$$^3(ZnHb)^*\cdot Fe^{III}(cyt\ b_5) \rightarrow (ZnHb^+)\cdot Fe^{II}(cyt\ b_5) \qquad \Delta E \equiv 1.0\ V^{13} \quad (1)$$

Results of laser flash photolysis experiments are shown in Figure 1.[14] The Hb derivative $\alpha_2^{Zn}\beta_2^{Fe^{III}CN}$ 5,12(Zn_2Hb) has a long-lived triplet excited state, with $^3k = 60\ s^{-1}$. However, when this derivative of Hb is bound to ferricytochrome b_5, the Zn lifetime is dramatically reduced: $^3k = 8 \times 10^3\ s^{-1}$ (Figure 1). *No* significant decrease in zinc porphyrin triplet lifetime is observed when Hb is bound to ferrocytochrome b_5 or under conditions of pH and ionic strength that are incompatible with formation of a complex between the two proteins. As shown elsewhere,[6] this decrease cannot be explained in terms of simple (dipolar) energy transfer. Moreover, on irradiation, a persistent increase in [Fe^{II}cyt b_5] is observed[16] (Figure 2), and the rate of formation of ferrocytochrome b_5 equals the rate of zinc(II) porphyrin triplet decay. These observations demonstrate that the observed enhancement of triplet decay rate in the Hb·cyt b_5 complex occurs by a direct electron transfer deactivation of the porphyrin triplet. The formation of a stable and detectable level of ferrocytochrome b_5 is in accord with observation by McGourty[5] of analogous redox chemistry on irradiating the $\alpha_2^{Fe(III)}\beta_2^{Zn(II)}$ Hb hybrid. This directly demonstrable reduction implies[5] that the zinc(II) porphyrin cation radical that is formed after electron transfer decays (by a yet uncharacterized pathway) in competition with the recombination reaction:

$$(HbZn^{II}\text{–porphyrin}^{+}\cdot) + Fe^{II}cyt\ b_5 \rightarrow (HbZn^{II}\text{–porphyrin})\cdot Fe^{III}cyt\ b_5 \quad (2)$$

Two interesting rate comparisons can be made with this result. First, the rate of intramolecular electron transfer within the complex of $a_2^{Zn}\beta_2^{Fe^{III}CN}$ and ferricytochrome b_5 ($k \sim 8 \times 10^3\ s^{-1}$; heme edge-to-heme edge distance ~7 Å[11]) far exceeds that reported[5] for intrasubunit electron transfer in Hb ($k \sim 60\ s^{-1}$; heme edge-to-heme edge distance ~ 20 Å[5]). This difference is not unexpected given the difference in separation between the donor and acceptor sites. If anything, the dependence of rate on distance is weaker than might have been expected from studies of nonadiabatic electron-transfer reactions in glasses.[18]

Second, although the physiological complexes of Hb·cyt b_5 and cyt c·cyt b_5 are thought to be structurally similar,[11,17] large differences are observed between the electron-transfer rates of $\alpha_2^{Zn}\beta_2^{Fe^{III}CN}$/cyt b_5 ($k \sim 8 \times 10^3\ s^{-1}$) and Zn(cyt c)/cyt b_5 ($k \sim 4 \times 10^5\ s^{-1}$).[6] Clearly, (subtle) structural differences between these complexes are sufficient to cause large rate differences. These differences may reflect direct differences in the "conductivity" of Hb vs. cyt c or may reflect a difference in protein flexibility, which allows stronger coupling between the cyt c/cyt b_5 hemes. These alternatives can be tested, and such tests are in progress.

Acknowledgment. G.L.M. is the recipient of an Alfred P. Sloan Foundation fellowship and a Camille and Henry Dreyfus Teacher–Scholar Award. This research was supported by grants from the NSF (CHE-8303896 (G.L.M.) and the NIH (HL-21416 (G.L.M.) and GM-28834 (A.G.M.)). We gratefully acknowledge extended discussions with Professors A. M. English, H. B. Gray, B. M. Hoffman, J. J. Hopfield, and J. Miller.

(13) $^3E_{00}$ = 1.8 V for zinc(II) protoporphyrin, $E°(ZnP^+/ZnP)$ = 0.85 V, $E°$(cyt b_5) = 0.05 V. Therefore, ΔE_{rxn}^2 = 1.8 − 0.85 + 0.05 = 1.0 V.

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Facile Deuterium Exchange of Alkyl and Methine Protons in Octaalkylporphyrins

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Received December 6, 1983

Selectively deuterated porphyrins and metalloporphyrins are of considerable utility for physicochemical studies of this important class of compounds. The deuterium-substituted species provide a direct means for resolving or identifying vibrational bands. In addition to clarifying peak assignments in NMR spectroscopy, deuterated metalloporphyrins permit in situ deuterium NMR spectroscopy of highly reactive electrochemically oxidized and reduced metalloporphyrin species.[1-3]

Deuterium incorporation through total synthesis is possible, but new procedures for deuterium exchange on preformed porphyrins would clearly be desirable. Such procedures have been developed for methine deuteration of porphyrins and metalloporphyrins. The simplest of these techniques involves refluxing the porphyrin or metalloporphyrin in deuteroacetic acid.[4] However, the assumption of methine specificity is called into question by the results presented herein (vide infra). The remainder of these techniques are limited to vinyl-substituted porphyrins,[5] metalloporphyrins which tend to demetalate in a side reaction,[6,7] those requiring sealed-tube reactions,[8] and base-catalyzed exchange on porphyrins with strong electron-withdrawing substituents.[9]

Among the techniques for methine deuteration is the report that naturally occurring porphyrins may be deuterated at the methine position by deuterio-*p*-toluenesulfonic acid in an *o*-dichlorobenzene reflux in 2–4 days.[10] While employing octaethylporphyrin deuterated by this procedure (in the presence of sodium chloride) we fortuitously discovered that a small fraction of the methylene protons had been exchanged. By increasing the concentration of the acid and the time of reflux, significant and useful levels of deuteration of the ring-adjacent protons can be achieved, as well as nearly quantitative methine deuteration. Furthermore, we have found that a melt of deuterio-*p*-toluenesulfonic acid serves to deuterate octaalkylporphyrins exclusively at the methine position in hours rather than days.

For simultaneous ring alkyl and methine hydrogen exchange typically 1.5 g of *p*-toluenesulfonic acid sodium salt was dissolved in 15 mL of deuterium oxide and 1.5 mL of 6 M DCl and rotoevaporated to dryness. To the flask were added 80 mL of dry *o*-dichlorobenzene and 75 mg of etioporphyrin (80/1 mol ratio of acid/porphyrin). The mixture was allowed to reflux under nitrogen for 4–8 days. The solution was filtered and shaken twice with 75 mL of water to extract the sodium chloride and acid. After freezing at −10 °C, most of the water was removed by decanting, and the solution was rotoevaporated to dryness. The porphyrin was redissolved in chloroform, the solution was filtered on a medium-porosity glass frit, and the porphyrin was precipitated by addition of heptane. Both deuterium and proton NMR spectra were recorded. The extent of deuteration was determined by integration of proton NMR peaks using the methyl peak of the ethyl group as a reference. Four days of reflux resulted in 92% methine deuteration and 45% deuteration of the ring-adjacent

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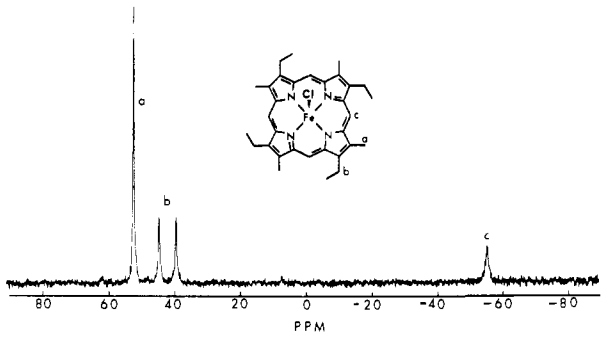

Figure 1. Deuterium NMR spectrum at 55.28 MHz of the chloroiron(III) etioporphyrin complex deuterated by the *o*-dichlorobenzene reflux procedure: $CDCl_3$ solvent, 25 °C, referenced to $(CD_3)_4Si$. The methylene deuterons are diastereotopically inequivalent due to the out-of-plane iron atom.

positions. The primary and secondary ring-adjacent positions were equally deuterated. Eight days of reflux produced the same level of deuteration at the methine position, but the ring methyl and methylene groups were 60% deuterated. The recovery of porphyrin was 84%. Integrity of the porphyrin is demonstrated by the deuterium NMR spectrum in Figure 1 in which case the chloroiron(III) etioporphyrin complex was prepared from deuterated porphyrin via a literature method.[11] Proton NMR assignments for this species have been made previously.[12,13] In addition to being prepared from the sodium salt, the deuterated *p*-toluenesulfonic acid can be prepared by addition of deuterium oxide to the acid followed by rotoevaporation to dryness. Acid prepared in this manner did not yield any detectable deuterium exchange at the methine or the ring-adjacent positions by the *o*-dichlorobenzene reflux method. Addition of 1 equiv of finely powdered sodium chloride gave results identical with those obtained when starting with the sodium salt of the acid. Surprisingly, it is apparent that sodium chloride serves an essential role in the exchange reaction.

An alternate more convenient procedure may be employed for methine deuteration. For the melt procedure 2 g of *p*-toluenesulfonic acid monohydrate was dissolved in 10 mL of deuterium oxide, the solution was rotary evaporated to dryness, and the residue was vacuum dried at 60 °C for 3 h. To the deuterated acid was added 25 mg of etioporphyrin and the mixture was fused under nitrogen at 120 °C. The porphyrin was precipitated by pouring the hot melt into 80 mL of 0.01 M aqueous sodium hydroxide. After removing the porphyrin by filtration, it was redissolved in chloroform and precipitated by addition of heptane. The product was found to be 83% methine deuterated after a 9-h melt, and no ring-adjacent deuteration was detected.[14]

The deuteroacetic acid procedure[4] mentioned above was investigated to determine the generality of this previously unnoticed phenomenon of ring-adjacent exchange. Refuluxing etioporphyrin in deuterioacetic acid for 24 h produced ~3% deuteration at the ring-adjacent methyls and ~0.5% at the ring-adjacent methylenes. Sealed-tube reactions produced 90% deuteration of the ring-adjacent methyls and 45% deuteration of the ring-adjacent methylenes after 8 days at 180 °C, but 40% of the porphyrin was degraded under these conditions.

No exotic role need be postulated for the sodium chloride essential to the ring-adjacent exchange procedure with *p*-toluenesulfonic acid. Toluenesulfonic acid was found to degrade in fusion reactions conducted above 160 °C. Considering this and the fact that even methine detueration was not observed in the absence of sodium chloride, it would seem that the salt must enhance the solubility of the extremely hydrophilic acid in refluxing *o*-dichlorobenzene. In the absence of salt the acid evidently forms a separate phase and is degraded at the reflux temperature of 180 °C.

It has previously been established that methine deuteration proceeds via electrophilic aromatic substitution of the free base porphyrin.[4] On the other hand, exchange of the ring-adjacent positions with deuterioacetic acid proceeds via deprotonation of the ring-adjacent position, with the porphyrin most likely in the dication form. Studies of the base-promoted exchange of benzylic hydrogens show that the exchange rate is 9 times greater for toluene than it is for ethylbenzene.[15] This may be compared with the 6-fold greater rate observed for the ring-adjacent primary vs. the ring-adjacent secondary positions with deuteroacetic acid and contrasted with the nearly equivalent rates of substitution for these two positions with the *p*-toluenesulfonic acid system. For a free radical mechanism the rate would be greater at the secondary than at the primary ring-adjacent position. We thus suggest that both a free radical and deportonation mechanism are at work, and the result is approximately equal rates of deuteration of the two positions.

In summary, we have shown that acid-catalyzed exchange potentially produces deuterium substitution at ring-adjacent alkyl moieties as well as at methine positions in octaalkylporphyrins. Combination of these procedures and a corresponding back-exchange technique allows selective deuteration of these compounds at the ring-adjacent and/or methine positions as well as preferential deuteration of the primary vs. secondary ring-adjacent positions.

Acknowledgment. Support from National Science Foundation Grant CHE-82-09398 is gratefully acknowledged. The Bruker WM-360 NMR spectrometer was purchased in part with National Science Foundation Grant CHE 82-01836.

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Iridium, Platinum, and Palladium Complexes of Some New Hybrid Aminophosphine Ligands. A Chelate-Assisted N-H Oxidative Addition to Iridium(I) and the Structural Characterization of a Novel Ortho C-Metalated Platinum(II) Complex

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Received March 19, 1984

The insertion of a transition-metal complex into an N-H bond is a reaction of potential synthetic utility for the directed catalytic functionalization of ammonia and amines.[2] Nevertheless, documented examples of the oxidative addition of a N-H bond are

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