rearrangement of the conjugate acid **3** to the σ complex **6** followed by fission of the latter (**1** → **3** → **6** → **10**), or from **2** by the analogous sequence **2** → **4** → **7** → **10**). The **2** → **1** and **1** → **2** isomerizations are completed by the reverse sequences, respectively. The rearrangements may be degenerate not only through the reversibility of the above sequences, but also through the intermediacy of the acylium ions **9** and **11**, formed by the corresponding sequences **1** → **3** → **5** → **9** and **2** → **4** → **8** → **11**. In addition to the driving force of intramolecularity and the para-directivity preference, the following factors may participate in the various stages of the rearrangements. The deacylation of either **1** or **2** may be assisted by the antiaromatic destabilization of their conjugate acids (**3** and **4**, respectively). However, **3** may be stabilized by the intramolecular (six-membered ring) hydrogen bond formed by the *o*-fluoro substituent. The deacylation of **2** may further be assisted (relative to **1**) owing to the directivity preference for para over ortho in electrophilic substitutions of fluoro aromatics, including protonation.[13] In contrast to the $\alpha \rightarrow \beta$ rearrangements of naphthyl ketones,[11] the para ⇌ ortho acyl rearrangements of fluorofluorenones are not mutually exclusive.

As a corollary, the synthetic merits of the rearrangement are noted. The preparation of 3-substituted fluorenes (in contrast to the 1 and 2 isomers) is problematical, involving lengthy, multistep routes. The controlled rearrangement of **1** to **2** in PPA illustrates a direct rational entry into this unconventional substitution pattern in the fluorenone series.

It remains to be seen whether all three components—intramolecularity, polycyclic aromatic substrates, and fluorine substituents—are essential ingredients of complete reversibility in Friedel–Crafts acyl rearrangements.

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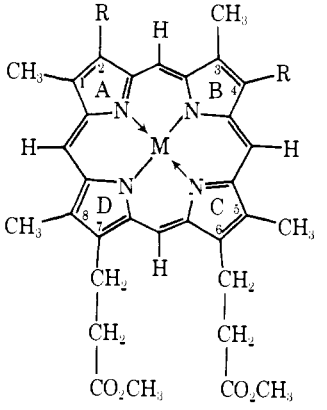
Regioselective Base-Catalyzed Exchange of Ring Methyl Protons in Protoporphyrin IX. A New Facet of Porphyrin Chemistry

Sir:

The literature documents several studies[1] of electrophilic deuteration at the methine (meso) positions of porphyrins, chlorins, and their metal complexes. However, with the exception of exchange reactions[2] which can be directly attributed to enolization, no example of a base-catalyzed exchange reaction of protons in porphyrin systems has been described. Such a phenomenon would be a further addition to the rapidly expanding literature[3] on the chemistry of porphyrin systems. In particular, susceptibility toward base-catalyzed exchange might be expected to be variable with respect to the nature of any chelated central metal ion in the inverse way to that noted for acid-catalyzed electrophilic substitution; i.e., it would be retarded by metals such as magnesium, yet be enhanced by metals such as iron.[4] In this communication we report a method for exchanging the methyl protons in protoporphyrin IX (**1**) and comment upon the nature of this novel process which provides both a convenient method for synthesis of regioselectively deuterated samples of protoporphyrin IX[5] and an insight into the mechanisms of electron delocalization in this porphyrin which is an indispensable feature of the prosthetic group in most heme proteins.



1, R = vinyl; M = 2 H
2, R = ethyl; M = 2 H
3, R = vinyl; M = $Mgpy_2$
4, R = vinyl; M = $Fe(CN)_2^-$
5, R = vinyl; M = FeX

Treatment of protoporphyrin IX (**1**) dimethyl ester[6] with CH_3ONa/CH_3OD in dimethylformamide over 5 days afforded a 50% recovery of the porphyrin. Mass spectrometric analysis indicated an extent of deuteration well in excess of that expected for exchange only of hydrogens adjacent to the two carbomethoxy functions. ^1H NMR of the exchanged **1** confirmed incorporation of deuterium in the methylenes α to the carbonyls; the integral also suggested deuteration in the largely unresolved ring methyl groups.

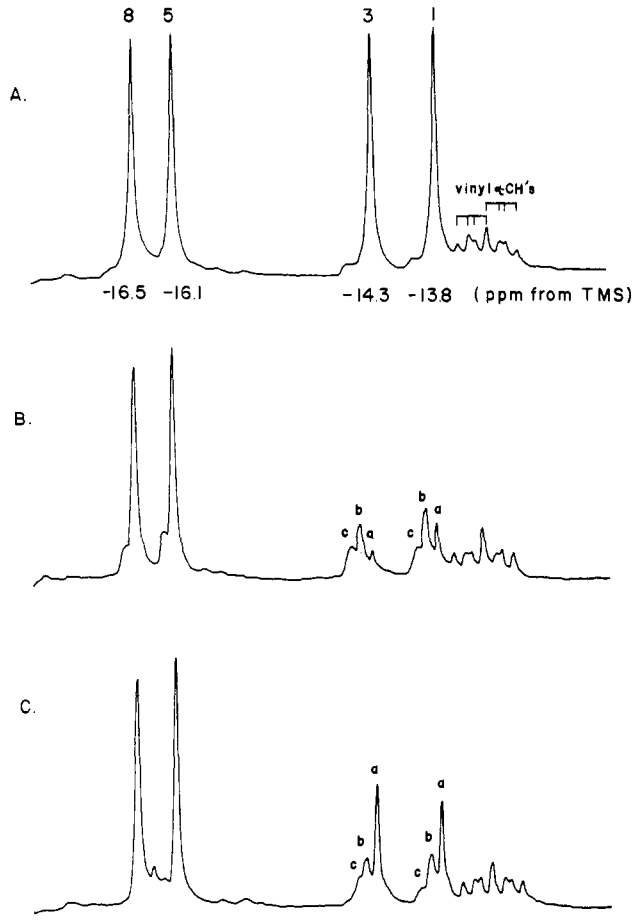


Figure 1. ^{1}H NMR traces of the ring methyl region (8–18 ppm downfield from TMS) of protoporphyrin IX iron(III) dicyanide (**4**), A; for a sample of **4** treated with CH_3ONa/CH_3OD to partially deuterate 1,3-methyls, B; and for a sample of **4** 90% deuterated at 1,3-methyls and then reprotonated via treatment with CH_3ONa/CH_3OH, C. All traces are in methanol-d_4 at 25 °C. The peaks a, b, and c for the partially deuterated methyls represent CH_3, CH_2D, and CHD_2, respectively, where the shift differences arise from isotope effects on the contact shift.[9]

The novel specificity and extent of deuteration of the ring methyls was determined by taking advantage of the excellent resolution and previous assignment[7] in the paramagnetic, low-spin ($S = 1/2$) dicyano ferric protoporphyrin complexes **4**. The upper trace[8] in Figure 1 illustrates the methyl region of **4** in methanol-d_4. In the middle trace we demonstrate that treatment of **1** with CH_3ONa/CH_3OD and subsequent conversion to **4** yields reduced intensities for only 1-CH_3 and 3-CH_3, with the latter clearly exhibiting a greater degree of deuteration. The multiple peaks observed are due to isotope effects on the coupling constant[9] for CH_3, CH_2D, and CHD_2. The greater reactivity of 3-CH_3 is also confirmed by the trace in the lower portion of Figure 1, which represents treatment with CH_3ONa/CH_3OH of a sample of **1** which had been previously 90% specifically deuterated at 1,3-methyls by total synthesis[5] prior to conversion to **4**. Here the preferential incorporation of protons into 3-CH_3 is manifested in its greater intensity relative to 1-CH_3.

When mesoporphyrin IX (**2**) dimethyl ester was subjected to exchange under the same conditions as described above for **1**, no detectable (NMR analysis) exchange of the methyl protons was apparent, though once again the propionate methylenes adjacent to the carbonyls were completely deuterated. This suggested that the origin of the novel reactivity in **1** lies in the electronic effect of the vinyl substituents in rings A and B. When the exchange reaction was carried out on the dipyridine–magnesium complex **3** of protoporphyrin IX, the extent of deuteration in the methyl groups was very considerably reduced. On the other hand, preliminary experiments have shown that high-spin iron(III) porphyrins, **5**, can be efficiently deuterated. We have also observed that the 1,3-methyl groups in 2,4-diacetyldeuterohemin are susceptible to exchange under mildly basic conditions; this may be another manifestation of this general phenomenon, though a direct enolization pathway could be envisaged (as in ref 2).

Two general circumstances can be visualized to explain this regiospecific exchange of the methyl groups in **1**. The first is a local substituent effect in which the inductively electron-withdrawing vinyl substituent renders the protons of the A and B ring methyls acidic relative to those of the propionate bearing rings; the difference in exchange between the 3- and 1-methyls would be the consequence of a second-order effect dependent upon the distance of the methyl group in one ring from the vinyl in another.[10]

If one accepts the highly delocalized nature of the π-electron system in porphyrins, then an alternate rationalization is that these vinyl groups in **1** instigate a small redistribution of the π system so as to increase the π-electron density in rings C and D while decreasing it in rings A and B. This latter possibility is also suggested[11] by analysis of methyl contact shifts of **4** with variable R, and may have important ramifications in the interpretations of the ^{1}H NMR spectra of paramagnetic heme proteins.[12] A firm delineation between these alternatives is not possible at the present time, and, in all probability, both the localized inductive and delocalized resonance perturbations on the system are important. Thus, it is unlikely that there is a simple relationship between methyl proton acidities and their contact shifts.

The existence of detectable asymmetry was anticipated[13] in a recent study of the structure of a solution dimer of **4**, which showed[11,13] it to be a molecular π complex[14] involving overlap of a single pyrrole A (π acceptor) of one complex with only pyrrole D (π donor) of the partner complex. With R = acetyl in **4**, both the A and B pyrroles act as π acceptors. Diamagnetic porphyrin dimers have also been shown[15,16] to involve π contacts between pyrroles A, B and C, D. However, further work is needed to relate the asymmetry as detected by methyl proton acidities and either contact shift patterns or dimer structure.

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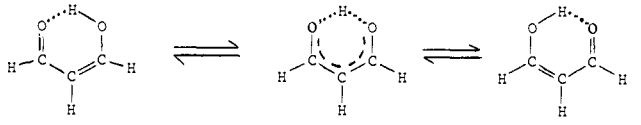
$1^1B_1(n\pi^*) \leftarrow 1^1A_1$ Transition of Malondialdehyde[1]

Sir:

The chemical composition of malondialdehyde, $(CHO)_2CH_2$, makes this molecule an important candidate for detailed spectroscopic studies of the quasi-symmetric hydrogen bond.[2-5] The rovibronic ground state of the molecule has recently been found[2-4] to be planar and intramolecularly hydrogen bonded. Hydrogen-bond proton tunneling apparently occurs through a rather low potential barrier which separates the two asymmetrical forms of the molecule. Recent theoretical work[5,6]



suggests that this potential barrier should be significantly increased in the lowest energy singlet excited state in which the $n\pi^*$ configuration dominates (1^1B_1). Chemical rationale for the increased barrier height resides in decreased electron density on the "lone-pair" oxygen atom relative to the ground electronic state (1^1A_1). Thus, the strength of the hydrogen bond to the oxygen atom is expected[5-8] to be less and the energy barrier separating asymmetrical forms increased.

Table I. 185-cm^{-1} Progression in Malondialdehyde Vapor

Band position, cm^{-1}, air	Rel intensity	Band position, cm^{-1}, air	Rel intensity
27797	2	28719	5
27972	5	28898	3
28157	7	29082	2
28341	10 (max)	29295	1
28527	9		

We have recently measured the $1^1B_1(n\pi^*) \leftarrow 1^1A_1$ electronic band system in the normal isotopic vapor of malondialdehyde and find it to contain ~150 vibronic components. There is apparently no other small molecule with a quasi-symmetric[5] hydrogen bond where *rovibronic* definition in the spectrum will permit detailed interpretation of structural dynamics. Further, this is also the first reported instance of the measurement of a highly structured $\pi^* \leftarrow n$ transition in a small organic molecule in which there is an intramolecular hydrogen bond in the vapor phase monomer.

Malondialdehyde was synthesized as previously reported[5] and extensively purified by vacuum sublimation immediately prior to measurements. Medium-resolution mass spectrometry identifies the molecular mass as 72. The crisp rotational contours and the similarity to a acetylacetone spectra of the banded infrared spectrum of the vapor strongly suggest a planar molecular geometry. Thus, our data support the microwave[2-4] identification of the structure of the monomeric species. The $1^1B_1(n\pi^*) \leftarrow 1^1A_1$ transition was measured under medium (~5 cm^{-1}) resolution at 300 K. A White-Herzberg[9,10] multiple-reflection gas cell set at 48-m optical path length was employed.

The most intense portion of the spectrum (3630 Å > λ > 2950 Å) is clearly evident at 5 Torr·m pressure-path length. The bulk of the total intensity consists of five repetitions of a prominent cluster of vibronic bands. Figure 1 shows the most intense such group of bands. These clusters appear at intervals of 1297 ± 10 cm^{-1}. It is likely that the 1297-cm^{-1} interval corresponds to the 1^1B_1 state totally symmetric carbonyl stretching frequency reduced from 1661 cm^{-1} (Q branch) in the 1^1A_1 state. Within each cluster of vibronic bands, an apparent progression of bands in 185 ± 10 cm^{-1} is found. These bands are marked in Figure 1 and given in Table I. There are two likely explanations for the 185-cm^{-1} intensity: first, a simple progression in 1^1B_1 state totally symmetric 185-cm^{-1} vibration, and, second, a progression in an upper-state nontotally symmetric (b_2 in G_4) vibration[5] originating from alternate levels of a ground-state (near) degenerate vibrational level pair

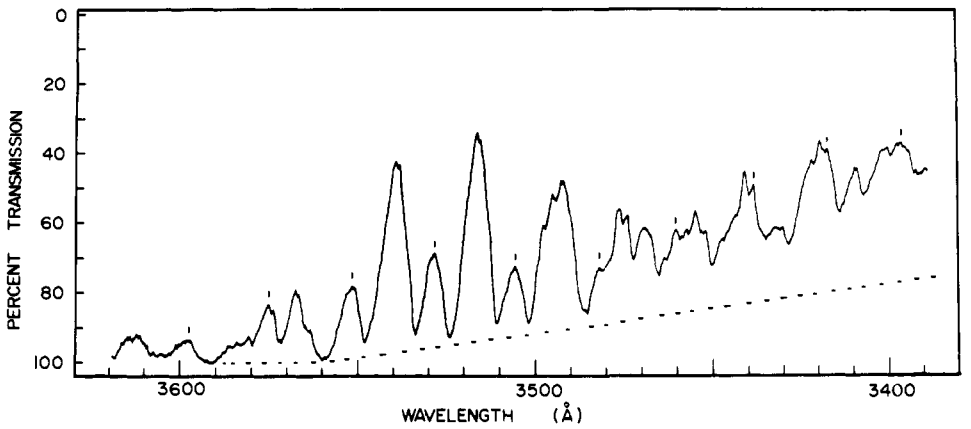


Figure 1. The medium resolution absorption spectrum of 100-mTorr malondialdehyde vapor at 48-m pathlength and 300 K. The dashed line denotes baseline absorption of the gas cell. Vertical hash marks denote bands forming a 185-cm^{-1} progression.