Bimetallic Organotransition-Metal Tautomers of a Chiral Enolate. Preparation of $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)C(CH_2)O(Cl)Zr(\eta^5\text{-}C_5H_5)_2]$ and $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)C(O)CH_2Au(PPh_3)]$. X-ray Crystal Structure of $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)C(CH_2)O(Cl)Zr(\eta^5\text{-}C_5H_5)_2]$

Ira Weinstock,[†] Carlo Floriani,*[†] Angiola Chiesi-Villa,[‡] and Carlo Guastini[‡]

Chemistry Department, Columbia University New York, New York 10027
Istituto di Strutturistica Chimica, Centro di Studio per la Strutturistica Diffrattometrica del CNR Università di Parma, 43100 Parma, Italy

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Use of the chiral organometallic enolate $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)C(CHR)O^-M^+]$ in the stereoselective delivery of the acyl fragment $[Fe]^*\text{-}C(O)\text{-}CHR^-$ to organic electrophiles has been studied extensively.[1] In these reactions, the nature of the counter cation M^+ and the substituent R plays a critical role in the control of both reactivity and stereoselectivity.[2]

We now report here that the chiral enolate $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)C(CHR)O^-Li^+]$, which is alkylated at carbon by a variety of organic substrates,[3] can be trapped in either the enol or keto form, by using either oxophylic, i.e., $[cp_2ZrCl_2]$, or carbophylic, i.e., $[Au(PPh_3)Cl]$, metal fragments. The enol form (a)

a, enol, $ML_x = [(\eta^5\text{-}C_5H_5)_2ZrCl]$ b, keto, $M'L_y = [Au(PPh_3)]$

is similar to some other titanium and zirconium enolates.[4-8] Several of these transition-metal enolates are highly erythroselective aldol condensation reagents.[4,5] The keto form (b) is best viewed as an α-functionalized metal alkyl,[9] $M\text{-}CH_2\text{-}(C(O)\text{-}[Fe]^*)$. Due to their divergent structures, however, and to the properties of the organometallic fragments required to trap these structural extremes, the reactivity patterns of the tautomeric forms a and b could differ from one another significantly.

The synthesis of two thermally stable organotransition-metal-stabilized tautomers of the chiral enolate $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)(COCH_2)^-]$ are herein reported. By reaction of the lithium salt of this anion with $[(\eta^5\text{-}C_5H_5)_2ZrCl_2]$ in THF at -78 °C, the enol derivative a was isolated as a red crystalline solid.[10]

A view of complex I is shown in Figure 1.[11] Geometry about the iron center is pseudooctahedral, similar to that reported for two related compounds, $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)[COCH(Me)Et]]$[1a] and $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)(COCH_2CH(OH)CH_2CH_3)]$.[2a] For complex I P-Fe-C18 = 90.8 (3)°, P-Fe-C16 = 92.9 (3)°, and C18-Fe-C16 = 92.1 (4)°. Analogous angles in $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)[COCH(Me)Et]]$ and $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)(COCH_2CH(OH)CH_2CH_3)]$ are respectively 92.5°, 91.6°; 95.3°, 92.12°; and 89.33°, 94.76°. Notably, the perpendicular distance from C16 (Figure 1) to the plane defined by the phenyl ring directly below is >3.3 Å, as compared to 2.89 Å for the analogous distance in $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)[COCH(Me)Et]]$.[1d] This, most likely, is the result of steric compression. As predicted for complexes of this type,[1d] the two oxygen atoms (O2 and O1, Figure 1) and *anti* to one another. The C16-C17 bond distance of 1.331 (12) Å, similar to that reported recently in an analogous (*E*)-zirconium enolate, (*E*)-$[Zr[OC(SiMe_3)=CHAr]Cl(\eta^5\text{-}C_5H_5)_2]$ (Ar = 9-anthryl),[6] 1.334 (7) Å, indicates a bond order of 2. In addition, the Zr-O bond distance of 1.950 (4) Å in this (*E*)-zircono enolate, compares to the 1.948 (8) Å bond distance found in complex I. The degree of stereoselectivity achieved in the reaction of $(\eta^5\text{-}C_5H_5)_2Zr(Cl)$-enolates with aldehydes[5c] is due to the steric interactions determined, in part, by the short Zr-O bond distance.

By reacting the lithium enolate $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)(COCH_2)^-Li^+]$ with chloro(triphenylphosphine)gold(I), $[AuCl(PPh_3)]$, in THF at -78 °C, the C-metalation product, b, was isolated as an orange crystalline solid.[12] Although crystals suitable for X-ray analysis were not obtained, the proposed structure is supported by the presence of a >CO band, IR (KBr/Nujol), at

[†] Columbia University.
[‡] Università di Parma.

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(10) $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)C(O)CH_3]$ (5.00 g, 11 mmol) was dissolved in THF (125 mL) and cooled to -78 °C; *n*-butyl lithium (6.88 mL, 1.6 M, 11 mmol) in hexane was then added by syringe. The solution immediately changed from orange to dark red. After $^1/_2$ h of stirring at -78 °C, $[(\eta^5\text{-}C_5H_5)_2ZrCl_2]$ (3.27 g, 11 mmol) was added directly. The solution was stirred at -78 °C until the white crystalline $[(\eta^5\text{-}C_5H_5)_2ZrCl_2]$ could no longer be seen. During this time, approximately 1 h, the solution turned from dark red, back to a bright orange-red. The solution was warmed to room temperature and concentrated to dryness. The resultant red solid was then extracted over a 2-day period with 200 mL of Et_2O, to give a red crystalline solid, $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)C(CH_2)O(Cl)Zr(\eta^5\text{-}C_5H_5)_2]$ (5 g, yield 60%). Anal. Calcd for $C_{36}H_{32}ClFeO_2PZr$: C, 60.89; H, 4.54; Cl, 4.99. Found: C, 60.79; H, 4.56; Cl, 5.15. IR (KBr/Nujol) ν(CO)(terminal) 1917 cm^{-1}. (The CO stretch of the enolate fragment was no longer visible in the carbonyl region.) ^1H NMR (benzene-d_6, 360 MHz) δ 6.90-7.70 (m, 15 H, PPh_3); 6.19 (s, 5 H, cpZr); 5.76 (s, 5 H, cpZr); 4.48 (d, J_{P-H} = 1.1 Hz, 5 H, cpFe); 4.34 (br, s, 1 H, -CH_2); 4.27 (br, d, 1 H, CH_2). Red solid, 1.6 g, was dissolved in 225 mL of an 8:1 Et_2O:THF mixture, filtered (no. 4) and cooled to 7 °C. After 3 days, red crystals, suitable for X-ray analysis, were recovered.

(11) Crystal data: $C_{36}H_{32}ClFeO_2PZr$, M_r = 710.1, triclinic, space group $P\bar{1}$ (from structural analysis), a = 15.192 (3) Å, b = 11.231 (2) Å, c = 9.829 (2) Å, α = 108.77 (2)°, β = 93.02 (2)°, γ = 79.04 (2)°; V = 1558.8 (6) Å^3, Z = 2, D_c = 1.513 g cm^{-3}, λ(Kα Mo) = 0.710 69 Å, μ(Mo Kα) = 9.6 cm^{-1}; crystal dimensions 0.20 × 0.30 × 0.35 mm. Intensities of 5843 independent reflections were measured at room temperature ($6 < 2\theta < 50°$) on a Philips PW 1100 diffractometer by using Mo Kα radiation. The structure was solved by the heavy-atom method and refined by blocked full-matrix least-squares with rigid body constraints applied to phenyl and cyclopentadienyl rings. All calculations were carried out using the SHELX-76 program. For 2656 unique observed reflections [$I > 2\sigma(I)$] the final R value is 0.053.

(12) $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)C(O)CH_3]$ (3.58 g, 7.88 mmol) was dissolved in THF (100 mL) and cooled to -78 °C. *n*-Butyllithium in hexane (4.90 mL, 1.6 M, 7.84 mmol) was then added by syringe. The resultant dark red solution was stirred at -78 °C for 10 min. Chloro(triphenylphosphine)-gold(I) (3.61 g, 7.89 mmol) was then added directly. Immediately, the solution began to turn yellow-orange. The mixture was stirred at -78 °C for 1.5 h until most of the $[AuCl(PPh_3)]$ had dissolved. The clear red-orange solution was then allowed to warm up to room temperature. Between 0 and +5 °C, the solution became turbid as LiCl began to precipitate. The solution, a bright red-orange at room temperature, was filtered (no. 4) to remove LiCl and concentrated to 30 mL. Et_2O (50 mL) was then added. After sitting overnight at room temperature, $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)C(O)CH_2Au(PPh_3)]$ was recovered as a red-orange crystalline solid (ca. 2 g, yield 28%). After three recrystallizations from 1:1 CH_2Cl_2/Et_2O, an orange microcrystalline solid, suitable for spectroscopic and elemental analysis, was obtained. Anal. Calcd for $C_{44}H_{37}AuFeO_2P_2$: C, 57.92; H, 4.09; P, 6.79. Found: C, 57.61; H, 4.38; P, 6.79. IR (KBr/Nujol) ν(CO)(terminal) 1888 cm^{-1}, ν(CO)(acyl) 1555 cm^{-1}; ^1H NMR (pyridine-d_5, 360 MHz) δ 7.20-8.00 (m), 4.63 (d, J_{P-H} = 70 Hz, 5 H, cp), 3.98 (br, m, 1 H, CH_2) 3.52 (br, m, 1 H, CH_2). The mass spectrum showed the parent peak at m/e 910 and a fragmentation pattern consistent with the empirical formula proposed.

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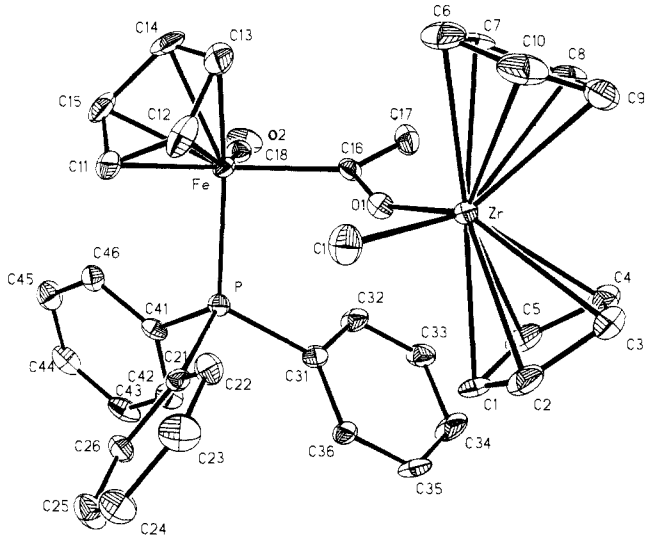

Figure 1. ORTEP diagram of complex I. Bond lengths (Å): Zr–O1 = 1.948 (8), Zr–Cl = 2.479 (3), Zr–cpl = 2.235 (9), Zr–cp2 = 2.239 (8), O1–C16 = 1.364 (14), C16–C17 = 1.331 (12), Fe–C16 = 1.993 (11), Fe–C18 = 1.740 (10), Fe–cp3 = 1.736 (7), Fe–P = 2.219 (3). Bond angles (°): P–Fe–C18 = 90.8 (3), P–Fe–C16 = 92.9 (3), C18–Fe–C16 = 92.1 (4), Fe–P–C31 = 118.1 (2), cp1–Zr–cp2 = 128.1 (3), Cl–Zr–O1 = 99.0 (2).

1555 cm^{-1}, 45 cm^{-1}, removed from that of the parent acyl, $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)C(O)CH_3]$, ν(CO)(acyl) 1600 cm^{-1}. (This band was not seen in the enol form, complex I.) By reaction of the thermally unstable lithium enolate $[(\eta^5\text{-}C_5H_5)Fe(CO)(PPh_3)(COCH_2)^-Li^+]$ with organotransition-metal halides, chiral metallo keto [Fe]*—C(=O)—CH_2M and metallo enol [Fe]*—C(=CH_2)—OM′ derivatives have been isolated.

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Supplementary Material Available: Positional and thermal parameters for complex I (Tables SI–SIII) (3 pages). Ordering information is given on any current masthead page.

Novel, Definitive NMR Evidence for N(7), α-PO_4 Chelation of 6-Oxopurine Nucleotide Monophosphates to Platinum Anticancer Drugs

Michael D. Reily and Luigi G. Marzilli*

Department of Chemistry, Emory University Atlanta, Georgia 30322

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The nature of compounds formed between diverse metal species and nucleotides has received extensive study.[1-7] Although many early studies sought metal chelation by the base and the α-phosphate group on the *same* nucleotide, no such species has been unambiguously established.[3] Furthermore, multiple products are formed between *cis*-PtA_2Cl_2 (A = amine ligand) and guanosine-type ligands; some of these have not yet been fully characterized.[4-7] Such products have been the subject of several studies because guanine bases are the preferred reaction site on DNA for Pt anticancer drugs.[8] We now report that one of these products is the first unambiguous example of the long sought species in which a nucleotide chelates the same metal via a base N and an α-phosphate O.

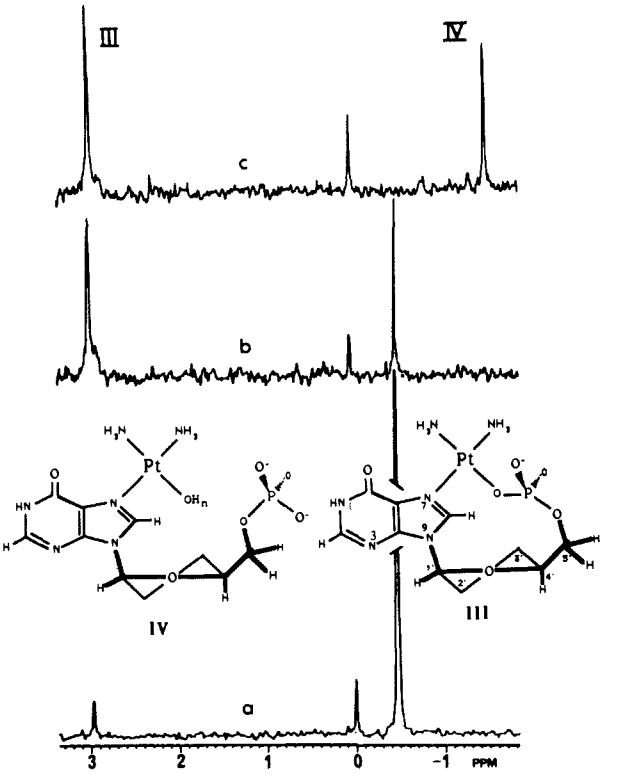

Figure 1. 81.01-MHz $^{31}P\{^1H\}$ NMR spectra of 5 mM 5′-IMP after reaction with 10 mM *cis*-$Pt(NH_2CH_3)_2(OH_2)_2$. All spectra were recorded on the same sample at 25 °C in D_2O, 90° pulse, 15-s RD. The pD was maintained at ~6.8 with 0.010 M PIPES buffer. Shifts were measured from internal trimethylphosphate (central peak). Total elapsed times to midpoint of acquisition were the following: (a) directly after mixing, t = 20 min; (b) after heating at 50 °C for 30 min, t = 90 min; (c) after lowering the pD to 5.8, t = 130 min.

We find that one of the reaction products of "aquated" *cis*-PtA_2 (A = NH_3, NH_2CH_3) with 5′-GMP, 5′-dGMP, 5′-IMP, or 5′-dIMP has spectral characteristics previously interpreted as evidence for dimers such as [*cis*-$Pt(NH_3)_2\mu$-(5′-GMP-*N7,O6*)]$_2$.[7] Our evidence that this species is in fact the N7,PO chelate *cis*-$Pt(NH_3)_2$(5′-GMP-*N7,PO*) (I) and that I is in equilibrium with *cis*-$Pt(NH_3)_2$(GMP-*N7*)(H_2O) (II)[1] is best illustrated by our study of the equilibrium between the species *cis*-$Pt(NH_2CH_3)_2$(5′-IMP-*N7,PO*) (III) and its aquated counterpart IV, where the CH_3 and H2 ^1H NMR signals provide deeper insight into the nature of this unusual compound (see Figure 1).

Our principal findings for monomeric N7,PO chelate compounds are as follows: First, the ^{31}P NMR spectrum of a pD 6.8 solution of IV has a signal at −0.50 ppm in the upfield region

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