely follow the D1 isomer. As the D3 isomer was relatively less soluble, this fraction was concentrated and kept in a refrigerator overnight. A small quantity of the D3 isomer was precipitated. Found D3: C, 28.73; H, 5.26; N, 12.07%. Calcd for $CoC_8H_{14}O_6N_3\cdot 1.5H_2O$: C, 28.75; H, 5.13; N, 12.57%.

A starting isomer (80 mg, 0.0024 mol) was dissolved in 100 ml water at 50 °C. To this solution, 20 mg of activated carbon was added. A reflux condensor was attached to the flask. The solution was stirred and maintained at 50 °C in a temperature-controlled reaction vessel. The reaction was timed with a stop clock whenever the carbon was introduced into the sample in the vessel. Since the isomerization is "frozen" upon the removal of the carbon from the sample solutions, rapid filtration is an excellent way to stop the reaction. The method adopted requires 7 mm glass tubing packed with a cotton filter. The packed tubes were placed, using a specially-prepared fitting, on the end of a 5 ml hypodermic syringe. The solution was examined for optical rotation immediately after withdrawal and at the end of the run. No loss of optical activity was noted. Sampling was continued for 24 h at intervals of 30 and 60 min. The concentrations of all isomers after sampling were determined as follows. First, the concentration of the D2 isomer was determined using high-speed liquid chromatography in comparison with a known concentration of the D2 isomer. The concentrations of the D1 and D3 isomers were determined using the molar rotation $[\phi]$ at 489 and 540 nm.

	489 nm	540 nm
D1	44.53	0.0
D2	8.20	−4.82
D3	0.0	−80.20

The concentrations of the D1 and D3 isomers were calculated using the following equation:

$$[\phi]_{D1}x + [\phi]_{D2}y + [\phi]_{D3}(1-x-y) = \alpha/c,$$

where $[\phi]_{D1}$, $[\phi]_{D2}$, and $[\phi]_{D3}$ are the molar rotations, x and y are the concentrations of the D1 and D2 isomers, respectively and c is the initial concentration of the isomer which is isomerized. α is the rotation of the plane of polarization, expressed in degrees. Since the concentration loss of the complex due to adsorption on the surface of the carbon and due to other reactions was less than 2 percent, it was possible to treat the complex concentration as constant throughout a run. The concentration of cobalt was determined using nitrosonaphthol.

Measurements. The electronic absorption spectra and the optical rotatory dispersion spectra were measured with a JASCO ORD-UV-5 spectrometer. The wavelength correction was cheked using neodymium glass which is absorping at 589 nm. The chromatographic separation was carried out with a JASCO LCP-350 high-speed liquid chromatograph. A 500×2.3 mm glass column containing 50 w X8 Dowex and a 200—400 mesh Na form was used for all measurements. The complexes were eluted with water at a flow rate of 1.0 ml/min at a pressure of *ca.* 40 kg/cm^2.

Results and Discussion

Figure 1 shows the possible isomers of [Co(D-asp)(L-dba)]. The D-*trans*O_5*trans*N_5 isomer (Fig. 1 (b)) has not previously been prepared. Figure 2 shows the results of high-speed liquid chromatography for the equilibrated mixture, starting from the D2 isomer. The D-*mer* isomer was found to appear in front of the D2 isomer. After the isomerization of more than 2 grams of the D1 or D2 isomer in 100 ml of H_2O in the presence of activated carbon, the equilibrated mixture was loaded on a cation exchange column (30×700 mm Na form) and eluted with water. The fractions were taken in a fraction collector. The optical rotatory dispersion and visible spectra of the rear part of the D-*mer* fractions did not agree with those of the D-*cis*O_5*cis*N_5 isomer. These fractions were collected, concentrated and kept under refrigeration overnight. A small amount of precipitate appeared. The optical rotatory dispersion and visible spectra of the filtrate agreed well with those of the D-*cis*O_5*cis*N_5 isomer. The elemental analysis of this precipitate coincided with those of the other two isomers. This isomer was named D3, with the possible

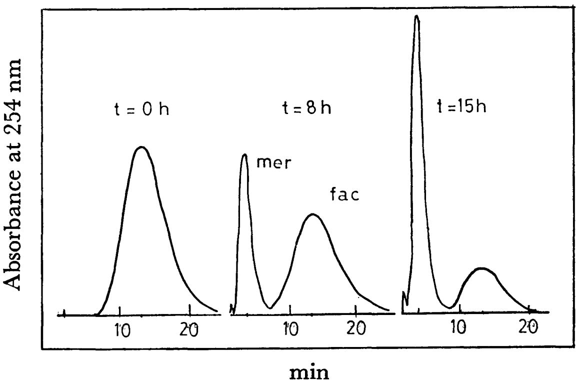

Fig. 2. High speed liquid chromatogram indicating the result of the isomerization for the D2 isomer (UV detector).

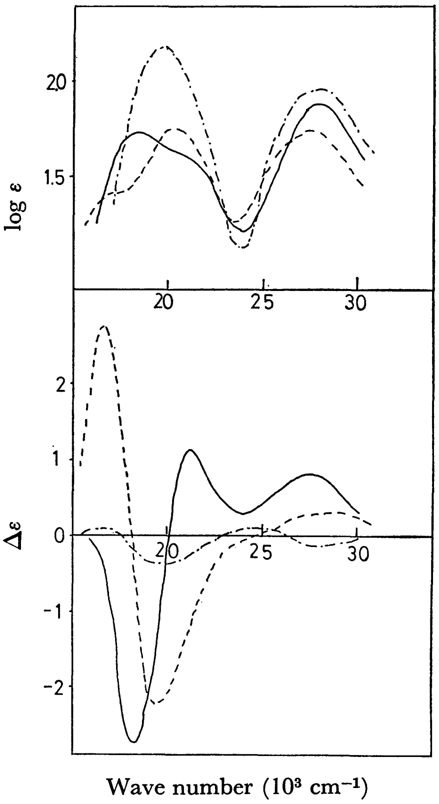

Fig. 3. The visible (upper) and the CD (lower) spectra of the [Co(D-asp)(L-2,4-dba)], —, D1 (*mer*); ---D3 (*mer*); -·-D2 (*fac*). The D3 isomer is eluted faster than the D2.

TABLE 1. NUMERICAL DATA FROM ABSORPTION AND CD SPECTRA OF [Co(L-or D-asp)(L-2,4-dba)]

Complex	I band				II band			
	Absorption		CD		Absorption		CD	
	$\tilde{\nu}_{max}$ $^{a)}$	log ε	$\tilde{\nu}_{max}$	Δε	$\tilde{\nu}_{max}$	log ε	$\tilde{\nu}_{max}$	Δε
D-*cis*O_5*cis*N_5	18.3	1.75	18.4	−2.80	27.3	1.88	27.8	0.80
	20.8	1.55	21.3	1.08				
D-*trans*O_5*trans*N_5	16.8	1.38	16.7	2.75	27.4	1.73	28.0	0.26
	20.5	1.75	19.5	−2.25				
D-*fac*	19.3	2.18	16.7	0.10	27.2	1.95	24.8	0.10
			19.8	−0.40			28.0	−0.20
L-*trans*O_5*cis*N_5	18.2	1.92	18.7	−2.50	27.2	2.05	27.2	0.96
	20.0	1.92	21.8	4.80				
L-*cis*O_5*trans*N_5	16.7	1.44	17.5	2.28	27.2	1.99	26.8	0.33
	20.4	1.97	19.8	−0.22				
L-*fac*	19.3	2.23	18.2	1.48	27.3	1.90	*ca.* 27	−0.11
			20.6	−0.56				

a) In 10^3 cm^{-1} units.

configuration D-*trans*O_5*trans*N_5. Figure 3 shows the visible absorption and circular dichroism spectra of the [Co(D-asp)(L-2,4-dba)] complex. All numerical data together with those obtained for [Co(L-asp)(L-2,4-dba)] are listed in Table 1. The visible absorption spectrum of the D-*fac* isomer is similar to that of L-*fac*. This shows that for these complexes which are diastereoisomers of each other, whether D-asp or L-asp is coordinated does not seriously affect the electronic absorption patterns. The first absorption bands for all the *mer* isomers exhibit splittings, though that for the L1 isomer is not obvious.[1] The intensity of the lower energy side of the first absorption band for D3 is smaller than that of the higher energy side. But in the case of D1, this relation is reversed. The L2 spectrum pattern is almost the same as that of the D3 isomer. In order to study the above findings, molecular models are considered. When the L-2,4-dba coordinated for all the *mer* isomers are placed in the same coordinates, the positions of the carboxylate and amino groups of the D-asp of the *trans*O_5*trans*N_5 isomer are quite similar to those of L-asp of the *cis*O_5-*trans*N_5 isomer for [Co(L-asp)(L-2,4-dba)]. The only difference between the complexes lies in the alteration of the 5-membered and 6-membered chelate rings for the asp ligand. The same situation occurs in the relation between the coordinated ligands of the *cis*O_5*cis*N_5 and *trans*O_5*cis*N_5 isomers. From the visible spectra, the assignment of one series, for example, [Co(L-asp)(L-2,4-dba)], is found to serve as an assignment for the other diastereoisomeric series, for example, [Co(D-asp)(L-2,4-dba)]. The circular dichroism spectra of [Co(D-asp)-(L-2,4-dba)] can not at present be correlated with those of [Co(L-asp)(L-2,4-dba)].[2] The PMR spectrum of the D3 isomer was not compared with those of the other isomers because this isomer was only slightly soluble in water. The racemization of $[\mathrm{Co(en)_3}]^+$ (en=ethylenediamine) and of $[\mathrm{Co(edta)}]^-$ (edta=ethylenediaminetetraacetate ion) using activated carbon as a catalyst has been studied.[3–8] Particularly, the racemization of $[\mathrm{Co(edta)}]^-$ has been examined in detail by Cooke *et al.* and Erdmann and Douglas.[6–8] In the present work, the isomerization of [Co(D-asp)(L-2,4-dba)] was studied using activated carbon. The optical rotatory dispersion spectral changes in the isomerization of [Co(D-asp)(L-2,4-dba)] are shown in Fig. 4. This indicates that the last equilibrating molar fraction were equal for all kinds of isomers used as the starting material. The rate of isomerization was found to essentially follow second-order kinetics, first order for the complex and first order for the carbon. The activated carbon once used was washed with water and dried at 100 °C for 3 h. This activated carbon was not deactivated in contrast with the experiments reported Erdmann *et al.*[4] Isomerization without activated carbon was very difficult. Since no direct measure of the effective concentration of activated carbon was available, this isomerization was treated as first-order kinetics in the complex only. This isomerization was considered to occur for the three possible isomers. Consequently, the system of differential equations representing the behavior of this system is:

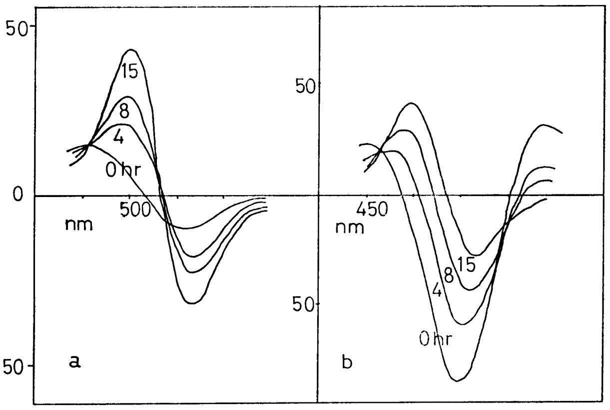

Fig. 4. The ORD spectral changes due to the isomerization for the D2 (left) and the D3 (right) isomers.

$$\begin{aligned}
\mathrm{d}a_1/\mathrm{d}t &= -(k_{12}+k_{13})a_1 + k_{21}a_2 + k_{31}a_3\\
\mathrm{d}a_2/\mathrm{d}t &= k_{12}a_1 - (k_{23}+k_{21})a_2 + k_{32}a_3\\
\mathrm{d}a_3/\mathrm{d}t &= k_{13}a_1 + k_{23}a_2 - (k_{31}+k_{32})a_3,
\end{aligned}$$

where a_i is the molar fraction, and the rate constant of the reaction, for which the notation of the $\mathrm{D}_i(i=1, 2, 3)$ isomers is transformed into D_j, is represented by k_{ij}. A method was easily applicable for obtaining the relative value of the rate constant but it was difficult to obtain absolute values. If k_{31} is taken to be unity, all the rate constants were determined as shown in Fig. 5. The values of the rate constants of this system decrease in the order $k_{31}, k_{21} > k_{12}, k_{32} > k_{13}, k_{23}$. D3 is isomerized most rapidly of the three isomers. The molar fractions at equiliblium are: a_1, a_2, a_3=0.68, 0.21, 0.11, respectively. Since these complexes are considered to involve no hydrogen bonding or steric hindrance between asp and 2,4-dba coordinated on the basis of the molecular model concept, such a distribution in favor of the D1 isomer is surprising. The free energy differences at 25 °C are as follows: $\Delta G_{12}=G(\mathrm{D1})-G(\mathrm{D2}) = -RT\ln 68/21 = -0.69$ kcal/mol and $\Delta G_{13} = -RT\ln 68/11 = -1.08$ kcal/mol. The reason for this distribuion in favor of the D1 isomer may be ascribed to the relative site of the atoms coordinated (α- and γ-amino nitrogens and α- and γ-carboxylate oxygens, as is shown in Fig. 1). Recently, investigations of the *trans* effect for the cobalt(III) complex containing S-bonded sulfite ligands have been reported.[10] In cobalt(III) chemistry, S-bonded sulfite produces a specific and dramatic labilization of the ligands situated the *trans* position relative to it. This electronic effect which is transmitted through

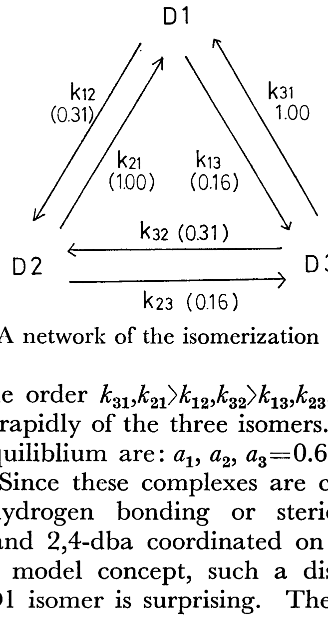

Fig. 5. A network of the isomerization system.

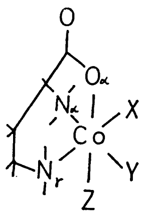

Fig. 6. Coordination axes to which L-2,4-dba ligand fixes.

the bonds may apply to our study. For example, L-2,4-dba coordinated axes (Fig. 6). The α-amino nitrogen seems to affect the atom of the D-asp which confirmly combines at the site y (Fig. 6). Similar relations arise for the other cases (N_r-Co-site x and O_α-Co-site z). It cannot at present be estimated whether any of these bond relations affect the partial mole fraction because of the lack of data. Only a small amount of the *trans*N isomer of $[Co(L\text{-}asp)_2]^-$[11] could be prepared. In addition to the above results and the low molar fraction of the D-*trans*O_5*trans*N_5 isomer of [Co(D-asp)(L-2,4-dba)] in equilibrium using activated carbon, it is suggested that the two α-nitrogen atoms avoid the *trans* position.

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