yielded the linear pentapeptide as the acetate salt (214 mg, 80% of theory). The compound moved as a single component on TLC: R_f (B) 0.52; R_f (C) 0.36.

Cyclo[D-Phe-Pro-Gly-Proψ[CH_2S]Gly]. To a solution of AcOH·D-Phe-Pro-Gly-Proψ[CH_2S]Gly (175 mg, 0.33 mmol) in dry degassed DMF (50 mL) maintained at -30 °C, DPPA (0.40 mmol), HOBt (62 mg, 0.4 mmol), DMAP (49 mg, 0.4 mmol), and triethylamine (0.8 mmol) were added. The reaction mixture was then placed in a freezer at -15 °C for 18 h. TLC analysis showed complete reaction. Water (6 mL) and Dowex MR-3 mixed-bed resin (6 mL) were introduced into the reaction mixture and stirred for 6 h. The resin was separated by filtration, and the solvents were completely removed in vacuum. Repeated lyophilization from 30% aqueous acetic acid solution yielded chromatographically pure cyclic pentapeptide (127 mg, 85% of theory): R_f (C) 0.64; mp 110-112 °C; $[\alpha]^{25}_D$ -103.2° (*c* 1.1, 50% HOAc).

Analytical HPLC on a C-18 reversed-phase column at 50 °C (Spherisorb, 4.6 mm i.d. × 250 mm) indicated the compound to be at least 99% pure, t_R = 10.5 min, k' = 8.39. The mobile phase consisted of a linear gradient of CH_3CN (20%-30% over 20 min) against 0.25 M triethylammonium phosphate buffer (pH 2.5). Mass spectral analysis indicated the precise mass to be 458.199 ± 0.003 (Calcd for $C_{23}H_{30}N_4O_4S$: 458.19876). Anal. Calcd for $C_{23}H_{30}N_4O_4S \cdot 1.5H_2O$: C, 56.88; H, 6.85; N, 11.33; S, 6.60. Found: C, 56.65; H, 6.14; N, 10.65; S, 6.96. Amino acid analysis: Phe, 1.00; Pro, 1.07; Gly, 0.99; Proψ[CH_2S]Gly, could not be detected due to its very weak color response with ninhydrin.

Registry No. 1, 99781-72-3; 2, 86044-88-4; Boc-Pro-OTs, 86661-32-7; Boc-Proψ[CH_2S]Gly-OH, 77489-32-8; Boc-Proψ[CH_2S]Gly-OH·Cs, 99726-40-6; Boc-Gly, 4530-20-5; Boc-Pro, 15761-39-4; Boc-D-Phe, 18942-49-9; H-D-Phe-Pro-Gly-Proψ[CH_2S]Gly-OH, 99781-71-2; L-prolinol, 23356-96-9; di-*tert*-butyl dicarbonate, 24424-99-5; Boc-prolinol, 69610-40-8; *p*-toluenesulfonyl chloride, 98-59-9; mercaptoacetic acid, 68-11-1.

Communications to the Editor

Generation of a *cis*-[$Mo^VO(OH)$] Center: ^1H- and ^{17}O-Superhyperfine Parameters Relevant to Molybdoenzymes

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Analysis of molybdenum EXAFS data[2,3] indicates the presence of [$Mo^{VI}O_2(SR)_n$] (*n* = 2, 3) units at the oxidized molybdenum sites of chicken liver sulfite oxidase (SO), *Chlorella* nitrate reductase (NR), and the desulfo form of chicken liver xanthine dehydrogenase. [$Mo^{VI}OS(SR)_2$] units are detected[2,4] in active xanthine dehydrogenase and bovine milk xanthine oxidase (XO). A single oxo group only is observed in the respective reduced Mo^{IV} forms and protonation of the other oxo or sulfido group to form an OH or SH ligand is suggested.[2,3] Indeed, the presence of ^1H-superhyperfine coupling[5] in the Mo^V ESR signals of SO (low pH form),[6,7] of E. coli and spinach NR (low pH forms),[8,9] and of XO (desulfo and active (rapid type 1) forms)[5,10] has been interpreted in the same way.[11] Further information is available from the extensive and inventive work of Bray:[12-15] substitution of $^{16}OH_2$ by $^{17}OH_2$ in solutions of oxidized SO and XO followed by interaction with reducing substrates permits observation of ^{17}O-superhyperfine coupling in the various ESR-active forms of the enzymes. Ligand oxo, OH, OH_2, and OR (where R is derived from substrate) are possible sources of the coupling.

cis-[$Mo^{VI}O_2L$] (LH_2 = ($HSCH_2CH_2N(Me)CH_2-)_2$) (I) is unusual for such compounds in that it exhibits[16] a one-electron redox process ($E°$ = -1.3 V vs. SCE) which is chemically reversible on the timescale of cyclic voltammetry. Electrolysis[17] of I in THF containing 0.1 M ^1H_2O at -42 °C in the cavity of an X-band ESR spectrometer leads to a resonance typical of Mo^V, except that each feature is present as a doublet (Figure 1a). In the presence of 0.1 M ^2H_2O, the structure collapses (Figure 1b), demonstrating the presence of superhyperfine coupling to a single hydrogen atom. Comparison of the derived parameters (*g*, 1.961; *a*(Mo), 39.3 × 10^{-4} cm^{-1}) with those[18,19] of *cis*-[MoOClL] (1.966; 37.8) and *cis*-[MoOClL'$_2$] (L'H = 8-mercaptoquinoline) (1.968; 37.6) is consistent with the expected spectrum of *cis*-[MoO(OH)L] (II). The ^1H-superhyperfine coupling constant of 13.6 × 10^{-4} cm^{-1} is listed with those for the "strongly coupled" protons of the

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(11) Note that the ^1H coupling under discussion is due to the so-called "strongly coupled" protons which exhibit *a* = (9-15) × 10^{-4} cm^{-1} and are exchangeable with solvent H_2O.[5] In active XO, the source of this proton is the C-8 proton of xanthine.[16] Also observed[5] in XO are "weakly coupled" protons with *a* = (0.5-3.0) × 10^{-4} cm^{-1} which are also exchangeable and, in certain "inhibited" signals, protons with coupling constants of intermediate magnitude and that are not exchangeable.

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Table I. Superhyperfine Coupling Constants ($\times 10^{-4}$ cm^{-1})

	^{1}H	^{17}O
cis-[MoO(OH)L]	13.7	7 ± 2[f]
"MoO(OH)(O_b)$_4$"	9-10[a]	
desulfo XO (slow signal)	13.7-14.9[b]	9[c]
active XO (rapid type 1)	11.7-12.8[b]	9-13[c]
spinach NR (signal A)	12.0[d]	
SO (aquo, low pH)	9.1[b]	5.5[c]
E. coli NR (aquo, low pH)	8.5[e]	

[a] References 20, 21: The osberved signals are generated by photolysis of single crystals of $A_6[Mo_7O_{24}]\cdot 3H_2O$ (A = NH_3Pr, NH_3-*i*-Pr). O_b are bridging oxygen atoms. [b] Reference 5: The ranges quoted are those observed for signals generated in the presence of different anions and buffers. [c] References 12, 22. [d] Reference 9. [e] Reference 8. [f] Estimated for the OH ligand, assuming a coupling constant of 2 × 10^{-4} cm^{-1} for the oxo ligand; see text.

different enzymes in Table I.

Incubation of I in THF solutions containing ^1H_2O (52.1 atom % ^{17}O; $I = {}^5/_2$) allows oxygen exchange. Careful drying, followed by electrolysis at -42 °C in the presence of 0.1 M $^2H_2{}^{16}O$ generates the ESR spectrum (Figure 1c) of II (100 atom % ^{2}H; 52.1 atom % ^{17}O).[23] In comparison with that of II (100 atom % $^2H^{16}O$; Figure 1b), this signal exhibits larger central[24] and hyperfine line widths and partially resolved structure is apparent on the central line. This structure is attributed to ^{17}O-superhyperfine coupling with a coupling constant of 7 (±2) × 10^{-4} cm^{-1} for the OH ligand. This value can be compared with those derived for the enzymes (Table I).

The data strongly support the presence of an OH ligand at the ESR-active site in SO and desulfo XO, at least. Closer comparison will be possible when anisotropic data for II become available.

Electrolysis of I at -42 °C in carefully dried CH_2Cl_2 solution generates a broad signal at g 1.89 characteristic[25] of $[Mo^VO_2L]^-$ (III), which converts to that of II in the presence of a proton source. The existing data are consistent with the following mechanism:

$$[Mo^{VI}O_2L] \underset{-e^-}{\overset{+e^-}{\rightleftharpoons}} [Mo^VO_2L]^- \underset{-H^+}{\overset{+H^+}{\rightleftharpoons}} [Mo^VO(OH)L]$$
I III II

$$E^\circ = -1.3 \text{ V}$$

The observation of this chemically reversible coupled electron-proton transfer relates to similar processes[26-28] in the enzymes of interest and suggests that the exact nature of the peripheral (cofactor?)[29] ligands can control the pK of the [MoO_2] and [MoOS] centers. Interestingly, a pH-dependent equilibrium exists in SO[30] and NR[31] but has not been detected in XO.[32]

Finally, estimation of ^{17}O coupling to the OH ligand in II (Table I) is complicated by the possible presence of ^{17}O coupling to the oxo ligand. The latter was assumed to be about 2 × 10^{-4} cm^{-1} and justification of this assumption rests upon the observation of the ESR spectrum of $[MoO(SPh)_4]^-$ (98.23 atom % ^{98}Mo; 51.2 atom % ^{17}O) at four frequencies (1.9, 2.9, 3.8, and 9.1 GHz).[33,34] ^{17}O coupling is resolved at the lower frequencies and simulation

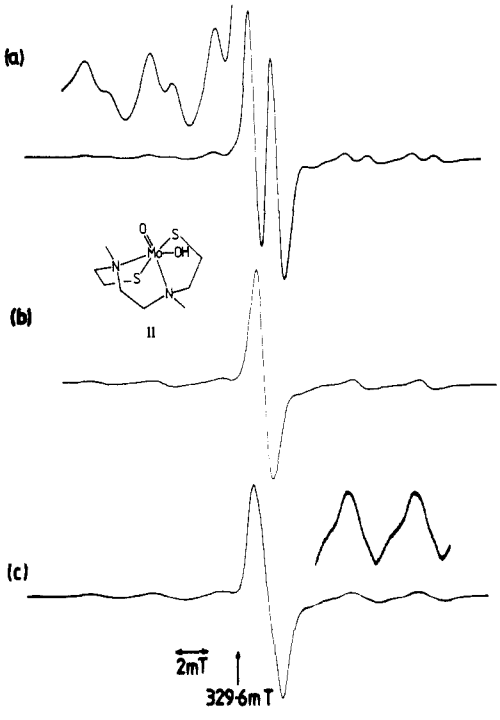

Figure 1. X-band ESR signals generated by electrolysis of 0.01 M [MoO_2L] (I) in THF (0.1 M Bu_4NBF_4) at -1.4 V (vs. SCE) and -42 °C in the presence of (a) 0.1 M ^1H_2O, (b) 0.1 M ^2H_2O, and (c) 0.1 M ^2H_2O after previous incubation of I with 0.1 M ^1H_2O (52.1 atom % ^{17}O) followed by drying (see text).

at all frequencies permits extraction of the ^{17}O-superhyperfine constants: a, 2.12; $A_\parallel$, 0.64; $A_\perp$, 2.86 × 10^{-4} cm^{-1}. Intriguingly, these parameters span the range ((0.6-2.9) × 10^{-4} cm^{-1}) observed for the two inequivalent oxygen atoms detected[12] in the "inhibited" signal of XO.

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Registry No. I, 80287-02-1; II, 99797-95-2; SO, 9029-38-3; XO, 9002-17-9; NR, 9013-03-0.

(23) Oxygen exchange in I occurs with a half-life of several hours in THF solutions containing 0.1 M H_2O, while that in II is much slower than hydrogen exchange at -42 °C.

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Pregeneration, Spectroscopic Detection, and Chemical Reactivity of (Trifluoromethyl)copper, an Elusive and Complex Species[1]

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Pharmaceutical and agricultural chemicals that contain a trifluoromethyl group have been the subject of increased research activity in recent years.[2] Concomitant with these applications have been increased efforts to develop a cheaper and more efficient synthetic methodology for the introduction of the trifluoromethyl group into organic compounds. An adjunct of this strategy has been numerous attempts to incorporate the trifluoromethyl group directly into the molecule via in situ generation and coupling of CF_3Cu with aryl halides.[3] Although some modest success has

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