

## Cobalt(III) Complex with Novel Chiral Amidate Ligand: (I) Synthesis, Structure and Characterization of [Co(*S*-metamp)(amp)](ClO<sub>4</sub>)<sub>2</sub>

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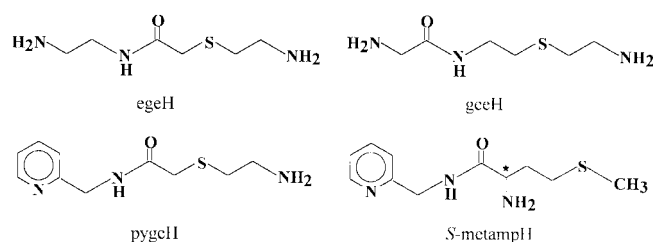
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During the past three decades, the studies of optically active metal complexes with nitrogen or oxygen donor atoms have attracted much attention.<sup>1</sup> Many studies have been investigated on the stereoselectivity in inert cobalt(III) complexes with flexible tetradentate ligands such as H<sub>2</sub>eddp (ethylenediamine-*N,N'*-dipropionic acid) and edda (ethylenediamine-*N,N'*-diacetate).<sup>2</sup> In this series, it was demonstrated that *cis*- $\beta$  ternary Co(III) complexes could be utilized for the optical resolution or asymmetric synthesis of  $\alpha$ -amino acids in high enantiomeric excess.<sup>3</sup> Especially, the chemistry of metal complexes with N,S-donor chelates have been interesting owing to their diverse roles in metalloenzymes and their varied catalytic properties.<sup>4</sup> Recently, Toscano *et al.*<sup>5</sup> have also reported the stereoselectivity of Co(III) complexes with linear tetradentate ligands geeH (= *N*-{2-[(2-aminoethyl)-thio]ethyl}-2-aminoacetamide), egeH (= *N*-(2-amino-ethyl)-2-[(2-aminoethyl)thio]acetamide) and pygeH (= *N*-[(2-pyridyl)methyl]-2-[(2-aminoethyl)thio]acetamide) containing sulfur atom in donor set as well as an amide group. There are three possible geometrical isomers, *cis*- $\alpha$ , *cis*- $\beta$  and *trans* but they were coordinated to Co(III) ion with only *cis*- $\beta$  configuration.<sup>5</sup> We prepared another novel ligand that can adopt the *cis*- $\beta$  configuration in octahedral transition complex.



We now present the preparation and structural characterization of [Co(*S*-metamp)(amp)](ClO<sub>4</sub>)<sub>2</sub> (**1**), where *S*-metamp = 4(*S*)-1-(2-pyridyl)-3-oxo-4-aza-7-thiaoctane and amp = 2-(aminomethyl)pyridine. The *S*-metampH is a novel non-linear tetradentate chiral ligand which has not only amide group but also a sulfur atom in *S*-methionine moiety. Thus, *S*-metampH may stereospecifically bind to Co(III) ion with the *cis*- $\beta$  geometry. In this paper we have used the following ligand abbreviations; *S*-metampH for the free ligand, *S*-metamp for the deprotonated ligand.

### Experimental Section

All materials were of reagent grade and were used without further purification. Elemental analyses were determined by perkin Elmer 240-C instrument, <sup>13</sup>C-NMR spectra were measured on a Bruker ARX(300MHz) in D<sub>2</sub>O. UV-vis and CD (circular dichroism) spectra were measured by a HP 8452 spectrophotometer and a Jasco J-715 spectropolarimeter, respectively.

**Preparation of *S*-metampH ligand.** *S*-phthaloylmethionine was prepared from *S*-methionine (29.8 g, 0.2 mol) and phthalic anhydride (32.6 g, 0.22 mol) according to the method of Asperger *et al.*<sup>6</sup> *N*-(*S*-phthaloylmethionine)-2-(aminomethyl)-pyridine was prepared from the *S*-phthaloylmethionine (33.5 g, 0.12 mol) and amp (13.0 g, 0.12 mol) by using dicyclohexylcarbodiimide (DCC) as coupling reagent in dichloromethane.<sup>7</sup> The amino protecting group was removed with hydrazine in ethanol, which was treated with 2 N HCl to yield the *S*-metampH·2HCl. Yield: 70%. <sup>13</sup>C NMR (75.47 MHz, D<sub>2</sub>O, 298 K):  $\delta$  = 16.88 (CH<sub>3</sub>), 31.26, 32.50, 43.62 (three CH<sub>2</sub>: in order of close to sulfur atom), 55.16 (CH), 126.14-154.40 (pyridyl ring), 173.13 (C=O).

**Preparation of **1**.** To a solution of *trans*-[Co(py)<sub>4</sub>Cl<sub>2</sub>]Cl (4.8 g, 0.01 mol) in ethanol (150 mL) was slowly added an aqueous solution (150 mL) of *S*-metampH (3.5 g, 0.01 mol) at room temperature for 30 min and the mixture was stirred for 24 h at 40 °C. During the reaction, pH was maintained at 8.0 and then the solution was diluted to 500 mL and adsorbed onto a cation exchange resin (SP-Sephadex C-25) column. Washing column with water sufficiently and eluted 0.2 M NaClO<sub>4</sub> aqueous solution. Adsorption band was separated and evaporated to a small volume under reduced pressure. After few days, brown crystals of **1** suitable for X-ray crystallography were obtained by slow evaporation of saturated aqueous solution. The crystals were collected by filtration and air-dried. Yield 45%. Calc. for CoC<sub>17</sub>H<sub>24</sub>N<sub>5</sub>O<sub>9</sub>SCl<sub>2</sub>: C, 33.79; H, 4.00; N, 11.59. Found: C, 33.81; H, 3.98; N, 11.63. <sup>13</sup>C NMR (D<sub>2</sub>O):  $\delta$  = 19.82 (CH<sub>3</sub>), 29.35, 33.70, 52.24, 53.44 (four CH<sub>2</sub>), 61.00 (CH), 125.39-168.69 (pyridyl ring), 180.37 (C=O).

**Safety note.** Although we have experienced no problem with the compounds reported in this work, perchlorate salts of metal complexes with organic ligands are often explosive

**Table 1.** Summary of crystallographic data of [Co(*S*-metamp)(amp)](ClO<sub>4</sub>)<sub>2</sub>

Empirical formula	C <sub>17</sub> H <sub>24</sub> Cl <sub>2</sub> Co N <sub>5</sub> O <sub>9</sub> S
Formula weight	604.30
Crystal system, space group	Orthorhombic, <i>P</i> 2 <sub>1</sub> 2 <sub>1</sub> 2 <sub>1</sub>
Unit cell dimensions	<i>a</i> = 12.171(1) Å <i>b</i> = 13.977(1) Å <i>c</i> = 14.485(1) Å
Volume	2464.1(3) Å <sup>3</sup>
<i>Z</i> , Calculated density (Mg/m <sup>3</sup> )	4, 1.629
$\mu$ (mm <sup>-1</sup> with Mo-K $\alpha$ )	1.055
Scan type	2 $\theta$ - $\omega$
Index ranges	-15 $\leq h \leq$ 15, -18 $\leq k \leq$ 18, -18 $\leq l \leq$ 18
Reflections collected / unique	6344/5646 [ <i>R</i> (int) = 0.0290]
Final <i>R</i> indices [ <i>I</i> > 2 $\sigma$ ( <i>I</i> )]	<i>R</i> <sub>1</sub> = 0.0441, <i>wR</i> <sub>2</sub> <sup>a</sup> = 0.0848
<i>R</i> indices (all data)	<i>R</i> <sub>1</sub> = 0.0666, <i>wR</i> <sub>2</sub> <sup>a</sup> = 0.0996
Absolute structure parameter	-0.023(19)
Extinction coefficient	0.0045(3)
Largest diff. peak and hole (eÅ <sup>-3</sup> )	0.294 and -0.308

$$^a w = 1/[\sigma^2(F_o^2) + (0.0291P)^2 + 2.0255P], \text{ where } P = (F_o^2 + 2F_c^2)/3$$

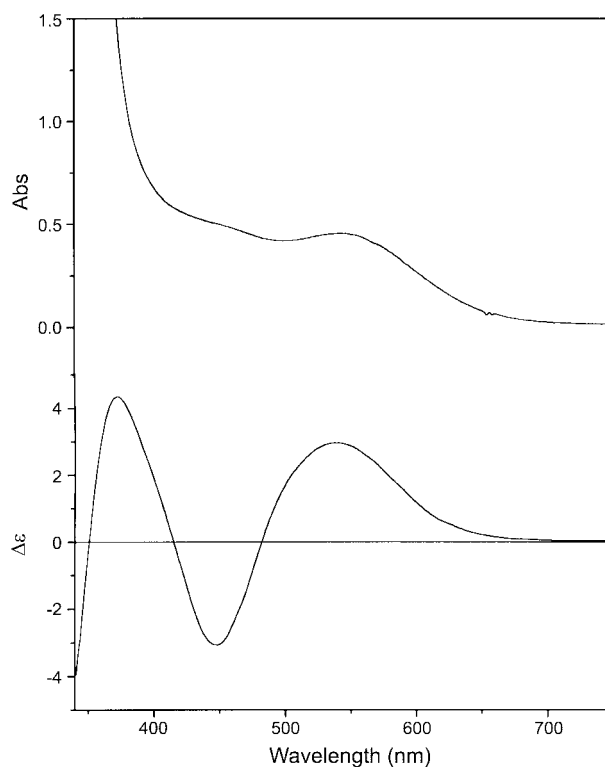
and should be handled with great caution.

**X-Ray data collection.** A brown crystal with the dimensions of 0.31 × 0.29 × 0.21 was mounted on a *STOE STADI 4* four circle X-ray diffractometer. The unit cell parameters were refined for 38 reflections with a 2 $\theta$  range of 19.0 to 21.0°, using graphite monochromatized Mo-*K* $\alpha$  radiation, wavelength 0.71069 Å. The data including Friedel pair for determination of the absolute structure were collected. A summary of crystal data, together with the details concerning intensity measurements and the results of refinement are shown in Table 1. Lorentz and polarization factors were applied and the empirical absorption correction of *psi-scan*<sup>8</sup> was made: the transmission factors were 0.8089 (min.) and 0.9089 (max.). The structure was solved by the direct method and refined by the full-matrix least-squares for observed reflections with *I* > 2 $\sigma$ (*I*).<sup>9,10</sup> The absolute structure was determined from the Flock parameter.<sup>11</sup> All non-hydrogen atoms were refined anisotropically. The hydrogen atoms in the ligand were generated in ideal position and refined in a riding model. All of the calculations were made using the *X-STEP* software package.<sup>8</sup> Two ClO<sub>4</sub><sup>-</sup> ions were refined by the rotation disorder. The rotation axes were Cl(1)-O(2) and Cl(2)-O(6), respectively. All oxygen atoms except of the O(2) and O(3) in the ClO<sub>4</sub><sup>-</sup> ions carried out occupancy as 1/2 in the refinement.

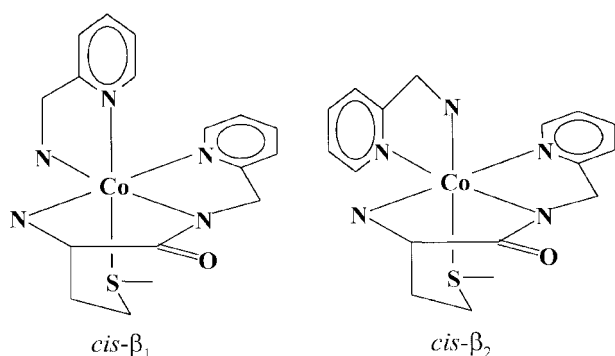
Crystallographic data for the structure reported here have been deposited with the Cambridge Crystallographic Data Center (Deposition No. CCDC-183580). The data can be obtained free of charge via [www.ccdc.cam.ac.uk/conts/retrieving.html](http://www.ccdc.cam.ac.uk/conts/retrieving.html) (or from the CCDC, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033; e-mail: [deposit@ccdc.cam.ac.uk](mailto:deposit@ccdc.cam.ac.uk)).

## Results and Discussion

The complex **1** was obtained by the reaction of *trans*-

**Figure 1.** Absorption and CD spectrum for **1**.

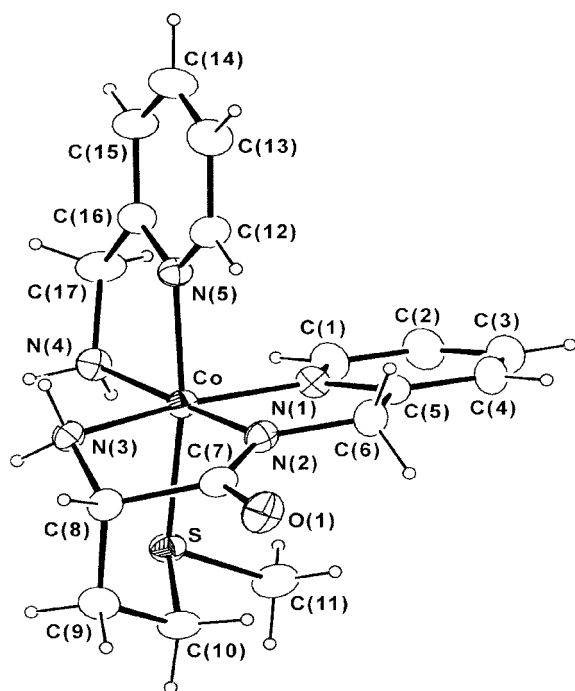
[Co(py)<sub>4</sub>Cl<sub>2</sub>]Cl and (*S*)-metampH in slightly basic aqueous solution under mild conditions. Elemental analysis and <sup>13</sup>C NMR spectrum indicate that the brown product is [Co(*S*-metamp)(amp)](ClO<sub>4</sub>)<sub>2</sub>. The absorption and CD spectra of **1** are shown in Figure 1. The electronic absorption spectrum of **1** in aqueous solution shows one broad peak at 542 nm ( $\epsilon$  = 378.54 cm<sup>-1</sup> mol<sup>-1</sup> L) and does not exhibit any shoulder peak. Jun *et al.*<sup>12</sup> have reported that the *cis*- $\beta$ -[Co(*SRS*-phchxn)Cl<sub>2</sub>]<sup>+</sup> (phchxn = *N,N*-bis(2-*S*-pyrrolidyl-methyl)-*trans*-*R*-1,2-cyclo-hexanediamine) complex has a broad absorption band at 550 nm but *cis*- $\alpha$  complexes such as [Co(trien)Cl<sub>2</sub>]<sup>+</sup> (trien = triethylenetetraamine) and [Co(SS-pyhn)Cl<sub>2</sub>]<sup>+</sup> (pyhn = 1,6-bis(2-*S*-pyrrolidyl)-2,5-diazahexane) have a shoulder peak at the high energy region differ from their *cis*- $\beta$ . Based upon these results, we suggest the **1** can be assigned to the isomer of *cis*- $\beta$ . The Circular Dichroism (CD) spectrum of **1** shows two separated maximum bands for the <sup>1</sup>A<sub>1g</sub> → <sup>1</sup>T<sub>1g</sub> ( $\lambda$  = 537 nm,  $\Delta\epsilon_{\text{max}}$  = +2.96 dm<sup>2</sup> mol<sup>-1</sup>) and <sup>1</sup>A<sub>1g</sub> → <sup>1</sup>T<sub>2g</sub> ( $\lambda$  = 448 nm,  $\Delta\epsilon_{\text{max}}$  = -3.06 dm<sup>2</sup> mol<sup>-1</sup>) transition in d-d region. This split in octahedral parentage indicates the loss of degeneracy in the excited states expected for a low symmetry species. This means complex **1** can take two possible absolute configurations ( $\Delta$  or  $\Lambda$ ). In **1**, asymmetric carbon atom has a fixed stereochemistry as a consequence of the *S* chiral carbon in methionine moiety. This is assumed to dominate the visible CD spectrum. In the previous reports, the absolute configuration of the *cis*- $\beta$  isomers with tetradentate ligands were assigned according to the sign of the CD component at the first absorption band region, that is, the plus sign to the  $\Lambda$  configuration.<sup>13</sup> In this complex, although



**Figure 2.** The two possible geometrical configurations for bidentate ligand in *cis-β* configuration.

it is difficult to assign the correct absolute configuration from only the CD and absorption spectrum but we thought  $\Lambda$ -*cis-β* configuration take into account of the stereospecificity of *S*-metamp ligand. In the case of a *cis-β* octahedral complexes containing an unsymmetrical bidentate ligand, two geometrical isomers are possible with respect to the tetradentate ligand. These configurations have been designated as *cis-β*<sub>1</sub> and *cis-β*<sub>2</sub> (Figure 2) by literature convention.<sup>14</sup> In order to establish unequivocally the orientation of the bidentate ligand (amp) with respect to the *S*-metamp, it was measured by single-crystal X-ray diffraction. In addition, we confirmed that the **1** has  $\Lambda$ -*cis-β*<sub>1</sub> configuration by chelate ring method<sup>15</sup> and X-ray structural analysis.

Figure 3 shows a perspective view of the **1** together with the atomic labeling scheme. The selected bond lengths and angles are listed in Table 2. As shown in figure 3, the *S*-

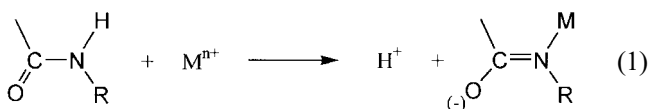


**Figure 3.** Perspective view of **1** with the atom numbering scheme. Thermal ellipsoids are drawn to include 50% probability. Two ClO<sub>4</sub><sup>-</sup> ions are omitted for clarity.

**Table 2.** Selected bond distances and angles for [Co(*S*-metamp)-(amp)](ClO<sub>4</sub>)<sub>2</sub>

Bond lengths (Å)			
Co-N(1)	1.953(3)	Co-N(5)	1.981(3)
Co-N(2)	1.876(3)	Co-S	2.270(1)
Co-N(3)	1.960(3)	N(2)-C(7)	1.315(5)
Co-N(4)	1.967(3)	O(1)-C(7)	1.252(5)
Bond angles (°)			
N(2)-Co-N(1)	83.7(1)	N(2)-Co-S	95.3 (1)
N(2)-Co-N(3)	82.5(1)	N(1)-Co-S	94.5(1)
N(1)-Co-N(4)	99.6 (1)	N(3)-Co-S	86.0 (1)
N(3)-Co-N(4)	94.3(1)	N(4)-Co-S	87.9 (1)
N(2)-Co-N(5)	94.4(1)	N(5)-Co-S	169.9 (1)
N(1)-Co-N(5)	89.3 (1)	N(1)-Co-N(3)	166.1 (1)
N(3)-Co-N(5)	92.5 (1)	N(2)-Co-N(4)	175.2 (2)
N(4)-Co-N(5)	82.2 (1)		

metamp ligand adopts the *cis-β*<sub>1</sub> configuration around cobalt atom in which one of the axial position is occupied by sulfur atom. This expected stereochemistry derives from the nature of the internal donor atoms of the ligand such as tren (= tris(2-aminoethyl)amine), 1-(2-aminopropyl)-1,5,9-triazacyclododecane.<sup>16</sup> On the other hand, the Co-N(2) distance is significantly shorter than those of the Co-N(sp<sup>3</sup>) bonds. This shortness is probably due to the increased basicity of deprotonated nitrogen in amide moiety. The bond lengths of an amide moiety in **1** are C(7)-N(2); 1.315(5) Å and C(7)-O(1); 1.252(5) Å, respectively. It should be noted that the C-N distance is shorter and C=O is longer compared to those found from free amide (C-N; 1.330, C=O; 1.240).<sup>17</sup> This result agrees with many investigations which reveal that complexation of the deprotonated amide nitrogen shortens the peptide C-N and lengthens the C-O bond.<sup>17</sup> These observations have been attributed to that the substitution of an amide proton by a metal ion results in the bond length change to the direction of double bond character in the C-N and single bond character in the C-O (eq. 1).<sup>17</sup>



## Conclusions

A novel chiral nonlinear tetradentate ligand, 4(*S*)-1-(2-pyridyl)-3-oxo-4-aza-7-thiaoctane (*S*-metampH) has been synthesized from the reaction of amp and *S*-methioine. As shown by spectroscopic methods and proven by single crystal X-ray diffraction study, the ligand serves as a monoanionic chiral tetradentate NNSN donor set in this complex. The geometrical structure of the **1** has an  $\Lambda$ -*cis-β*<sub>1</sub> configuration which three nitrogen atoms of the ligand chelates to a meridional around metal center and one of the axial position is occupied by sulfur atom.

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