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[Fe^{III}(SR)₄]¹⁻ Complexes Can Be Synthesized By the Direct Reaction of Thiolates With FeCl₃**

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Abstract

It is shown that the previously characterized [Fe^{III}(SR)₄]¹⁻ (R = Et, i-Pr, Ph) complexes can be synthesized by the direct reaction of 4 equiv of LiSR with FeCl₃ in DMF solution. [Fe^{III}(SR)₄]¹⁻ complexes are synthetic analogs for the [Fe^{III}(S-Cys)₄] center in rubredoxin proteins.

Keywords

Iron(III); thiolate; rubredoxin

1. Introduction

In 1969, the protein crystal structure of oxidized rubredoxin revealed its [Fe^{III}(S-Cys)₄] center [1–3]. The obvious route to synthetic analogs for this center involved the direct reaction of thiolate anions with a simple Fe(III) salt such as FeCl₃. Early attempts with aromatic or alkyl thiolate in alcohol solvents were not successful:

These reactions demonstrated the strong tendency of thiolates (1) to induce autoredox reactions which produce reduced metal ions and disulfides and (2) to bridge metal centers leading to oligomeric and polymeric complexes. In 1975, Holm and coworkers reported the first synthesis of a stable [Fe^{III}(SR)₄]⁻ complex by the air oxidation of [Fe^{II}(S₂-o-xylene dithiolate)₂]²⁻ [4, 5]. Millar reported in 1982 that sterically hindered aromatic thiolate ligands inhibited the autoredox reaction such that the first examples of [Fe^{III}(SR)₄]⁻ complexes (R = 2,3,5,6-Me₄C₆H₃; 2,4,6-*i*-Pr₃C₆H₂) with monodentate ligands were achieved [6–8]. In 1983, we reported a general synthesis of [Fe^{III}(SR)₄]¹⁻ complexes for a variety of monodentate thiolate including R = Ph, Et, and Me [9–11]. This reaction involved the titration of [Fe(OAr)₄]¹⁻ complexes with thiols.

**In memory of Ed Stiefel, my undergraduate research advisor, whose enthusiasm for inorganic chemistry changed my life.

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As part of an investigation of the use of $[\text{Fe}^{\text{III}}(\text{SR})_4]^-$ complexes as starting materials for the synthesis of $[\text{FeS}(\text{SR})]$ clusters, we have reinvestigated the direct reaction of FeCl_3 with thiolates.

2. Experimental

All reactions were performed with dry solvents under a dinitrogen atmosphere.

2.1 Synthesis of $[\text{Et}_4\text{N}][\text{Fe}^{\text{III}}(\text{SEt})_4]$ from FeCl_3

To a 100mL side-arm flask charged with 0.65g (4.0 mmol) of FeCl_3 , 1.52g (18.0 mmol) of NaSEt , and 0.65g (4.0mmol) of Et_4NCl , 10mL of DMF was added. The reaction mixture was stirred for about 20 min at 0°C , then 5 hours at room temperature. The reaction mixture was filtered to remove NaCl , and 70–80mL of ether was added to the filtrate. After cooling overnight at -20°C , the dark brown precipitate was collected by filtration, and washed with diethyl ether. The dark brown crystalline compound was dried under vacuum (1.35g, 77.0%). UV-vis in DMF, λ in nm (ϵ in $\text{M}^{-1} \text{cm}^{-1}$): 353 (1.09×10^4), 488 (5.36×10^3)

2.2 Synthesis of $[\text{Et}_4\text{N}][\text{Fe}^{\text{III}}(\text{S-}i\text{-Pr})_4]$ from FeCl_3

To a 200mL side-arm flask charged with 0.54g (3.3 mmol) of FeCl_3 , 1.47g (15.0 mmol) of $\text{NaS-}i\text{-Pr}$, and 0.55g (3.3mmol) of Et_4NCl , 30mL of DMF was added at 0°C . The reaction mixture was stirred for about 30 min at 0°C , then overnight at room temperature. The reaction mixture was filtered to remove NaCl and 80–90mL of ether was added to the filtrate. After cooling overnight at -20°C , the dark reddish purple precipitate was collected by filtration and washed with diethyl ether. The compound was dried *in vacuo* to give a dark reddish purple crystalline solid (1.33g, 80 %). UV-vis in DMF, λ in nm (ϵ in $\text{M}^{-1} \text{cm}^{-1}$): 257 (1.06×10^4), 356 (9.45×10^3), 488 (4.84×10^3)

2.3 Synthesis of $[\text{Et}_4\text{N}][\text{Fe}^{\text{III}}(\text{SPh})_4]$ from FeCl_3

To a 100mL side-arm flask charged with 0.30g (1.8 mmol) of FeCl_3 , 1.10g (8.3 mmol) of NaSPh , and 0.31g (1.8 mmol) of Et_4NCl , 20mL of DMF was added at 0°C . The reaction mixture was stirred for about 30 min at 0°C , then overnight at room temperature. The reaction mixture was filtered to remove NaCl and 60mL of ether were added to the filtrate. After cooling overnight at -20°C , the black precipitate was collected by filtration and washed with diethyl ether. The black crystalline compound was dried under vacuum (0.81g, 70%). UV-vis in DMF, λ in nm (ϵ in $\text{M}^{-1} \text{cm}^{-1}$): 328 (1.68×10^4), 554 (9.8×10^3).

3. Results and Discussion

The reaction of FeCl_3 with 4 equiv. of NaSR in DMF gives stable solutions of $[\text{Fe}^{\text{III}}(\text{SR})_4]^{1-}$ complexes.

The other product of the reaction, NaCl , can be removed by filtration. The addition of a quaternary ammonium or phosphonium cation and subsequent addition of diethylether gives high isolated yields of $[\text{R}_4\text{E}][\text{Fe}^{\text{III}}(\text{SR})_4]$ complexes. For convenience the cations can be added to the initial reaction mixture. The products $[\text{Et}_4\text{N}][\text{Fe}(\text{SEt})_4]$, $[\text{Et}_4\text{N}][\text{Fe}^{\text{III}}(\text{S-}i\text{-Pr})_4]$ and $[\text{Et}_4\text{N}][\text{Fe}(\text{SPh})_4]$ are spectroscopically (UV-vis and ^1H NMR) identical to the compounds previously reported by the synthesis via eqn 3 [9,10]. As previously reported, these complexes must be handled carefully in solution to prevent their decomposition by the reactions shown in equations 1 and 2. Previously we had ascribed the success of eqn 3 versus 1 and 2 to the

stabilization of the Fe(III) redox state in $[\text{Fe}^{\text{III}}(\text{OAr})_4]^{1-}$ versus FeCl_3 and to the choice of solvent: DMF, DMSO, CH_3CN versus alcohols [10].

In hindsight, with a different initial choice of solvent (DMF versus MeOH), this direct and general synthesis of $[\text{Fe}^{\text{III}}(\text{SR})_4]^{1-}$ complexes could have been achieved 35 years ago. This work is a further demonstration of the importance of the solvent in the reaction of metal ions with thiolate ligands. A recent study of the reaction of FeCl_3 with ethyl thiolate in DMF supports our conclusions [12]. $[\text{Fe}^{\text{II}}(\text{SR})_4]^{2-}$ complexes have been extensively studied as the basic starting material for the systematic construction of a wide variety of FeS clusters [13–15]. In contrast, $[\text{Fe}^{\text{III}}(\text{SR})_4]^{1-}$ complexes have only seen limited use for the synthesis of FeS clusters [16,17]. Despite their sensitivity, $[\text{Fe}^{\text{III}}(\text{SR})_4]^{1-}$ complexes with alkyl thiolate ligands are attractive starting materials for the synthesis of FeS clusters. $[\text{Fe}^{\text{II}}(\text{SR})_4]^{2-}$ complexes with alkyl thiolate ligands are extremely air sensitive, and as a result such compounds have rarely been synthesized or structurally characterized [14,18].

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References

1. Meyer J, Moulis JM. Handbook of Metalloproteins 2001;1:505–517.
2. Sieker LC, Stenkamp RE, LeGall J. Methods Enzymol 1994;243:203–216. [PubMed: 7830611]
3. Romao, MJ.; Archer, M. Iron Metabolism. Ferreira, GC.; Moura, JIG.; Franco, R., editors. Wiley-VCH Verlag: Weinheim: 1999. p. 341–358.
4. Lane RW, Ibers JA, Frankel RB, Holm RH. Proc Natl Acad Sci U S A 1975;72:2868–2872. [PubMed: 1059080]
5. Lane RW, Ibers JA, Frankel RB, Papaefthymiou GC, Holm RH. J Am Chem Soc 1977;99:84–98. [PubMed: 830690]
6. Millar M, Lee JF, Koch SA, Fikar R. Inorg Chem 1982;21:4105–4106.
7. Millar M, Lee JF, O'Sullivan T, Koch SA, Fikar R. Inorg Chim Acta 1996;243:333–343.
8. Millar M, Koch SA, Fikar R. Inorg Chim Acta 1984;88:L15–L16.
9. Koch SA, Maelia LE, Millar M. J Am Chem Soc 1983;105:5944–5945.
10. Maelia LE, Millar M, Koch SA. Inorg Chem 1992;31:4594–4600.
11. Czernuszewicz RS, Kilpatrick LK, Koch SA, Spiro TG. J Am Chem Soc 1994;116:7134–7141.
12. Frank P, Hodgson KO. J Biol Inorg Chem 2005;10:373–382. [PubMed: 15864505]
13. Hagen KS, Holm RH. J Am Chem Soc 1982;104:5496–5497.
14. Hagen KS, Watson AD, Holm RH. J Am Chem Soc 1983;105:3905–3913.
15. Rao PV, Holm RH. Chem Rev 2004;104:527–559. [PubMed: 14871134]
16. Cambray J, Lane RW, Wedd AG, Johnson RW, Holm RH. Inorg Chem 1977;16:2565–2571.
17. Han S, Czernuszewicz RS, Spiro TG. Inorg Chem 1986;25:2276–2277.
18. Bose K, Huang J, Haggerty BS, Rheingold AL, Salm RJ, Walters MA. Inorg Chem 1997;36:4596–4599. [PubMed: 11670127]