The product compositions from the TMM precursor diazene **6** depended on the concentration of the trapping agent. Such dilution effects have been observed previously[3-5,11] in alkylidenecyclopentane-1,3-diyl chemistry and signify a sequential cascade of capturable intermediates. In the reactions of the model 2-methylene diazene **6**, five concentrations of DEF in the range 0.0026–0.5 M were studied. The changes in product composition closely paralleled those observed[11] in the 2-isopropylidene analogue: the fused product dominated at high concentration, but dilution relatively favored the formation of bridged product. Plots of the yields of each fused adduct **3** or **4** vs. the yield of bridged adduct **5** ("product vs. product" plots) were linear, a finding that indicates a sequence of two (and only two) capturable intermediates.[11] Reference to a large body of experience[3-5,11,12] strongly suggests that these are a singlet and a triplet state of the biradical **1**.

Dilution effects also were observed in the oxidative decomposition of the TMM–Fe(CO)$_3$ complex **2**. Again, the "product vs. product" plots were linear, indicating two sequential intermediates. However, these plots differed sharply from those obtained in the diazene runs, as is graphically displayed in Figure 1. Whereas from diazene **6**, tF_1 is favored over tF_2 at the left extreme of the plot, a region in which singlet-derived products dominate,[3-5,11] this preference is *reversed* in the products from the iron complex **2**, where tF_2 is favored. Hence, the immediate precursor (designated M) of the products from iron complex **2** at high olefin concentration cannot be the singlet biradical.

The right-hand extreme of the percent **5** range corresponds to the low concentration limit, where triplet biradical-derived product prevails.[11] Figure 1 shows that in this domain, the product compositions from **2** and **6** are in exact agreement, which suggests that at low concentration the triplet biradical is the common immediate precursor of both sets of products.

By exclusion, the most likely candidate for the role of M is an unstable metallic complex. Scheme I shows a (perhaps oversimplified) way in which product could be formed by intermolecular capture of the species. It is not known whether the first oxidized metal complex and the product-forming metal complex are identical, but the present results demonstrate that the final demetalation step liberates free **1** triplet directly and does not pass through **1** singlet.

Previous experiments, employing optical activity[13-15] and three-phase traversal[16] criteria have shown convincingly that metal-free cyclobutadienoid species can be liberated from cyclobutadiene (CBD)–Fe(CO)$_3$ complexes. Although an *intramolecular* capture of a metal-bound CBD was observed,[15] no evidence was found for intermolecular capture. In terms of Scheme I, this would mean that $k_3 \gg k_4[\mathrm{G}]$. It remains to be seen whether increasing the concentration or intrinsic reactivity of the trapping agent (G) may yet permit an intermolecular interception of a metal-bound CBD analogous to that of the metal-bound[17] TMM observed here.

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Registry No. 1, 60743-11-5; **2**, 85370-27-0; **3**, 85370-28-1; **4**, 85370-29-2; **5**, 85370-30-5; diethyl fumarate, 523-91-6.

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^{195}Pt NMR Investigation of the Head-to-Head to Head-to-Tail Isomerization of α-Pyridonate-Bridged Ethylenediamineplatinum(II) Dimer

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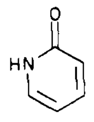
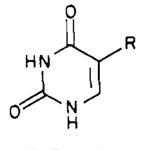
cis-Diamminedichloroplatinum(II) (*cis*-DDP) forms a variety of mononuclear and bridged polynuclear complexes with α-pyridone, including a crystalline platinum blue.[2] The range of structural types displayed by these complexes and their nucleobase (e.g., uracil, thymine) analogues[3] offers insight into the binding of the antitumor drug *cis*-DDP to its likely biological target, DNA. Little is known about the dynamic properties[4] of the large family of binuclear complexes bridged by the α-pyridonate ligand class.[5] Here we present results of ^{195}Pt NMR studies of α-pyridonate-bridged binuclear ethylenediamineplatinum(II) complexes, $[(\mathrm{en})\mathrm{Pt}(\mathrm{C_5H_4NO})]_2^{2+}$, that clearly demonstrate the occurrence of a reversible, intramolecular, dissociatively activated stereochemical rearrangement from the head-to-head (HH) to head-to-tail (HT) isomer. This isomerization requires a relatively rapid off-rate for the Pt–N(heterocycle) bond in its approach to equilibrium. The proposed mechanism may be relevant to rearrangements of other binuclear complexes with asymmetric, bidentate bridging ligands,[3,6] and to the DNA binding properties of *cis*-bis(amine)platinum(II) antitumor drugs.



α-pyridone



uracil, R = H
thymine, R = CH_3

As expected from its known structure,[7] the ^{195}Pt NMR spectrum of a freshly prepared aqueous solution of the HH $[(\mathrm{en})\mathrm{Pt}(\mathrm{C_5H_4NO})]_2^{2+}$ isomer consists of two resonances, Figure 1. The low- and high-field resonances are assigned to the N_2O_2- and N_4-coordinated platinum atoms, respectively, on the basis of established ^{195}Pt chemical shift trends.[2,8] As the solution is allowed to stand with time, a third resonance slowly appears at a chemical shift value midway between the other two resonances. The new signal results from the HT isomer, which is formed at the expense of the HH species. The appearance of the HT resonance and the disappearance of the HH resonances may be fit by a first-order approach to equilibrium (Figure 1) derived from the rate law given in eq 1. Specific rates obtained for HH loss and HT appearance

$$d[\mathrm{HT}]/dt = -d[\mathrm{HH}]/dt = k_f[\mathrm{HH}] - k_r[\mathrm{HT}] \qquad (1)$$

are in satisfactory agreement. Moreover, there is little or no dependence of the rate on pH (in the range 2.3–7.8), added free α-pyridone (up to a 5-fold excess at pH 6.5), added 6-methyl-α-pyridone (up to a 5-fold excess at pH 6.5), or added $[(\mathrm{en})\mathrm{Pt}(\mathrm{H_2O})_2](\mathrm{NO_3})_2$ (up to a 5-fold excess at pH 2.3).

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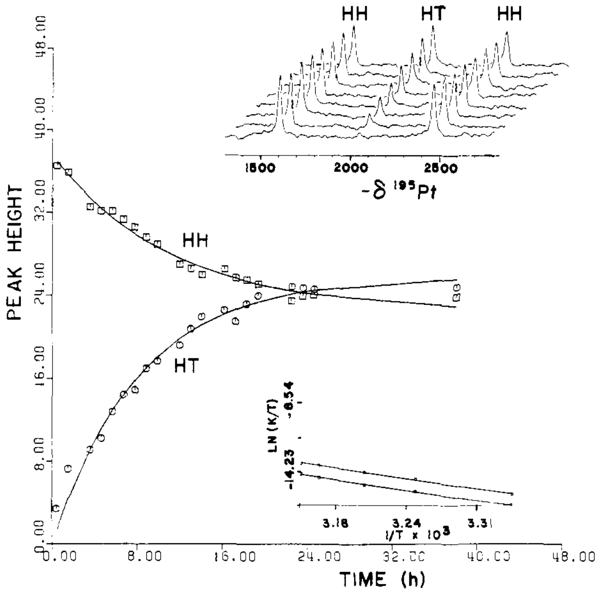
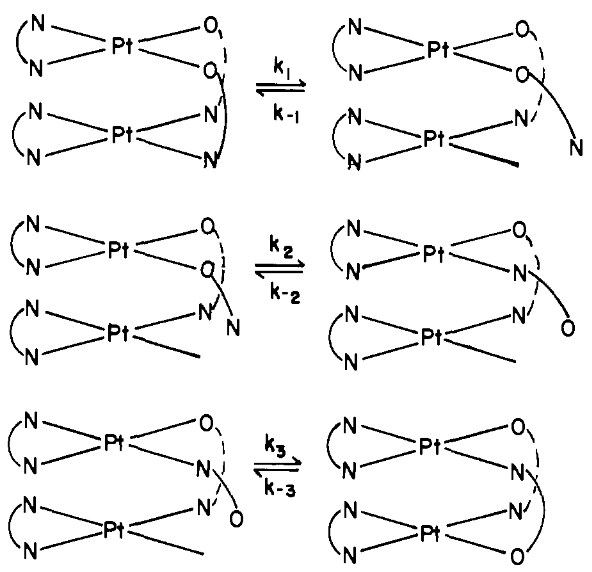


Figure 1. ^{195}Pt NMR spectra (upper right) of an initial 17.9 mM solution of HH $[(en)Pt(C_5H_4NO)]_2(NO_3)_2$, acquired on a Bruker WM-300 spectrometer at 64.38 MHz, 26.4 °C, pH 6.5 (μ = 60 mM potassium phosphate buffer), showing the time course of the isomerization reaction. The spectrum closest to the insert abscissa was taken after 0.43 h, and subsequent spectra were recorded after 3.6, 5.7, 7.8, 10.9, 13.1, 18.3, and 23.6 h. We used a fixed-frequency 20-mm probe with a spectral width of 100 kHz and a 5-μs (5°) pulse width and accumulated 75 000 transients per spectrum. Spectra were collected in 1K of memory with a 0.0252-s real repetition time and are referenced to K_2PtCl_6. Also shown are peak height vs. time curves fitted to the integrated form of eq 1 by a nonlinear least-squares program. The solid lines are the calculated appearance of the HT isomer, $x_t = x_e[1 - \exp(-k_{obsd}t)]$, $k_{obsd} = 3.23\ (1) \times 10^{-5}\ s^{-1}$, and disappearance of the HH isomer, $x_t = x_e + (x_0 - x_e)[\exp(-k_{obsd}t)]$, $k_{obsd} = 2.5\ (2) \times 10^{-5}\ s^{-1}$. An Eyring plot showing the temperature dependence of the rate constant is depicted in the inset in the lower right-hand corner. The upper line plots k_f and the lower line k_{obsd}. The forward ($k_f = 1.19 \times 10^{-5}\ s^{-1}$) and reverse ($k_r = 2.04 \times 10^{-5}\ s^{-1}$) rate constants were calculated for the appearance of the head-to-tail isomer using the equilibrium constant K_{eq} = [HT]/[HH] = 0.59 (6). This value was determined from the peak intensities at equilibrium, taking into account the fact that the concentration of the HT isomer is proportional to half the individual peak intensities.

The classic first-order k_1 step in square-planar substitution processes may be solvent assisted (solvolytic) or dissociative.[9] Three lines of evidence support a rate-determining dissociative k_1 pathway for the HH $\rightleftarrows$ HT isomerization. First, an Eyring plot (Figure 1) of temperature dependence of the rate constants shows a large enthalpy ($\Delta H^\ddagger$ = 114 kJ/mol) and a positive entropy ($\Delta S^\ddagger$ = 40 J/(mol K)) of activation, parameters typical of a dissociative, bond-breaking step.[10] Second, the isomerization rate is drastically reduced in Me_2SO but not affected by a 10% aqueous solution of Me_2SO. Since Me_2SO is a better nucleophile than water, acceleration of the rate would be expected for a solvolytic k_1 path in neat Me_2SO. Apparently, solvation of the departing ligand is important while platinum–solvent bond formation is not. A similar solvent role has been proposed to rationalize the utilization of a dissociative k_1 path for substitution reactions of sterically hindered platinum(II) phosphine halide complexes.[11] Finally, preliminary studies[12] of the HT *cis*-$[(NH_3)_2Pt(C_5H_4NO)]_2^{2+}$ analogue show its rate of isomerization to be much slower than that of the more highly strained[13] ethylenediamine dimer. Thus, there is a steric acceleration which is also characteristic of a dissociative k_1 pathway.[14]

Scheme I



In a mononuclear complex, a dissociative rate-determining step for linkage isomerization would imply an overall intermolecular process.[15] With $[(en)Pt(C_5H_4NO)]_2^{2+}$ dimers, however, there are several possibilities. A fast dissociative step could follow k_1, leading to loss of the bridging ligand or $(en)Pt^{2+}$ moiety. This possibility is ruled out by lack of change in the isomerization rate or product distribution in the presence of excess α-pyridone or $[(en)Pt(H_2O)_2]_2^{2+}$, by lack of observable exchange products or effect on the rate upon addition of a 5-fold excess of 6-methyl-α-pyridone, and by failure to observe mononuclear platinum species in the NMR spectrum,[12] all over a period of at least 10 half-lives. We therefore conclude that, subsequent to the rate-determining dissociative k_1 step, an intramolecular linkage isomerization occurs, followed by bond formation between the metal with the "vacant" coordination site and the uncoordinated end of the ligand (Scheme I).

Although we have no kinetic evidence for the intermediates drawn in this scheme, the mechanism is a logical consequence of an initial dissociative step where k_f is assigned to k_1. The rate-determining step for the reverse (k_r) process could be assigned either to k_{-3} or k_{-1}/K_2K_3. Our results do not establish whether the initial step is Pt–N or Pt–O bond breaking, but Scheme I is supported by steric considerations and the fact that $k_f < k_r$. Study of CPK space-filling models revealed Pt–N bond breakage in the HH isomer to be stereochemically more favorable than Pt–O bond breakage. Moreover, the larger rate constant for the reverse process (k_r) is consistent with the greater kinetic lability of Pt–O vs. Pt–N bonds. In either case rotation of the resulting monodentate ligand by 180° about the bond to platinum must occur during the intramolecular linkage isomerization step. There is ample precedence for such rotations in platinum(II) amine chemistry.[16] These and other aspects of the mechanism are currently being investigated.

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Registry No. HH$[(en)Pt(C_5H_4NO)](NO_3)_2$, 85370-20-3; HT$[(en)Pt(C_5H_4NO)](NO_3)_2$, 85370-22-5; ^{195}Pt, 14191-88-9.

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