

Figure 1. ORTEP view of **3**. Additional distances (Å) and angles (deg): Zr-Cl, 2.536 (1); Zr-O 2.248 (1); Zr-C11, 2.183 (2); C11-O, 1.244 (3); Cl-Zr-O, 80.86 (4); Cl-Zr-C11, 113.42 (6); Zr-C11-Si, 163.87 (13); O-C11-Si, 119.56 (16).

OCMe₃.⁸ This presumably reflects competition between lone pairs on the silylacyl oxygen and the butoxide ligand for the same orbital on zirconium.^{10b} In contrast, the triflate complex (η^5 -C₅H₅)₂Zr(η^2 -COSiMe₃)(OSO₂CF₃)¹⁴ (**4**) was obtained in high yield after stirring **3** with an excess of Me₃SiOSO₂CF₃ in dichloromethane. We are examining further aspects of the insertion chemistry of **2** but have been unable to observe reactions with ethylene (90 psi, diethyl ether, 2 days), phenylacetylene (excess, hexane, 1 day), carbon dioxide (100 psi, diethyl ether, 2 days), and carbon disulfide (excess, C₆D₆, 1 day).

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Supplementary Material Available: A listing of bond lengths, bond angles, positional and thermal parameters, and observed and calculated structure factors for **3** (14 pages). Ordering information is given on any current masthead page.

(14) For **4**: ¹H NMR (CD₂Cl₂, 20 °C, 360 MHz) δ 0.51 (s, 9 H, SiMe₃), 5.90 (s, 10 H, C₅H₅); ¹³C{¹H} NMR (CD₂Cl₂, 20 °C, 50.3 MHz) δ -2.85 (s, SiMe₃), 110.0 (s, C₅H₅), 389.7 (s, ZrCOSi); IR (Nujol, cm⁻¹) ν_{CO} = 1500. Anal. (C₁₅F₃H₁₉O₄SSiZr) C, H, S.

Fluoride Ion Catalyzed Aldehyde Addition of Labile α - or β -Halocarbanion Species Generated from the Corresponding α - or β -Halo Organosilanes

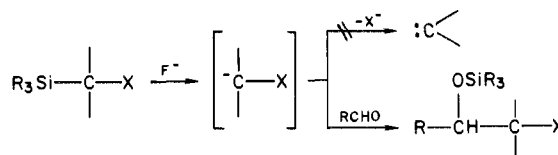
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Organometallic compounds having such leaving group(s) as halogen at the α -position to the metal are called carbenoids and are labile and decompose to carbenes readily.¹ Though uniquely versatile in organic synthesis,^{1,2} carbenoid reactions require generally extremely low temperatures.³ The instability of the carbenoid species is attributed to coordination of the halogen(s) to the metal (e.g., Li⁺ and Mg²⁺) to produce a metal-halogen bond

and induce its decomposition to carbene. In spite of attempts at stabilization of the carbenoids by employing basic solvents^{1b,4} or by adding metal halide salts,⁵ handling the reactive organometallics still needs careful experimentations.⁶ We assumed that in the absence of a metal gegen cation, the interaction between the metal cation and the leaving group halogen(s) should be completely neglected, and the corresponding carbanions having α -halogens should have longer lifetimes to undergo synthetic reactions before decomposition. Herein we report that such naked carbanion species can be generated from the corresponding α -halo organosilanes by the action of fluoride ion catalyst and add to aldehydes at ambient temperature without appreciable decomposition.



When tris(diethylamino)sulfonium difluorotrimethylsilicate (TASF)^{7,8} (1 M tetrahydrofuran (THF) solution, 0.25 mmol) was added to a THF (2 mL) solution of benzaldehyde (1 mmol) and (dichloromethyl)trimethylsilane (1.2 mmol) at room temperature, exothermic reaction took place. After being stirred for 8 h, the reaction mixture was treated with acid (1 M HCl-MeOH solution, room temperature, 0.25 h). Workup followed by chromatographic purification (silica gel, CH₂Cl₂-hexane) gave 2,2-dichloro-1-phenylethanol in 74% yield. Experiments using *N,N*-dimethylformamide (DMF) or hexamethylphosphoric triamide (HMPPA) as the solvent or tetrabutylammonium fluoride (TBAF) as the catalyst gave somewhat lower yields. Various (polyhalomethyl)silanes gave the corresponding aldehyde adducts in good yields (Table I) except Me₃SiCH₂Cl and PhMe₂SiCF₂H which were recovered unchanged. Since the corresponding (polyhalomethyl)lithium compounds decompose even at -78 °C,³ the procedure described herein should be of great significance from a practical viewpoint. For example, introduction of dichloromethyl unit to 3,4-dichlorobenzaldehyde gave an insecticide (run 13),⁹ whereas the product of run 14 is a precursor of 3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylic acid, an acid part of permethrin and its derivatives.¹⁰ Ketone adducts were not isolated thus far.¹¹

Stereoselectivity of the carbonyl addition is worthy of note. In the reaction of 2-phenylpropanal with Me₃SiCCl₃ the erythro isomer of the adduct was formed as the major product (87% selectivity).^{12,13} The erythro:threo ratio (87:13) did not change significantly on employment of PhMe₂SiCCl₃ (87:13) or *t*-BuMe₂SiCCl₃ (90:10). Thus, the observed selectivity seems to be an intrinsic value of a naked trichloromethyl anion. A possibility that a pentavalent silicate species is involved may be rejected on the basis of the lack of the substituent effect at silicon

(4) (a) Villieras, J.; Bacquet, C.; Normant, J. F. *Bull. Soc. Chim. Fr.* **1975**, 1797. (b) Villieras, J. *Ibid.* **1967**, 1511.

(5) Tarhouni, R.; Kirschleger, B.; Rambaud, M.; Villieras, J. *Tetrahedron Lett.* **1984**, 25, 835.

(6) A practical modification of the procedure for (di- and trihalomethyl)lithiums is the addition of lithium dicyclohexylamide to a mixture of ketone and excess polyhalomethane at -95 to 0 °C. See: Taguchi, H.; Yamamoto, H.; Nozaki, H. *Bull. Chem. Soc. Jpn.* **1977**, 50, 1588.

(7) TASF was prepared from (diethylamino)sulfur trifluoride (DAST) and (diethylamino)trimethylsilane according to the procedure described in ref. 8.

(8) U. S. Patent 3 940 402; *Chem. Abstr.* **1976**, 85, 6388j.

(9) (a) *Fr. Adm.* 95 753; *Chem. Abstr.* **1972**, 76, 99326d. (b) *Fr.* 1 550 129; *Chem. Abstr.* **1970**, 72, 111004k.

(10) *Ger. Offen.* 2 639 777; *Chem. Abstr.* **1977**, 87, 134026t.

(11) In the reaction of acetophenone and Me₃SiCHCl₂, the enol silyl ether, α -trimethylsilyloxystyrene, was formed, suggesting that the dichloromethyl anion species generated in the present reaction has considerable basicity (see: Nakamura, E.; Murofushi, T.; Shimizu, M.; Kuwajima, I. *J. Am. Chem. Soc.* **1976**, 98, 2346).

(12) The relative configuration is assigned as "erythro" or "threo" according to the definition of Noyori (Noyori, R.; Nishida, I.; Sakata, J. *J. Am. Chem. Soc.* **1983**, 105, 1598).

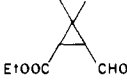
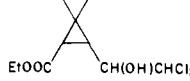
(13) The configuration of the product was determined by comparison of the chemical shift of the methine proton α to hydroxyl group with the reported value.¹⁴

(1) (a) Kirmse, K. "Carbene Chemistry", 2nd ed; Academic Press: New York, 1971. (b) Köbrich, G. *Angew. Chem., Int. Ed. Engl.* **1967**, 6, 41. (c) Köbrich, G. *Ibid.* **1972**, 11, 473.

(2) (a) Villieras, J.; Rambaud, M. *Synthesis* **1980**, 644. (b) Villieras, J.; Rambaud, M.; Tarhouni, R.; Kirschleger, B. *Synthesis* **1981**, 68. (c) Tarhouni, R.; Kirschleger, B.; Rambaud, M.; Villieras, J. *Tetrahedron Lett.* **1984**, 25, 835. (d) Siegel, H. *Top. Curr. Chem.* **1982**, 106, 55.

(3) For instance, LiCH₂Cl decompose even at -130 °C^{2b,c} and preparation of LiCHCl₂ or LiCCl₃ must be carried out at -110 or -78 °C, respectively.¹

Table I. Aldehyde Addition of α -Polyhalo Silanes

| run | RCHO | R ₃ Si-C-X ^a | TASF, mol % | conditions ^f | product | yield, % ^{b,c} |
|-----|---|--|------------------|--|---|-------------------------|
| 1 | PhCHO | Me ₃ SiCHCl ₂ | 25 | THF, rt, 8 h | PhCH(OH)CHCl ₂ (I) | 77 ^{d,e} |
| 2 | PhCHO | Me ₃ SiCHCl ₂ | 25 | DMF, rt, 20 h | I | 66 ^d |
| 3 | PhCHO | Me ₃ SiCHCl ₂ | 25 | HMPA, rt, 20 h | I | 41 ^d |
| 4 | PhCHO | Me ₃ SiCHCl ₂ | 100 ^f | THF, rt, 12 h | I | 59 ^d |
| 5 | PhCHO | Me ₃ SiCCl ₃ | 10 | THF, rt, 8 h | PhCH(OH)CCl ₃ | 77 |
| 6 | PhCHO | Me ₃ SiCCl ₂ Me | 25 | THF, rt, 12 h | PhCH(OH)CCl ₂ Me | 97 |
| 7 | PhCHO | PhMe ₂ SiCF ₂ CH=CH ₂ | 10 | DMPU, ^g rt, on ^h | PhCH(OH)CF ₂ CH=CH ₂ | 58 ⁱ |
| 8 | <i>n</i> -C ₁₀ H ₂₁ CHO | Me ₃ SiCHCl ₂ | 25 | THF, rt, 18 h | <i>n</i> -C ₁₀ H ₂₁ CH(OH)CHCl ₂ | 72 |
| 9 | <i>n</i> -C ₁₀ H ₂₁ CHO | Me ₃ SiCCl ₃ | 10 | THF, 0 °C, 12 h | <i>n</i> -C ₁₀ H ₂₁ CH(OH)CCl ₃ | 79 |
| 10 | PhCH=CHCHO | Me ₃ SiCHCl ₂ | 25 | THF, rt, 18 h | PhCH=CHCH(OH)CHCl ₂ | 95 ^j |
| 11 | PhCH(Me)CHO | Me ₃ SiCHCl ₂ | 25 | THF, 0 °C, 9 h | PhCH(Me)CH(OH)CHCl ₂ | 62 |
| 12 | PhCH(Me)CHO | Me ₃ SiCCl ₃ | 25 | THF, 0 °C, 4 h | PhCH(Me)CH(OH)CCl ₃ ^k | 75 |
| 13 | 3,4-Cl ₂ C ₆ H ₄ CHO | Me ₃ SiCHCl ₂ | 25 | THF, rt, 3 h | 3,4-Cl ₂ C ₆ H ₄ CH(OH)CHCl ₂ | 75 |
| 14 |  | Me ₃ SiCHCl ₂ | 25 | THF, rt, 6 h |  | 67 |

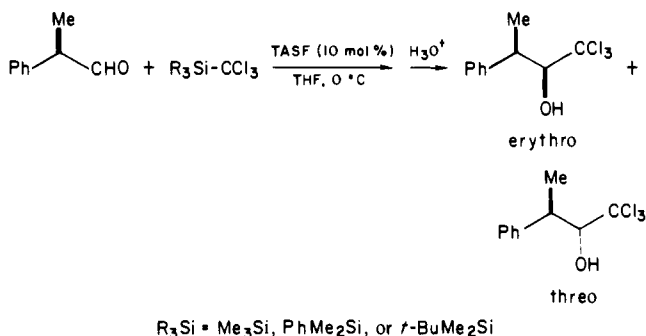
^aThe silane (1.2 mol equiv) was used. ^bIsolated after desilylation (1 M HCl-MeOH, room temperature, 0.25–0.5 h). ^cIsolated yields are given unless noted. ^dGLC yield. ^eIsolated yield was 74%. ^fTBAF was used instead of TASF. ^gDMPU = 1,3-dimethyl-3,4,5,6-tetrahydro-2(1*H*)-pyrimidinone. ^hOvernight. ⁱIt is contrastive that PhMe₂SiCF₂H was recovered unchanged. See ref 19. ^jA 1,4-adduct was not observed. ^kThe ratio erythro:threo = 87:13.^{12,13} ^lrt = room temperature.

Table II. Aldehyde Addition of (Polyhalovinyl)silanes^a

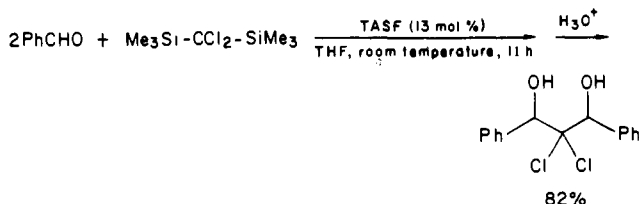
| RCHO | vinylsilane ^b | TASF, mol % | reaction time, h | product | yield, % |
|---|---|-----------------|------------------|---|----------|
| PhCHO | Et ₃ SiCF=CF ₂ | 20 ^c | 5.5 | PhCH(OSiEt ₃)CF=CF ₂ (II) | 42 |
| PhCHO | Et ₃ SiCF=CF ₂ ^d | 10 | 24 | II | 66 |
| PhCHO | PhMe ₂ SiCF=CF ₂ | 10 | 7 | PhCH(OH)CF=CF ₂ ^e | 61 |
| PhCHO | Et ₃ SiCF=CF- <i>n</i> -Bu | 10 | 4 | PhCH(OSiEt ₃)CF=CF- <i>n</i> -Bu | 84 |
| PhCHO | Me ₃ SiCF=CF- <i>t</i> -Bu | 10 | 7 | PhCH(OR)CF=CF- <i>t</i> -Bu R=H | 48 |
| | | | | R=TMS | 38 |
| PhCHO | Et ₃ SiCF=CFSEt | 10 | 8 | PhCH(OSiEt ₃)CF=CFSEt | 86 |
| PhCHO | Et ₃ SiCCl=CF ₂ | 10 | 12 | PhCH(OSiEt ₃)CCl=CF ₂ | 38 |
| <i>n</i> -C ₁₀ H ₂₁ CHO | Et ₃ SiCF=CF ₂ ^f | 10 | 12 | <i>n</i> -C ₁₀ H ₂₁ CH(OSiEt ₃)CF=CF ₂ | 59 |
| <i>n</i> -C ₁₀ H ₂₁ CHO | Et ₃ SiCF=CFH | 10 | 24 | <i>n</i> -C ₁₀ H ₂₁ CH(OSiEt ₃)CF=CFH | 47 |
| PhCH=CHCHO | Et ₃ SiCF=CF ₂ | 10 | 12 | PhCH=CHCH(OSiEt ₃)CF=CF ₂ | 43 |

^aAll reactions were carried out in THF at room temperature. ^bThe silane (1.2 mol equiv) was used unless noted. ^cTBAF was employed instead of TASF. ^dRCHO/silane = 1.5/1. ^eIsolated after desilylation (H⁺, MeOH, room temperature). ^fRCHO/silane = 1.2/1.

and on the similar erythro:threo ratio (86:14) in the same transformation by electrochemical method.¹⁴



Bis(trimethylsilyl)dichloromethane reacted with 2 mol of benzaldehyde to give a 1:2 adduct and thus can be regarded as a synthon of dichloromethylene dianion (CCl₂²⁻).

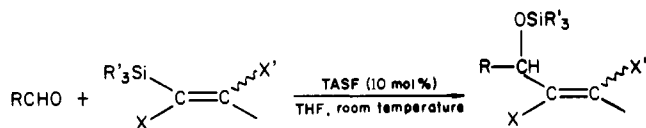


The concept of stabilization of carbanions by removal of metal cations was extended to those having β -halogen(s).¹⁵ Actually,

(14) Shono, T.; Kise, N.; Suzumoto, T. *J. Am. Chem. Soc.* **1984**, *106*, 259.

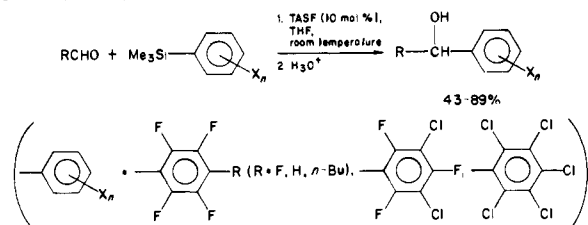
(15) The feasibility of this extension may be warranted in view of the metal cation effect on elimination reactions: (a) Bartsch, R. A. *Acc. Chem. Res.* **1975**, *8*, 239. (b) Sicher, J. *Angew. Chem.* **1972**, *84*, 177.

this extension was realized when TASF was applied to (polyhalovinyl)silanes. For example, TASF (0.1 mmol) was added to a THF solution of benzaldehyde (1.5 mmol) and triethyl(trifluorovinyl)silane (1 mmol) at room temperature. Workup after 24 h reaction time gave the desired adduct in 66% yield. It is noteworthy that β -elimination to difluoroacetylene is suppressed even at ambient temperature, whereas (trifluorovinyl)lithium¹⁶ is quite labile and should be handled below -78 °C.^{16b} Various (polyfluorovinyl)silanes gave the aldehyde adducts in moderate to high yields as summarized in Table II. Applications to other kinds of β -halo organosilanes are currently under investigation.^{17,18}



(16) (a) Tarrant, P.; Johncock, P.; Savory, J. *Org. Chem.* **1963**, *28*, 839. (b) Normant, J. F.; Foulon, J. P.; Masure, D.; Sauvetre, R.; Villieras, J. *Synthesis* **1975**, 122. (c) Chuit, C.; Sauvetre, R.; Masure, D.; Baudry, M.; Normant, J. F.; Villieras, J. *J. Chem. Res., Synop.* **1977**, 104. (d) Sauvetre, R.; Masure, D.; Chuit, C.; Normant, J. F. *Synthesis* **1978**, 128. (e) Hiyama, T.; Nishide, K.; Obayashi, M. *Chem. Lett.* **1984**, 1765.

(17) We have experienced that (polyhaloaryl)silanes also gave the corresponding aldehyde adducts without β -elimination to benzyne.



A closely related reaction: Ishikawa, N.; Isobe, K. *Chem. Lett.* **1972**, 435.

The organosilane-F⁻ reagent system allows us to study the stability and reactivity of metal-free carbanion species which are otherwise labile even at low temperatures.

(18) Protodesilylation of (polyfluorovinyl)silanes with the aid of KF in aqueous dimethyl sulfoxide is recently disclosed: Martin, S.; Sauvetre, R.; Normant, J. F. *Tetrahedron Lett.* **1983**, *24*, 5615.

(19) Hiyama, T.; Obayashi, M. *Tetrahedron Lett.* **1983**, *24*, 4113.

Iron-57 Nuclear Magnetic Resonance Spectroscopic Study of Carbonmonoxymyoglobin[†]

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Iron-57 has a very large nuclear magnetic resonance (NMR) chemical shift range^{1,2} and is expected to be a sensitive probe of heme-ligand coordination, or electronic structure, in heme proteins. Unfortunately, it is not a sensitive nucleus ($I = 1/2$, 2.2% natural abundance, $\nu_L = 11.7$ MHz at 8.45 T (360-MHz ¹H resonance frequency)), so to date no iron-57 NMR spectra of proteins have been reported. In this paper, we report the first observation of iron-57 NMR spectra of a metalloprotein, carbonmonoxymyoglobin ($M_r \sim 18$ 000 daltons), which has been made possible by combined use of isotopic enrichment and a sensitive "home-built" NMR spectrometer, equipped with a 20-mm sideways-spinning probe.³ Sensitivity is adequate to record partially relaxed spectra for T_1 measurements, and we show that combined T_1 and T_2 determinations yield values for the anisotropy of the chemical shielding tensor and the rotational correlation time, τ_R , of the protein, the latter values being in accord with previous carbon-13 NMR determinations.⁴ Our results indicate that the iron-57 isotropic chemical shifts (σ_i) and chemical shift anisotropies ($|\sigma_{||} - \sigma_{\perp}|$) of a variety of other proteins (e.g. hemoglobin, chloroperoxidase, cytochrome P450) should be accessible via iron-57 enrichment and high-field large-sample operation, yielding potentially useful information on the nature of iron-ligand interactions in such systems.

We show in Figure 1A the natural-abundance iron-57 NMR spectrum of ferrocene ($(\pi-C_5H_5)_2Fe$, 0.8 M in C_6H_6) obtained in a 20-mm sideways-spinning probe at 8.45 T (corresponding to an ⁵⁷Fe resonance frequency of 11.7 MHz). This spectrum (S/N ~ 9 , total acquisition time = 30 min) compares favorably with results presented previously by others.^{2,5-7} On the basis of previous work, we assign ferrocene a chemical shift of 1531 ppm downfield from $Fe(CO)_5$.⁵ The line width is $\sim 2.5 \pm 0.5$ Hz, in accord with the 2.6-Hz value (at 9.7 MHz) observed by Nozawa et al.⁷

In contrast to the narrow line spectrum of ferrocene, we show in Figure 1B the iron-57 NMR spectrum of [⁵⁷Fe]carbonmon-

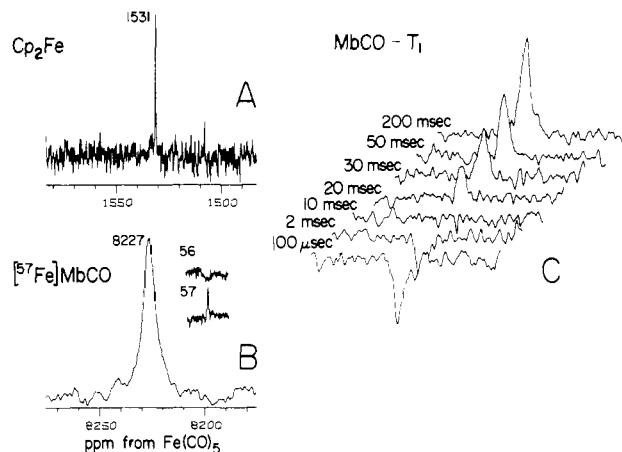


Figure 1. Iron-57 NMR spectra of ferrocene and [⁵⁷Fe]carbonmonoxymyoglobin at 8.45 T (corresponding to an ⁵⁷Fe resonance frequency of about 11.6 MHz or a ¹H resonance frequency of 360 MHz) and partially relaxed Fourier transform (PRFT) data set for MbCO. (a) 0.8 M Cp_2Fe in C_6H_6 , 1040 scans, 2-s recycle time, 35- μs 90°-pulse excitation, 2-Hz line broadening; (B) [⁵⁷Fe]MbCO (15 mM in 50 mM phosphate buffer, pH 7.1, 23 °C) 120 001 scans, 500-ms recycle time, 35- μs pulse excitation, 20-Hz line broadening; (inset) spectra of natural abundance MbCO and [⁵⁷Fe]MbCO recorded under same sample and spectrometer condition as in (B), except only 27 400 scans per spectrum; (C) PRFT data set using the basic conditions noted in (B), the τ values are given on the Figure.

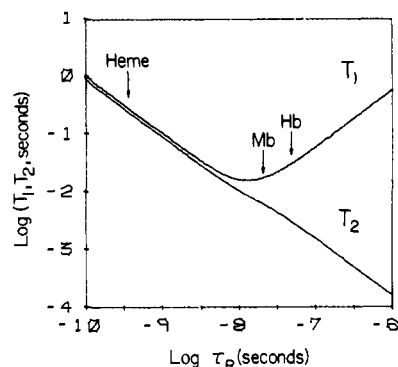


Figure 2. log-log plots of T_1 and T_2 vs. τ_R (both in seconds) for iron-57 relaxation via a chemical shift anisotropy mechanism at 8.45 T and assuming $|\sigma_{||} - \sigma_{\perp}| = 3600$ ppm. T_1/τ_R combinations appropriate for $Fe(PP-IX)(CO)(py)$, MbCO, and HbCO are indicated.

oxymyoglobin (MbCO, 15 mM in 50 mM phosphate buffer, pH 7.1, at 23 °C). The chemical shift observed is 8227 ppm downfield from $Fe(CO)_5$, slightly more deshielded than the 8211 ppm value found for $Fe(PP-IX)(CO)(py)$ (PP-IX = protoporphyrin-IX) 0.05 M in pyridine,¹ and the line width (55 ± 5 Hz) is considerably greater than the ~ 2.5 -Hz value found for ferrocene, due to the increased rotational correlation time of the protein. The protein sample appeared to contain exclusively MbCO, as determined by visible absorption spectrophotometry and by natural abundance carbon-13 NMR spectroscopy (data not shown), shortly after iron-57 NMR data acquisition. A second set of iron-57 NMR experiments (inset in Figure 1B) showed no NMR signals from a natural-abundance sample of MbCO but again contained a well-resolved signal at 8227 ppm from the enriched material.

We now consider the relaxation of iron in proteins. We show in Figure 1C inversion-recovery ($180^\circ - \tau - 90^\circ$, ref 8) partially relaxed Fourier transform (PRFT) data for [⁵⁷Fe]MbCO, at 8.45 T. Analysis of the results in Figure 1C yields $T_1 = 17 \pm 3$ ms, at 23 °C. Since there are no protons particularly close by, it seems reasonable to believe that relaxation will be dominated by the chemical shift anisotropy mechanism,^{1,8} in which case⁸

$$1/T_1 = \frac{1}{2} \gamma^2 H_0^2 (\sigma_{||} - \sigma_{\perp})^2 \frac{2\tau_R}{1 + \omega^2 \tau_R^2} \quad (1)$$

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(4) Oldfield, E.; Norton, R. S.; Allerhand, A. *J. Biol. Chem.* **1975**, *250*, 6368.

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(6) Haslinger, E.; Robien, W.; Schlogl, K.; Weissensteiner, W. *J. Organomet. Chem.* **1981**, *218*, C11.

(7) Nozawa, T.; Hatano, M.; Sato, M.; Toida, Y.; Batholdi, E. *Bull. Chem. Soc. Jpn.* **1983**, *56*, 3837.