level, $22a''^{\alpha}$ ($20a''^{\beta}$ lies at slightly lower energy in Figure 2, but an electron entering this minority-spin level would receive a much smaller exchange stabilization than one entering $22a''^{\alpha}$). Occupation of $22a''^{\alpha}$ would yield a quintet state, in agreement with the experimental result.[4] Since $22a''^{\alpha}$ is localized largely on Mo and β-Fe, occupation of this level should alter ΔE_Q primarily for the minority iron site, as is found experimentally.[4]

A more detailed analysis of the $MoFe_3S_4$ cluster and results of other studies on iron–sulfur and molybdenum–iron–sulfur clusters will be reported in future publications.

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$IrH_4(PMe_2Ph)_3^+$: Its Characteristic Reactivity and Use as a Catalyst for Isomerization of $IrH_3(PMe_2Ph)_3$

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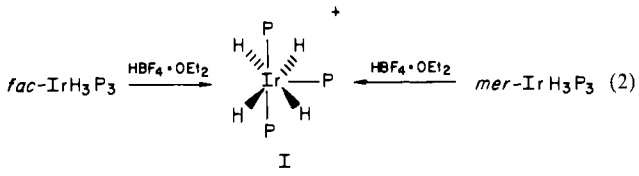
Our studies of the interaction of transition-metal polyhydrides with electrophiles and oxidants has succeeded in characterizing a variety of simple adducts as precursors to electron transfer or to H_2 elimination.[1-5] We have noted that binding of the electrophile Cu^+ to *fac*-IrH_3P_3 ($P \equiv PMe_2Ph$) gives an adduct which shows *no* interconversion with the Cu^+ adduct of *mer*-IrH_3P_3 at 25 °C (eq 1).

$$Cu(\textit{fac}\text{-}IrH_3P_3)_2^+ \not\rightleftharpoons Cu(\textit{mer}\text{-}IrH_3P_3)_2^+ \quad (1)$$

Thus, in spite of the apparent higher coordination number at iridium in these trimetal clusters, the iridium centers are stereochemically rigid.

Six-coordinate trihydride complexes are unique among polyhydrides in being stereochemically *rigid*. For example, *fac*- and *mer*-IrH_3P_3 do not isomerize in 2 days at 25 °C. Protonation of IrH_3P_3 isomers allows passage from the manifold of nonfluxional six-coordination isomers to the fluxional energy surface of coordination number 7. We report here on attempts to use this unique feature to selectively carry out an endergonic[6] isomerization of *fac*-IrH_3P_3.

The stoichiometric protonation of a CD_2Cl_2 solution of *fac*-IrH_3P_3 using 1 equiv of $HBF_4 \cdot Et_2O$ shows complete conversion (^1H and $^{31}P\{^1H\}$ NMR) to a single product.[7] Each resonance is a singlet, the implied equivalence of the phosphine ligands and of the hydride ligands being consistent with a fluxional seven-coordinate product formulated as $IrH_4P_3^+$. At -80 °C, the $^{31}P\{^1H\}$ NMR singlet splits into an AX_2 pattern, indicating that $IrH_4P_3^+$ has a pentagonal bipyramidal structure analogous to that of the isoelectronic molecule $OsH_4(PMe_2Ph)_3$[8] (see I). Curiously,



I

$IrH_4P_3^+$ exhibits no resolvable coupling of P to H in the ^1H NMR, even at −80 °C. The product of protonation of *mer*-IrH_3P_3 is identical (^1H and ^{31}P NMR) with that from *fac*-IrH_3P_3 (eq 2).

The following observations are consistent with H_2 elimination being a characteristic (but spectroscopically undetectable) reaction of $IrH_4P_3^+$ in dichloromethane: (1) stirring a CH_2Cl_2 solution of I at 25 °C under 150 psi of D_2 for 1 h resulted in complete conversion (^1H and ^2D NMR) to $IrD_4P_3^+$. (2) Sweeping a CH_2Cl_2 solution of $IrH_4P_3^+$ with N_2 for 20 min gives 80% conversion to *cis,mer*-$IrH_2(N_2)P_3^+$;[9] conversely, $IrH_4P_3^+$ is regenerated upon sweeping H_2 through the solution after an N_2 purge. (3) Several other ligands L (CO,[9] MeCN[9]) also yield *cis,mer*-$IrH_2LP_3^+$ when they are added to $IrH_4P_3^+$ in CH_2Cl_2 (eq 3). Even a ligand as

$$IrH_4P_3^+ \rightleftharpoons IrH_2P_3^+ + H_2 \xrightarrow{L} \textit{cis,mer}\text{-}IrH_2LP_3^+ \quad (3)$$

weak as THF will trap the unsaturated transient $IrH_2P_3^+$ when $IrH_4P_3^+$ is produced from *fac*-IrH_3P_3 and $HBF_4 \cdot OEt_2$ in THF as solvent.[9] This kinetically significant (even if endergonic[6]) reductive elimination (Ir(V) → Ir(III)) of H_2 is analogous to the same reaction that has been postulated[10] for $RuH_4(PPh_3)_3$, isoelectronic with $IrH_4P_3^+$. This ready loss of cis hydride ligands as H_2 from pentagonal-bipyramidal d^4 species is intriguing since the valence-isoelectronic $M(CO)_3(PR_3)_2H_2$ species (M = Mo, W; R = cyclohexyl and *i*-Pr) is now known to contain coordinated (η^2) dihydrogen.[11]

The *de*protonation of I using NEt_3 in CH_2Cl_2 was carried out and analyzed ($^{31}P\{^1H\}$ NMR) at -80 °C. By use of excess NEt_3, $IrH_4P_3^+$ is converted quantitatively to *mer*-IrH_3P_3. This isomer, obviously the kinetic product, has a planar T-shaped IrP_3 framework also present in $IrH_4P_3^+$ and thus is an obvious "least motion" product from removal of a proton from either inequivalent site in I. Since $IrH_4P_3^+$ is produced from *fac*-IrH_3P_3, the protonation/deprotonation sequence represents an acid-promoted stereoselective isomerization of *fac*- to *mer*-IrH_3P_3 which may be effected at −80 °C (eq 4).[12] Thermal equilibrium favors *fac* over *mer* in CH_2Cl_2 (see below).

$$\textit{fac}\text{-}IrH_3P_3 \xrightarrow{H^+} IrH_4P_3^+ \xrightarrow{NEt_3} \textit{mer}\text{-}IrH_3P_3 \quad (4)$$

The use of stoichiometric acid in a two-step procedure to catalyze isomerization of *mer*- and *fac*-IrH_3P_3 may be simplified by employing a substoichiometric amount of acid. Such an experiment is in fact a variant on the NEt_3 deprotonation described above, except that one of the isomers of IrH_3P_3 is now the attacking base. In practice, addition of 0.1 molar equiv of $HBF_4 \cdot OEt_2$ to *fac*-IrH_3P_3 in CD_2Cl_2 at 25 °C, followed by ^1H NMR (25 °C) measurement within 10 min, revealed an 88:12 mixture of *fac* and *mer* isomers (in addition to $IrH_4P_3^+$). When the experiment and analytical procedure are repeated beginning with *mer*-IrH_3P_3, the same 88:12 *fac/mer* equilibrium is reached. Finally, if 1:10 $HBF_4 \cdot OEt_2$ and *fac*-IrH_3P_3 are combined at −80 °C in CH_2Cl_2, catalyzed isomerization reaches equilibrium within 2 h at −80 °C, and an 88:12 ratio of *fac/mer* is again achieved. The fact that these isomerizations with substoichiometric quantities of acid do not function to give only *mer* is of course determined by thermodynamics; in the stoichiometric procedure with NEt_3

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(12) Deprotonation using NEt_3 at 25 °C is complicated by production of *cis,mer*-IrH_2ClP_3, from reaction with CH_2Cl_2 solvent. We attribute this to attack of solvent on $IrHP_3$, the Ir(I) product of deprotonation of the equilibrium concentration of $IrH_2P_3^+$. Compare: Harrod, J. F.; Yorke, W. J. *Inorg. Chem.* **1981**, *20*, 1156.

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and *fac*-IrH_3P_3, it is the heat of protonation of NEt_3 that drives the endergonic *fac* → *mer* transformation. Nevertheless, the fact that substoichiometric $IrH_4P_3^+$ can convert not only *fac* to *mer* but also the reverse indicates that this system lacks the stereospecificity that characterizes the transition state $(P_3IrH_4\cdots NEt_3^+)^\ddagger$. One possibility is that the proton transfer occurs not from $IrH_4P_3^+$ but instead from the unsaturated $IrH_2P_3^+$ whose existence we have demonstrated (eq 3). It is well established that unsaturated complexes condense with hydride complexes to form hydride bridged dimers.[13,14] Such reactions are fast, and fragmentation of $(P_3IrH_2\cdots H_3IrP_3)^+$ (eq 5) need not occur with the

$$IrH_2P_3^+ + \textit{mer}\text{-}Ir^*H_3P_3 \rightarrow P_3IrH_2\cdots H_3Ir^*P_3^+ \rightarrow Ir^*H_2P_3^+ + \textit{fac}\text{- and }\textit{mer}\text{-}IrH_3P_3 \quad (5)$$

same stereoselectivity as shown by $(P_3IrH_4\cdots NEt_3)^+$. This mechanism has the added advantage that it is less susceptible to the steric rate reduction reported previously for proton transfer between a saturated transition-metal hydride and its conjugate base $(HMo(CO)_2(dppe)_2^+$ with $Mo(CO)_2(dppe)_2$.[15] Discrimination between mechanistic alternatives for this unusual reaction is the focus of current work.

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Supplementary Material Available: A listing of spectroscopic data for the cations $IrH_2L(PMe_2Ph)_3^+$, L = N_2, CO, MeCN, and THF (2 pages). Ordering information is given on any current masthead page.

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Oxygen Transfer by Bleomycin Analogues Dysfunctional in DNA Cleavage

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The bleomycins are a family of glycopeptide-derived antitumor antibiotics used clinically for the treatment of squamous cell carcinomas and malignant lymphomas.[1] At least three metallobleomycins mediate oxidative DNA strand scission,[2] and it is this property of the bleomycins that is believed to be responsible for their therapeutic effects. Bleomycin-mediated DNA cleavage is sequence selective[3] and is generally thought to result from DNA recognition and binding by the bithiazole moiety and C-terminal substituent of BLM,[4] and metal chelation and oxygen activation

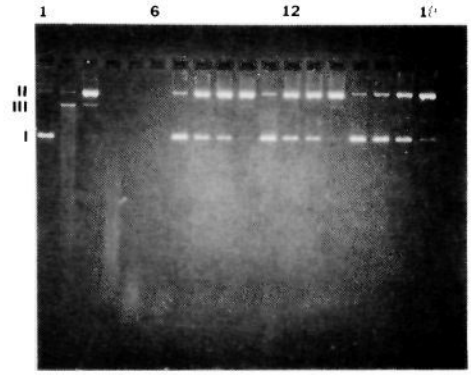
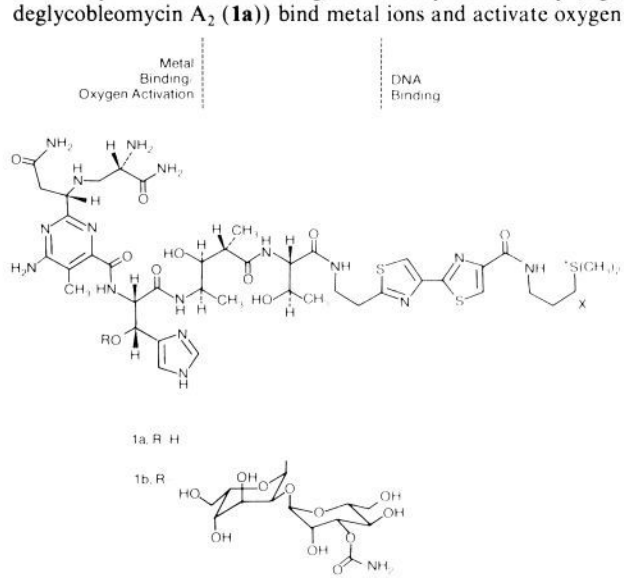


Figure 1. DNA cleavage by bleomycin analogues. Reaction mixtures contained 15 μM SV40 DNA in 20 mM sodium cacodylate, pH 7.0 (lane 1), plus 0.5 μM Fe^{II}·BLM A_2 (lane 2), 1, 5, 10, and 50 μM Fe^{II}·deglyco-BLM A_2 (lanes 3–6, respectively), 1, 5, 10, and 50 μM $Fe(NH_4)_2(SO_4)_2$ (lanes 7–10), 1, 5, 10, and 50 μM Fe^{II}·**2** (lanes 11–14), or 1, 5, 10, and 50 μM Fe^{II}·**3** (lanes 15–18). Lanes 4–6 reflect extensive DNA degradation by deglyco-BLM A_2.

by the N-terminus,[1c,5] although there is only limited direct supporting evidence. The appearance of several recent reports containing data whose interpretation appears inconsistent with this view[6] prompts us to describe experiments that employ bleomycin analogues lacking the putative DNA binding domain. Presently, we demonstrate that the C-terminus of bleomycin is required for DNA strand scission, and that oxygen activation can be effected by the N-terminus alone. Also illustrated for the first time is the transfer of oxygen from an activated Fe complex to a cis olefin with preferential formation of the *trans*-epoxide.

Bleomycin derivatives lacking the carbohydrate moiety (e.g., deglycobleomycin A_2 (**1a**)) bind metal ions and activate oxygen



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