Synthesis and Stereochemistry of Co-ordinated Sulphenate and Sulphinate

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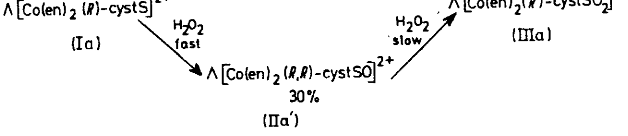
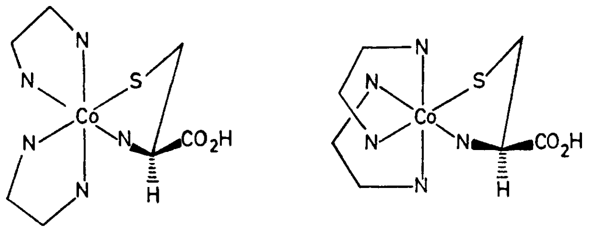
Summary Peroxide oxidizes S-co-ordinated (*R*)-cysteine to two isomeric sulphenates and a sulphinate derivative; the *X*-ray cyrstal structure of one of the sulphenates is described.

Two diastereoisomeric complexes (Ia), (Ib) of stoicheiometry [Co(en)(*R*)-cysteinatol[$ClO_4]_2\cdot H_2O$ were obtained from the redox reaction between (*R*)-cystine (1 mol), ethylenediamine (en) (6 mol), and a Co^{II} salt (2 mol) in aqueous solution. The proposed structures for these isomers are shown in Figure 1.



SCHEME

Complex (Ia) was oxidised by H_2O_2 in neutral-to-slightly acidic solution to give two separable orange-brown derivatives (IIa) and (IIa′). Prolonged reaction with H_2O_2 gave a single yellow complex (IIIa). The stoicheiometry of the isolated complexes indicated stepwise oxidation of the co-ordinated thiolate ion to two *S*-bound sulphenate isomers and a yellow sulphinate. These oxidations for the cysteine complexes have been carried out previously but the diastereoisomerism was not recognised.[2] They have also been carried out for co-ordinated cysteamine, cysteine, thioglycollic acid, and penicillamine in a variety of complexes.[3] The peroxide oxidation is summarised in the Scheme.



(Ia) (Ib)

FIGURE 1. (*R*)-Cysteinatobis(ethylenediamine)cobalt(III) ions. (Ia) (Λ) ϵ_{max} (483 nm) 128, ϵ_{max} (283 nm) 12,000 l mol^{-1} cm^{-1}; $[M]^{40}_{20}$ − 9320 deg mol^{-1} dm^2, 10^{-2}M $HClO_4$; (Ib) (Δ) ϵ_{max} (484 nm) 133, ϵ_{max} (281 nm) 12,500 l mol^{-1} cm^{-1}; $[M]^{483}_{20}$ + 9020 deg mol^{-1} dm^2, 10^{-2}M $HClO_4$.

A rate difference of *ca.* 100 : 1 allowed the clean isolation of both sulphenates from the common sulphinate. Similar observations to those reported here have been made for other tetra-amine cobalt(III) complexes containing SN bound cysteamine, (*S*)-penicillamine, and SO bound thioglycollate.

Sulphenic acids and sulphenate ions appear to be elusive species in organic chemistry and stabilisation of the anion by co-ordination was an interesting prospect. Moreover addition of oxygen to the co-ordinated thiol renders the S atom chiral and the stereospecificity and optical stability at sulphur needed to be established. The more abundant sulphenato complex was isolated as a 1 : 1 adduct containing both [Co(en)$_2$(*R*)-cysteinesulphenato](ClO$_4$)$_2$ and [Co(en)$_2$(*R*)-cysteinesulphenato]ClO$_4$ (deprotonated at CO$_2$H).† The NS bonding implied by the visible spectra has been confirmed by an *X*-ray crystallographic investigation. The structure‡ (Figure 2) shows the trapped S-bound sulphenate unit. It establishes the configuration about the Co atom as Λ and confirms the (*R*) configuration of the cysteine unit. Moreover the structure confirms the Λ configuration for the parent ion (Ia) since the reaction involves oxidation at the bound sulphur which should not involve Co–S cleavage.

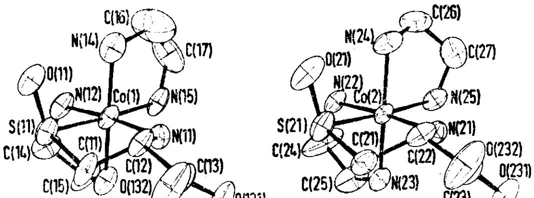
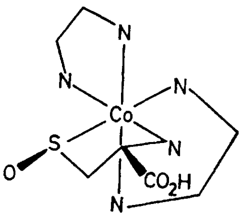


FIGURE 2. Molecular structure of the two crystallographically independent Λ[Co(en)$_2$(*R*)cysteine(*S*)sulphenato] ions (IIa).

The expectation for the (*R*)-cysteinato isomers (Ia) and (Ib) in solution is that the five-membered NS cysteine ring will be λ with the carboxy-substituent equatorial. For the (Ia) (Λ) isomer the delivery of the oxygen in the H$_2$O$_2$ oxidation is expected to be more favourable at the axial position on the S atom. This orientation ensures a minimum interaction between the incoming oxidant and the adjacent ethylenediamine chelate and the expectation is borne out by the structural analysis in the form that the more abundant isomer has this configuration (*S*).

A more pronounced differentiation was observed in an alternative route to the [Co(en)$_2$(*R*)-cysteinesulphenato]$^{2+}$ diastereoisomers which involves reaction of (Ia) or (Ib) with trityl chloride or *p*-nitrobenzenesulphonyl chloride in Me$_2$SO followed by hydrolysis. The oxidations may be viewed as addition of Ph$_3$C$^+$ or *p*-NO$_2$C$_6$H$_4$SO$_2$$^+$ to co-ordinated thiol followed by hydrolysis at the bound sulphur atom with proton capture by the leaving groups Ph$_3$C$^-$ or *p*-NO$_2$C$_6$H$_4$SO$_2$$^-$. Alternatively the solvent Me$_2$SO may be *O*-alkylated and the resultant sulphonium derivative attacked at sulphur by co-ordinated thiolate giving Co–$\overset{+}{\text{S}}$–SMe$_2$, and Ph$_3$CO$^-$ or *p*-NO$_2$C$_6$H$_4$SO$_3$$^-$. Subsequent hydrolysis gives the sulphenate and SMe$_2$. The major product from (Ia) and these reagents was the sulphenate isomer (IIa) depicted in Figure 2 (trityl chloride, 93%) and



(IIb′)

FIGURE 3. Δ[(*R*)cysteine(*R*)sulphenatobis(ethylenediamine)-cobalt(III)]$^{2+}$.

the ratio of the diastereoisomers (*ca.* 13 : 1) differs sharply from that for the H$_2$O$_2$ reagent (2·3 : 1). Dilute solutions of both sulphenates were stable for at least 2 days at 20 °C at pH 2—7, *i.e.* the isomers do not interconvert. Two conclusions follow; the isomer distributions derive from kinetic and not equilibrium control and the chiral S atom of the co-ordinated sulphenate ion is optically stable. A further implication of this optical stability is that the Co–S bond remains intact since bond rupture would result in mutarotation at S.

In 0·1 M NaOD, (IIa) mutatorates completely to one of the other diastereoisomers (IIb′) without any exchange of the carbon protons. Indeed no significant C–H exchange occurs over 12 h at 20 °C.§ The rates of mutarotation were irreproducible and a Co$^{\text{II}}$ catalyst generated by the basic conditions is implied. The mutarotated product has properties identical to one of the two diastereoisomers obtained by oxidising (Ib), *i.e.* mutarotation occurs about the chiral cobalt centre. Further, the stereospecific rearrangement indicates that the configuration of this isomer is (IIb′) (Figure 3), with both CO$_2$H and the sulphenate oxygen occupying equatorial positions involving minimal interactions with the neighbouring chelates. We have observed similar base-induced Co$^{\text{II}}$ equilibrations with analogous cysteinato and cysteinesulphinato isomers.

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† (IIa): ϵ_{470}476, $[M]^{20}_{539}$ + 3225; 10^{-2}M HClO$_4$; satisfactory elemental analyses were obtained.

‡ *Crystal data*: C$_{14}$H$_{45}$Co$_2$Cl$_3$N$_{10}$S$_2$O$_{19}$; monoclinic; space group $P2_1$ (C_2^2, No. 4); a = 8·745(3), b = 16·042(5), c = 12·859(4) Å, β = 93·96(2)°; U = 1799·8 Å^3; D_m = 1·75(1), D_c = 1·745 g cm^{-3}; Z = 2; μ(Cu-K_α) = 109·2 cm^{-1}. Reflection data were collected on a Picker FACS-I fully automatic four-circle diffractometer using graphite-crystal monochromated Cu-K_α radiation. The structure was solved by direct methods (MULTAN 74) and was refined by block-diagonal least-squares methods using 3616 reflections with $I \geqslant 3·0\sigma(I)$ (corrected for absorption) to an *R*-factor of 0·050. Correct absolute configuration has been determined by inclusion of reflection data of the form $hk \pm l$ and $h\bar{k} \pm l$, which, in space group $P2_1$, are inequivalent in the presence of anomalous scatterers. Full details of this *X*-ray structural work will be published later. Principal bond lengths are as follows: Co(*n*)—N(*n*1), 2·000(6), 1·974(5); Co(*n*)—N(*n*5), 2·036(7), 2·048(6); Co(*n*)—N(*nm*), 1·957(7), 1·97(2); Co(*n*)—S(*n*1), 2·225(2), 2·237(3); S(*n*1)—O(*n*1), 1·523(6), 1·499(6); S(*n*1)—C(*n*1), 1·796(7), 1·824(7); C(*n*3)—O(*n*31), 1·215(8), 1·200(9); C(*n*3)—O(*n*32), 1·267(8), 1·293(9); *n* = molecule 1 or 2, respectively, and *m* = atom nos. 2—4. The two molecules shown differ in the conformation of *one* of their en rings (1, λ; 2, δ), and are joined through a H-bond, O(32) sharing a proton.

§ It is claimed in ref. 2 that the methine and methylene protons exchange.

[1] W. G. Jackson, A. M. Sargeson, H. C. Freeman, and C. J. Moore, unpublished work.

[2] C. P. Sloan and J. H. Krueger, *Inorg. Chem.*, 1975, **14**, 1481.

[3] B. A. Lange, K. Libson, E. Deutsch, and R. C. Elder, *Inorg. Chem.*, in the press; M. P. Schubert, *J. Amer. Chem. Soc.*, 1933, **55**, 3336; L. S. Dollimore and R. D. Gillard, *J. C. S. Dalton*, 1975, 369; W. G. Jackson and A. M. Sargeson, unpublished work.