°C with zinc and acetic acid to afford **16** in ~70% yield. Without purification, amine ester **16** was treated with a catalytic amount of NaOMe in refluxing methanol, followed by reduction with $LiAlH_4$, to give (±)-perhydrogephyrotoxin **3** and its C_1 epimer in a ratio of ~8:1 (50% yield). Pure (±)-perhydrogephyrotoxin[23] was obtained by silica gel chromatography and was identical (TLC, capillary GLC, ^1H NMR, ^{13}C NMR, solution IR, EI, and CI mass spectra) with an authentic sample prepared by hydrogenation[2] of gephyrotoxin.[24]

Efforts aimed at converting intermediates such as **13** to gephyrotoxin, as well as developing a more concise method for elaborating the hydroxyethyl-substituted pyrrolidine ring, are being actively pursued and will be reported in due course.

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(19) IR (film) 2930, 2860, 2790, 2720, 1710, 1450, 1360, 1100 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$, major epimer) 7.3 (broad s, C_6H_5), 4.51 (s, OCH_2Ph), 3.50 (d, $J = 7.3$ Hz, $CHCH_2O$), 2.16 ppm (s, CH_3CO); ^{13}C NMR (22.6 MHz, $CDCl_3$, major epimer) 208.6, 138.5, 128.0, 127.3, 127.2, 72.8, 72.1, 53.9, 53.5, 50.4, 48.2, 39.5, 37.0, 33.1, 31.4, 28.7, 25.7, 22.8, 20.3, 17.6 ppm. The minor isomer showed characteristic ^{13}C NMR absorptions at 54.6, 53.1, and 17.9 ppm.

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(23) ^1H NMR (90 MHz, $CDCl_3$) 4.0 (dt, $J = 11, 2$ Hz), 3.7 (m), 3.2 ppm (m); ^{13}C NMR (C_6D_6) 60.1, 56.8, 56.3, 51.1, 41.8, 40.5, 33.4 (two carbons), 32.9, 32.0, 31.6, 28.6, 27.2, 27.1, 25.9, 23.5, 21.1, 17.3, 14.8 ppm; IR ($CHCl_3$) 3250 (br), 2930, 2860, 1465, 1380, 1100, 1040 cm^{-1}; mass spectrum (CI, isobutane) *m/z* (rel intensity) 294 (100), 276 (5), 248 (40), 222 (4).

(24) We are indebted to Dr. John Daly for providing us with a sample of natural gephyrotoxin and for initially arousing our interest in this problem.

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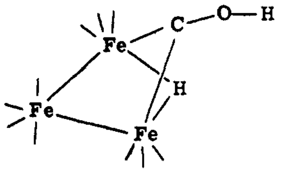
A New Reaction for the Conversion of Carbon Monoxide into Methane: Proton-Induced Reduction of CO in a Metal Carbonyl Cluster, $[Fe_4(CO)_{13}{}^{2-}]$

Sir:

In an attempt to better understand the heterogeneous reduction of CO[1] and possibly to develop homogeneous analogues, attention has focused on the reduction of coordinated carbon monoxide in molecular systems. The reactions available to date involve external reducing agents such as dihydrogen[2-5] or alane.[6] We report here a new route based on the protonation of a polynuclear metal carbonyl anion.

Protonation of coordinated carbon monoxide, which recently was observed in the polynuclear complexes I and II,[7,8] may be interpreted as a partial reduction of the CO ligand. This interpretation prompted us to attempt further reduction by treating metal carbonyl clusters with very strong acids. The components necessary for reduction, H^+ and electrons, may be supplied by the acid and metal atoms of the cluster, respectively. The most successful results to date have been obtained with the cluster $[Fe_4(CO)_{13}{}^{2-}]$.



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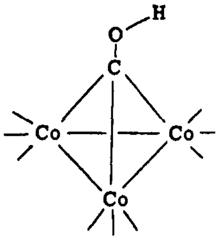

II

A substantial yield of methane was obtained when 0.11 mmol of $[PPN]_2[Fe_4(CO)_{13}]$ [PPN = μ-nitrido-bis(triphenylphosphorus)(+1)][9] was dissolved in 2.0 mL of HSO_3CF_3 and allowed to react for 3 days at room temperature on a vacuum line. Analysis of the evolved gases by a combination of selective low-temperature adsorption on silica gel, mass spectroscopy, PVT measurement, and quantitative infrared spectroscopy demonstrated the following yields of moles of gas per mole of cluster: CH_4, 0.56; H_2, 0.20; and CO, 2.2. Extraction of the acid solution with cyclohexane followed by infrared spectroscopy on the deep brown hydrocarbon layer demonstrated the presence of a metal carbonyl having bands at 2047 (s), 2029 (s), 2015 (m), 1990 (s), and 1980 (m) cm^{-1}. The 1990-cm^{-1} band is assigned to $Fe(CO)_5$; among the remaining bands, all but the lowest are in good agreement with those reported for $Fe_5(C)(CO)_{15}$.[10] In a separate run the acid layer was diluted with water and titrated with Ce^{4+}. Assuming that the sole oxidizable component is Fe^{2+}, this result indicates the production of 1.56 Fe^{2+} per cluster. (An independent qualitative colorimetric test confirmed the presence of large quantities of Fe^{2+} in the acid phase.) Based on the average oxidation state of $-\frac{1}{2}$ for each iron in the cluster, this yield of Fe^{2+} provides 3.9 electrons per cluster, and an additional 1.2 electrons are available assuming that the remaining iron-containing products are in the zero oxidation state. The yield of reduction products listed above would require 3.8 electrons per cluster. Thus the quantity of Fe^{2+} is of the right magnitude to account for the observed yields of CH_4 and H_2, but the exact electron balance will depend on the oxidation state of iron in the iron carbonyl products. These observations are consistent with the reaction summarized in eq 1.

$$[Fe_4(CO)_{13}{}^{2-}] + HSO_3CF_3 \rightarrow CH_4 + H_2 + CO + Fe^{2+} + H_3O^+ + SO_3CF_3{}^- + \text{iron carbonyls} \quad (1)$$

The yield of methane is sensitive to the acidity. Thus no methane is produced with a 1:1 mixture of HSO_3CF_3–H_2O.

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As mentioned above the yield of CH_4 is ~0.56 per cluster when pure HSO_3CF_3 is employed, and it is increased to 0.82 per cluster when the reaction medium is 1:1 HSO_3CF_3–$O(SO_2CF_3)_2$. Neither concentrated HCl nor pure HSO_3F produces volatile hydrocarbons, but concentrated H_2SO_4 yields a trace of CH_4 along with SO_2, CO_2, CO, COS, and H_2.

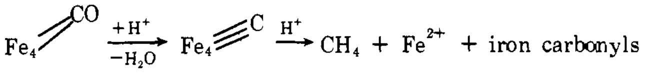
Two experiments were performed to test whether the methane originates from the coordinated carbon monoxide, or from an adventitious source. In the first of these, DSO_3CF_3 was employed as reactant with the Fe_4 cluster, and infrared spectra of the methane–carbon monoxide fraction showed the presence of CD_4 and no indication of ^1H-containing methane. In the second experiment, the $[Fe_4(CO)_{13}{}^{2-}]$ was enriched such that 26% of the carbon monoxide contained the ^{13}C isotope. The reaction of this enriched metal carbonyl with HSO_3CF_3 according to the procedure indicated above produced methane which was 25% $^{13}CH_4$ as judged by quantitative infrared spectroscopy. These experiments convincingly show that the methane originates from carbon monoxide in the metal cluster, and therefore confirm eq 1.

Since H_2 is a product of the reaction, it was conceivable that methane might arise from a H_2 reduction rather than direct attack of H^+ on the metal cluster. To check this possibility the reaction was run under the uniform conditions outlined above but with the addition of 457 Torr of H_2, which is 58 times greater than the H_2 produced in a typical run. The yield of CH_4 was 0.53 per cluster, which, within experimental error, is equal to the yield in the absence of added H_2. Two isotopic experiments also demonstrate the lack of incorporation of dihydrogen into the product. When H_2 (344 Torr) was placed over the reaction mixture containing DSO_3CF_3 in place of HSO_3CF_3, the only methane produced was CD_4 as judged by infrared spectroscopy (eq 2) and, when the reaction was run with D_2 over a reaction mixture containing HSO_3CF_3, only CH_4 was produced (eq 3). From these experiments it is clear that the hydrogen in the methane originates from H^+ and not from H_2 intermediate.

$$[Fe_4(CO)_{13}{}^{2-}] + DSO_3CF_2 \xrightarrow{H_2} CD_4 \qquad (2)$$

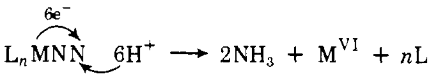
$$[Fe_4(CO)_{13}{}^{2-}] + HSO_3CF_3 \xrightarrow{D_2} CH_4 \qquad (3)$$

One possible mechanism is attack on the CO oxygen by protons to split off water, leaving a carbide which subsequently is attacked by H^+ to produce methane (eq 4). Any carbide intermediate would have to display a different reactivity pattern from known carbides, because we have observed the conversion of $[Fe_6(CO)_{16}C^{2-}]$ into $Fe(CO)_{15}C$ in HSO_3CF_3[10] without the production of CH_4.



$$Fe_4{-}CO \xrightarrow[-H_2O]{+H^+} Fe_4{\equiv}C \xrightarrow{H^+} CH_4 + Fe^{2+} + \text{iron carbonyls} \qquad (4)$$

The work of Chatt and co-workers[11] on the reduction of coordinated dinitrogen (eq 5) indicates that the necessary equivalents for CO reduction may be supplied by a mononuclear complex of a metal such as Mo or W, which can easily reach a high oxidation state. In the iron series, however, it appears that a cluster is necessary to supply the six electrons required for the complete reduction of CO. Thus the mononuclear carbonyl $Fe(CO)_5$ in HSO_3CF_3 produces the known ion $[HFe(CO)_5{}^+]$.[12] The three-iron cluster $[Fe_3(CO)_{11}{}^{2-}]$ yields traces of CH_4 when treated with HSO_3CF_3, and as described above a good yield of methane was obtained from the four-iron cluster.



$$L_nMN\overset{6e^-}{N}\ \ 6H^+ \longrightarrow 2NH_3 + M^{VI} + nL \qquad (5)$$

$$M = Mo \text{ or } W$$

It is probable that the reaction of metal carbonyl clusters with the surface of hydrated metal oxides is analogous to the homogenous reaction reported here.[13] A closer comparison of the two reactions will be possible when the role of dihydrogen is delineated in the heterogenous reaction.

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Tandem Directed Metalation Reactions. Short Syntheses of Polycyclic Aromatic Hydrocarbons and Ellipticine Alkaloids

Sir:

Directed metalation of aromatic substrates[1] is an increasingly important strategy for the regiospecific synthesis of highly substituted benzene derivatives,[2] heterocycles,[2b,c,3] and natural products.[4] The rapidly growing list of functionalities capable of promoting and stabilizing ortho metalation which includes oxazolines,[3a,5] imidazolidine,[6] CH═NR,[2a,4a,7] $CO\bar{N}R$,[3l,4b,f,g,8,9] $CS\bar{N}R$,[3c] $CONR_2$,[2b,3b,4c,d] $CH(OMe)_2$,[4i] OCH_2OMe,[3d,4e,h] OCH(Me)OEt,[3k] CH_2SMe,[10] CH_2O^-,[3e,f] $\bar{N}COR$,[3h] N≡C,[3i] and halo and methoxy $ArCr(CO)_3$[3j] offers attractive and, at times, highly advantageous solutions to preparative problems not readily achieved by classical (usually electrophilic) chemistry. We report on the new concept of tandem directed metalation (Scheme I) involving ortho-lithiated tertiary benzamide (**1**) and benzyl alkoxide (**3**) intermediates which provides rapid access to polycyclic anthraquinones and unusual heterocyclic benzoquinones (Table I). We delineate the scope of this one-pot aromatic ring construction reaction and demonstrate its utility for the synthesis of carcinogenic polycyclic aromatic hydrocarbons (PAH's)[11] and chemotherapeutic ellipticine alkaloids (**6**).[12] Both classes of compounds currently constitute lively and urgent areas of study.[13,14]

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