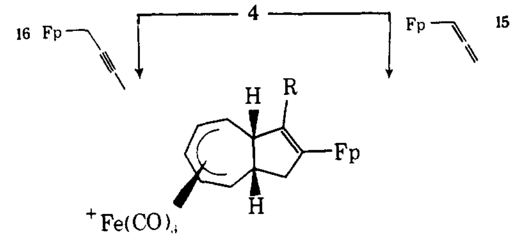
H_7), 4.05 (m, 2, $H_{6,8}$), 5.0 (m, 3, $H_{5,9}$ OCHO) 5.12, 5.14 (2 s, 5, Cp) 6.0 (m, 4, OCH_2CH_2O), 6.4 (m, 2, $H_{4,10}$), 7.5-8.7 (m, 4, $H_{1,2,3}$).

The use of (η^1-allenyl)Fp or (η^1-propargyl)Fp complexes as partners in condensations with **4** is illustrated by the conversion of **15** and **16** to the hydroazulene complexes **17a** (55%) and **17b** (78%), respectively, by treatment with **4** in nitromethane solution at room temperature for 15 min.



17a, R = H
b, R = Me

Further elaborations of these reactions are being examined.

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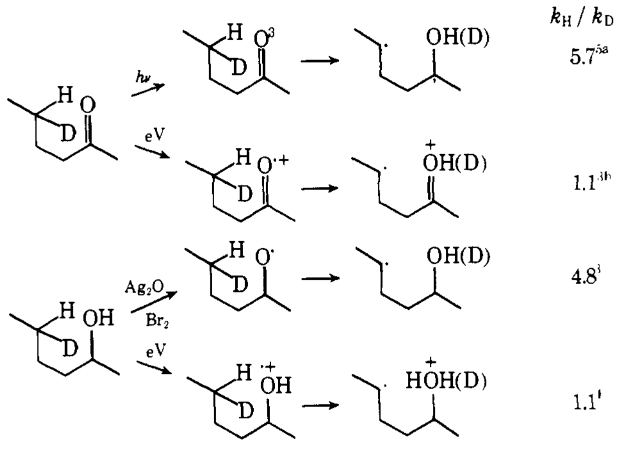
The Hofmann-Loeffler-Freytag Bridge between Mass Spectrometry and Free Radical Chemistry

Sir:

The regiospecific γ-hydrogen transfers observed in alkoxy radicals and triplet ketones are analogues on many levels to the formally similar hydrogen transfers observed in the molecular cation radicals of alcohols and ketones (McLafferty rearrangement), respectively.[1,2] Nevertheless, the isotope effects for the reactions occurring in the mass spectrometer are nearly unity[3,4] while the neutral analogues exhibit high discrimination against transfer of deuterium[5,6] (Scheme I).

Scheme I



Established theory[7] offers a ready explanation for the differing isotope effects in these otherwise similar intramolecular γ-hydrogen transfers (Scheme I). Reactions involving breaking of carbon hydrogen bonds have been observed to occur with a wide range of hydrogen deuterium isotope effects. These isotope effects have been directly related to the energy of activation for the process and through transition state theory to the extent of carbon hydrogen bond breaking and bond making in the activated complex. Thus, bromine atom and chlorine atom, in abstraction of benzylic hydrogen vs. deuterium from toluene, exhibit, under identical conditions, isotope effects of 4.6 and 1.3, respectively.[8] There is a great deal of support for these ideas.[9]

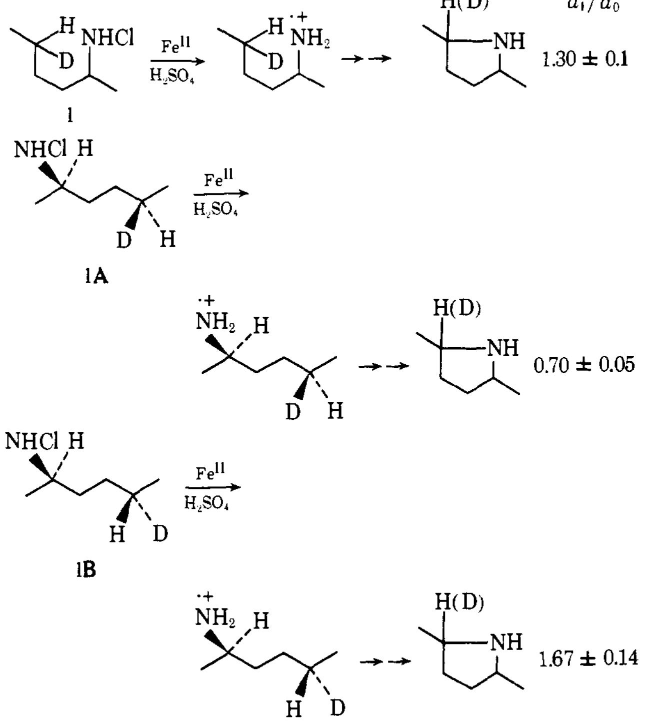
For the reactions exhibited in Scheme I the electron denying character of *both* sources of reactivity for the radical cations may reasonably be hypothesized to lead to abstraction of carbon bound hydrogen with lowered energy of activation compared to the related neutrals. As seen above, this would lead to decreased isotope effects[7] in line with the observations (Scheme I).

If this view were correct the decreased isotope effects (Scheme I) should be observed whatever the source of the cation radicals. To test this hypothesis we have determined the isotope effect for the γ-hydrogen transfer to amminium cation radical in the Hofmann-Loeffler-Freytag reaction[10] of deuterated *N*-chloro-2-hexylamine (**1**). Furthermore we have taken advantage of the chirality of **1** to simultaneously determine the stereoselectivity for the γ-hydrogen transfer. The compounds studied and the deuterium incorporation results are shown in Scheme II.

The d_1/d_0 ratio of the pyrrolidine obtained from **1** is equal to the isotope effect (k_H/k_D). The average of the d_1/d_0 ratios for the pyrrolidines from **1A** and **1B**, prepared independently, is within experimental error of the value obtained for **1** as it should be. The values for d_1/d_0 from **1A** and **1B** may be treated by Curtin's analysis[15] to yield the stereoselectivity for abstraction of the C-5 diastereotopic hydrogens[16] from (*R*)-*N*-chloro-2-hexylamine. These results of these calculations as well as comparable data on other γ-hydrogen abstracting reactions are presented in Table I.

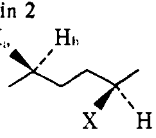
The common regioselectivity for γ-hydrogen for all the intramolecular rearrangements shown (Table I) as well as the preferential abstraction of H_a over H_b for the *R* configuration at the chiral center in all cases is very strong evi-

Scheme II[a]



[a] All reactions were conducted in concentrated sulfuric acid (25 °C) following the literature.[11,12] The *N*-chloro compounds were analyzed by titration for oxidizing power with sodium thiosulfate and shown to be at least 0.95 equivalent to theoretical. The deuterated 5-deuterio-2-hexylamine precursor of **1** was prepared from 5-deuterio-2-hexanone by conversion to the imine derivative followed by reduction with lithium aluminum hydride. **1** is therefore a 50:50 mixture of the diastereomers **1A** and **1B**. The diastereomeric precursor amines to **1A** and **1B** were prepared from the known diastereomers of 5-deuterio-2-hexanol by stereospecific inversion of configuration.[13] The optical purity was determined to be >97% by conversion to Mosher's derivative[14] followed by ^{19}F NMR at 56.4 Hz. The cis and trans isomers of the 2,5 dimethylpyrrolidine products from **1**, **1A**, and **1B** were separated by gas chromatography (GC) on a KOH–pennwalt column and shown to have d_1/d_0 ratios within experimental error of each other. The deuterium incorporation was determined by numerous runs on a Hitachi RMU-6 and an MS-902 mass spectrometer at both high and low voltage and by analysis of the molecular ion and the molecule minus methyl ion. All compounds prepared were shown to be identical with authentic protium material by GC analysis and all materials give IR, NMR, and mass spectra in accord with their structure and position of and content of deuterium. The Hofmann–Loeffler–Freytag reaction of *N*-chloro-5,5-dideuterio-2-hexylamine yielded >95% *d* of 2-deuterio-2,5-dimethylpyrrolidine by NMR analysis.

Table I. Stereoselectivity (k_a/k_b) and Isotope Effect (k_H/k_D) for γ-Hydrogen Transfer to X in **2**



2

X	$\dot{N}H_2^{+}$-(Fe^{II})[a]	OH·+ (70 eV)[1,4]	Cl·+ (70 eV)[1]	O·(Pb-(OAc)$_4$)[1]	O·(Ag$_2$O–Br$_2$)[1]
k_a/k_b	1.54	1.10	1.28	1.23	1.19
k_H/k_D	1.20	1.1	1.1	4.60	4.75

[a] Calculated from the d_1/d_0 ratios in Scheme II (see the text).[15] Precision ±0.10; all other data from the literature.[1,4] See the footnote to Scheme II.

dence that these reactions are driven by common forces. The diminution of the isotope effect in the Hofmann-Loeffler-Freytag reaction of 2-hexylamine (X = $NH_2^{\cdot+}$), a reaction of a cation radical not generated by electron impact, strongly supports our proposal that the excess electron deficiency of the charged radicals in the mass spectrometer (Scheme I and Table I) leads to hydrogen transfer with lowered activation energy and, by implication, earlier, more reactant resembling transition states than the neutral counterparts.[17]

The results here support a model for the electron impact induced rearrangement reactions (Scheme I) in which the reduced isotope effects do not arise from the excess energy of the ions[18] but rather from their early transition state demands. The comparable stereosensitivity (Table I) in solution and in the mass spectrometer[19] also strongly suggests that the rearranging molecular cation radicals are not excessively energized over that necessary for ionization. These results are entirely consistent with the qualitative predictions of the quasi-equilibrium theory.[20] Thus low energy molecular cation radicals will undergo fragmentations involving low energies of activation and slow frequency factors, i.e., rearrangements. The higher energy ions produced by electron impact will fragment competitively by simple bond cleavages involving high energies of activation and fast frequency factors; this will act to preempt rearrangement from these high energy molecular cation radicals.

Remarkably therefore, the electron beam, in producing γ-hydrogen rearranging molecular radical ions in mass spectrometers at high vacuum, is similar in character to the action of ferrous ion on *N*-chloroamines in concentrated sulfuric acid.[21] Clearly, mass spectrometric experiments offer an important opportunity to study radicals in a state of molecular isolation, that is, *free* radicals.[22]

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(22) We are grateful to the National Institute of General Medical Sciences for generous support.

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Observation of the Effect of Water on the ^{31}P Nuclear Magnetic Resonance Spectra of Dipalmitoyllecithin

Sir:

Phospholipids, one of the primary components of cell membranes, have been extensively examined with a variety of physical and spectroscopic techniques. However, the motion of the polar head group of phospholipids and the factors which affect this motion are as yet poorly understood. In addition little direct information is available on the specific orientation of the phosphate or choline moieties in a phospholipid bilayer. In order to investigate these phenomena, we have begun an examination of the ^{31}P NMR spectra of phospholipids and we present a preliminary account of our results here; specifically, we have studied dipalmitoyllecithin (DPL) at varying water concentrations. Initially we chose a relatively low temperature (15 °C) and low water content (0-10%) because we wished to observe a nearly rigid lattice ^{31}P chemical shift anisotropy. However, we have found that under these conditions the spectra reveal interesting changes in what we think are the motional properties of the phosphate, and these changes allow us to draw conclusions regarding the effect of water on the conformation of the phosphate part of the polar head group.

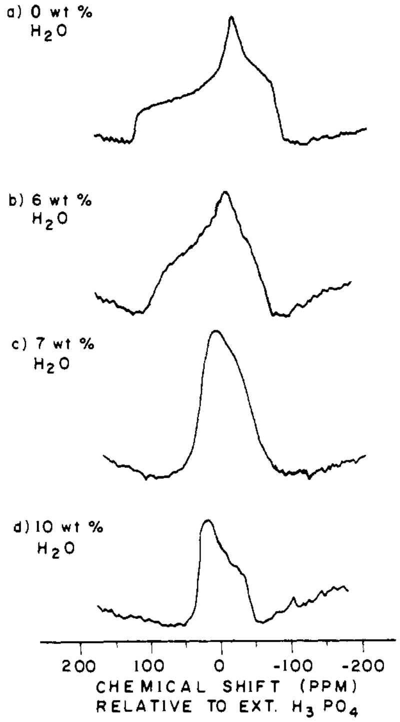

Figure 1. Proton decoupled ^{31}P spectra of DPL as a function of water concentration at 15 °C. $\nu_{^{31}P}$ = 118.5 MHz.

Table I. ^{31}P Chemical Shift Tensor Components of DPL as a Function of Water Concentration at 15 °C Relative to External 85% H_3PO_4. Errors in the Principal Values are Discussed in the Text

Wt % H_2O	σ_{11}	σ_{22}	σ_{33}	$^1/_3\,\Sigma(\sigma_{ii})$
0	−97.6	−34.5	131.0	−0.4
6	−68.9	−18.1	96.9	3.3
7	−54.7	20.2	20.2	−4.8
10	−38.9	21.4	21.4	1.3

Figure 1a shows a proton decoupled ^{31}P powder spectrum of anhydrous DPL[1] which is ~230 ppm wide, and we discern from the spectrum that the ^{31}P shift tensor is axially asymmetric. The principal values of the shift tensor, relative to external 85% H_3PO_4, are given in Table I. Upon addition of 6, 7, and 10 wt % H_2O, Figures 1b-d, we find that the broad spectrum of Figure 1a collapses to an axially symmetric pattern of ~60 ppm breadth and of reversed sign. Increasing the water concentration further (we have examined 12, 22 and 46 wt %) produces no additional change in the breadth or shape of the powder spectrum at this temperature. The principal values of the shift tensor components at each water concentration are also compiled in Table I where we have used the convention $\sigma_{11} < \sigma_{22} < \sigma_{33}$. The errors in the principal values are ±0.5 ppm for spectra 1a and 1d while for spectra 1b and 1c they are ±1.5 ppm. The larger errors for the latter spectra are due to the fact that the shoulders which determine the principal values are, as one can see, not well defined. The spectra of Figure 1 are intended to illustrate the collapse of the ^{31}P powder pattern, and a precise knowledge of the principal values of the shift tensors, or of the sample water contents at intermediate water concentrations, is not crucial to the conclusions which we discuss below.