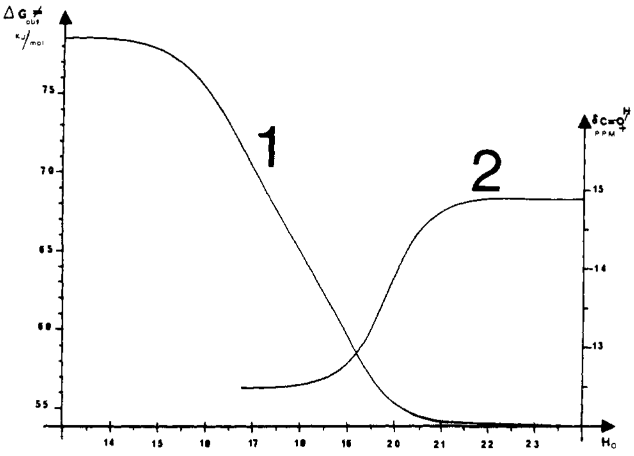

Figure 1.

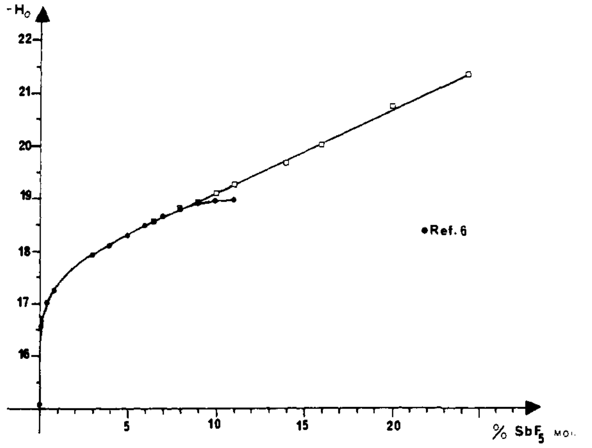

Figure 2.

is easy to see how the two methods are complementary and allow measurement of the acidity over 5 units of the scale.

By application of the experimental $\Delta G^{\neq}{}_{obsd}$ and δ C=OH$^+$ values on the calculated curves 1 and 2, it is possible to evaluate the acidity of the FSO_3H-SbF_5 mixture from 8 to 25 mol % of SbF_5 (Figure 2). Our values first overlap with Gillespie's values and show a continuous increase in acidity on SbF_5 addition. The discrepancy in the 9–10% region can probably be ascribed to some lack of accuracy due to the use of diprotonated indicators in uv determination. The extrapolation to higher SbF_5 concentrations suggests for magic acid a H_0 value of nearly −25, which is much stronger than previously stated. As almost all the exchange rates could be measured in the −20 to +20 °C temperature range, we neglected as a first approximation the temperature dependence of the acidity.

Despite the fact that aromatic carbonyl compounds do not behave like true Hammett bases, we feel, considering the wide range of pK available,[15] that these indicators using the DNMR method may be useful not only to determine relative acidities of much stronger superacids but eventually also for reinvestigation of less acidic systems.

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Origin of the Anomalous Soret Spectra of Carboxycytochrome P-450

Sir:

The cytochrome P-450 class of heme proteins are important hydroxylating enzymes involved in detoxification, drug metabolism, carcinogenesis, and steroid biosynthesis.[1] The compounds are named for the red shifted Soret band of the CO-ferrous derivatives, occurring at wavelengths 30 nm longer than the usual CO-heme complex. This prominent optical feature plays an important role in biochemical assays of the protein and in characterizing synthetic porphyrin analogues.[2-4] In this note we present an electronic interpretation of the anomalous absorption based on: (1) polarized single crystal absorption spectra of bacterial cytochrome P-450_{cam} which show an intense optical transition at 363 nm with the same polarization as the Soret band at 446 nm; (2) similar spectra shown by tin(II), lead(II), arsenic(III), antimony(III), bismuth(III) metalloporphyrins, which have one intense band in the 350–380-nm region and another in the 440–480-nm region; (3) model synthetic compounds for CO-P-450 reported elsewhere,[2-4] which show that the strong near-uv band and red shifted Soret band can be attributed to mercaptide as a fifth ligand; and (4) iterative extended Huckel (IEH) calculations, which provide a common interpretation of these similar spectra.

The major experimental finding is the characterization of an optical transition in the near-ultraviolet (uv) region of the CO-P-450_{cam}[5] spectrum at 363 nm, which has the same integrated intensity as the Soret [B(π-π^*)] band at 446 nm (Figure 1). The intense near-uv band has been observed previously in CO-P-450_{cam} solution spectra, but its significance was not explored.[6] The single-crystal spectrum (Figure 1) shows that this uv band has the same polarization as the Soret band, indicating that both bands have the same symmetry. Moreover, the total integrated intensity of the CO-P-450_{cam} bands at 446 and 363 nm is within 10% of the total integrated intensity observed in the same region in carboxyhemoglobin (COHb).[7] In COHb two bands are observed at 421 and 345 nm;[8] however, in COHb the near-uv band has only 40% of the integrated absorption strength of the Soret band and is identified as an N(π-π^*) band.[8,9] There are two possible interpretations for the dramatic change in spectrum between COHb and CO-P-450_{cam}: (1) The N(π-π^*) and B(π-π^*) states of CO-P-450 strongly interact for some unknown reason causing a redistribution of intensity and a shift of both bands to the red

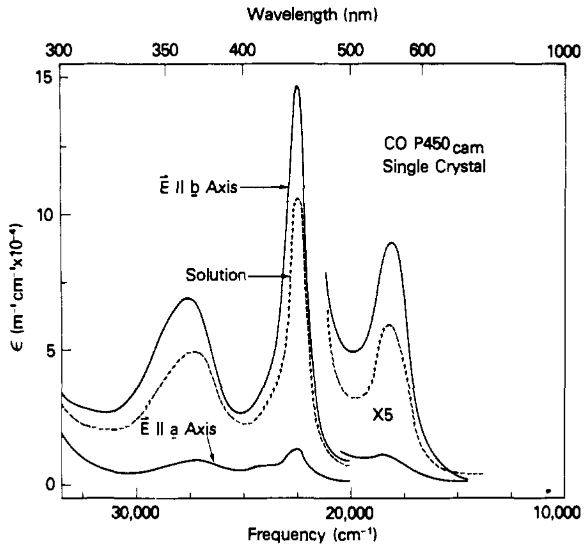

Figure 1. CO-P-450_{cam} polarized single-crystal absorption spectra (solid lines) and solution spectrum (dotted line). Single crystals of camphor-bound P-450_{cam} from *P. putida*, space group $P2_12_12$,[5] were reduced with dithionite and exposed to CO. Polarized absorption spectra were obtained in the (001) face, E‖ *a*,*b* axes, respectively, with a recording microspectrophotometer.[22] The heme chromophores are oriented nearly parallel to the *bc* crystallographic plane so that transitions polarized in the plane of the heme (*x*,*y* polarized) can be readily distinguished from transitions polarized perpendicular to the heme plane (*z* polarized). The average polarization ratio for both the Soret and uv bands is eight, and the ratios of the *b* axis to solution intensities for the two bands are also identical. The solution spectrum was obtained by photoreduction of P-450_{cam} in the presence of 12 mM EDTA and 50 mM KPO_4 buffer at pH 7.0.

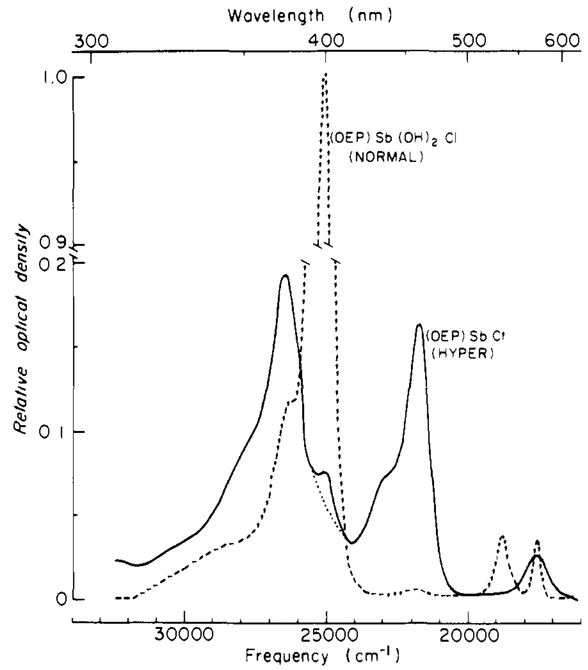

Figure 2. Absorption spectra of (octaethylporphinato)antimony(III) chloride (solid line) and (dihydroxo)(octaethylporphinato)antimony(V) chloride (broken line) in dichloromethane at room temperature show the conversion of hyper type Sb(III) compound to normal type Sb(V) compound by spontaneous oxidation in air and light. The presence of normal type impurity in the hyper type is denoted by the dotted line.

relative to COHb. (2) A new transition of N, B symmetry is introduced in CO-P-450 between N and B which mixes strongly with B, stealing its intensity and shifting it to the red. A strong argument for choosing the second alternative comes from studies on similar spectra observed in other (*hyper*) metalloporphyrins, for which an interpretation is now clear.

Metalloporphyrin absorption spectra have been classified as *normal*, *hypso*, and *hyper*.[10] Normal porphyrin spectra show Q(visible), B(Soret), and N(near-uv) bands in the spectral region 700-300 nm which are well characterized as π-π^* transitions, with a_{1u} (π), a_{2u} (π) $\rightarrow$ $e_g(\pi^*)$ largely responsible for the visible Q and the Soret B bands according to the four orbital model.[11] Hypsoporphyrins are complexes with group 8b[12] or 1b[13] transition metals with filled $e_g(d_\pi)$ orbitals, which shift the four orbital transitions to the blue. Hyperporphyrins show strong extra bands in the 800-300-nm region. A common spectral pattern exhibited by a number of hyperporphyrins has "two Soret bands", one in the near-uv 350-380-nm region and the second in the 440-480-nm region.

Iterative extended Huckel (IEH) calculations have provided an orbital mechanism for the two types of metalloporphyrins that exhibit *hyper* spectra. The *d-type* hyperporphyrins, of which Cr(III)[14] and Mn(III)[15] are examples, contain transition metals with vacancies in the $e_g(d_\pi)$ orbitals.[14] New charge transfer transitions $a_{1u}(\pi)$, $a_{2u}(\pi)$ $\rightarrow$ $e_g(d_\pi)$ can then occur. In cases where these have energies comparable to the B(Soret) transition, the charge transfer and the Soret transitions strongly interact to produce "two Soret bands", as in manganese(III) porphyrins.[15] Extra bands due to these same charge transfer transitions have also been identified in iron porphyrins with partly filled $e_g(d_\pi)$ orbitals, but in iron complexes these transitions appear at lower energy, in the visible or the near-ir.[16,17] The *p-type* hyperporphyrins have similar absorption spectra with "two Soret bands" but contain main group metals in lower oxidation states. Tin(II) and lead(II) porphyrins have been previously discussed.[18] In these cases IEH calculations show that a metal to porphyrin charge transfer transition $a_{2u}(np_z)$ $\rightarrow$ $e_g(\pi^*)$ mixing with B(π-π^*) and sharing its intensity is responsible for the two Soret bands. Recent work supports this earlier hypothesis by showing that the same behavior occurs in arsenic(III), antimony(III), and bismuth(III) porphyrins.[19] Figure 2 shows the *hyper* absorption spectra of (octaethylporphinato)antimony(III) chloride and its subsequent conversion to (dihydroxo)(octaethylporphinato)antimony(V) chloride through spontaneous air oxidation. In this conversion the integrated absorption strength in the region between 310 and 620 nm is conserved to within 6%. The IEH calculations on antimony(III) and antimony(V) porphine models are shown in Figure 3.

The CO-P-450 absorption spectrum has strong similarities to hyperporphyrin spectra. This similarity becomes the key to the orbital mechanism underlying the CO-P-450 spectrum. Additional important experimental information comes from studies on P-450 model compounds.[2-4] These show that mercaptide (RS^-) carbon monoxy ferrous porphyrin complexes have *hyper* spectra[4] whereas the mercaptan (RSH) complexes have Soret bands at "normal" wavelengths (413-422 nm).[2,3] The experiments suggest that the mercaptide but not the mercaptan sulfur might have a lone pair orbital that plays the same role as the metal $a_{2u}(np_z)$ orbital in *p-type* hyperporphyrins. (These compounds cannot be *d-type* because their $e_g(d_\pi)$ orbitals are filled.[20]) IEH calculations on CH_3S^- and CH_3SH ferrous porphine CO complexes support this conjecture (Figure 3). The mercaptide complex has two lone pair sulfur orbitals below the porphyrin $e_g(\pi^*)$. One of these, designated $p^\dagger$ in Figure 3, has the correct symmetry for an allowed sulfur $p^\dagger$ $\rightarrow$ porphyrin $e_g(\pi^*)$ charge transfer transition. Population analysis of the $p^\dagger$ orbital shows it contains 17% porphyrin $p_z(\pi)$ character (mostly $a_{2u}(\pi)$) which should allow the $p^\dagger \rightarrow e_g(\pi^*)$ charge transfer transition to interact strongly with the porphyrin $a_{1u}(\pi)$, $a_{2u}(\pi)$ $\rightarrow$ $e_g(\pi^*)$ transitions and could result in the intense uv and red shifted Soret bands in both the model compounds and CO-P-450. On the other hand the mercaptan complex does not exhibit lone pair sulfur p or-

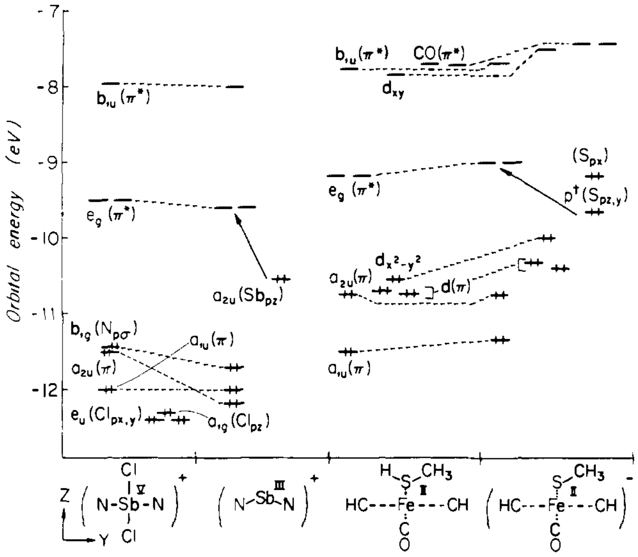

Figure 3. Orbital energy levels for Sb(V) (normal type), Sb(III) (hyper type), Fe(II) CO mercaptan (normal type), and Fe(II) CO mercaptide (hyper type) porphines by iterative extended Huckel (IEH) method. Arrows indicate charge transfer transitions. Porphine geometries in the *y–z* plane are illustrated: *y* axes through either the pyrrole nitrogens (Sb) or the methine carbons (Fe) are equivalent and related by a 45° rotation. Detailed bond lengths and angles will be given in ref 19 and 21. Both antimony compounds form stable cations and their anions were not included in the calculation. The iron d_{z^2} orbitals, which occur at energies higher than −7 eV, are not shown.

bitals among its valence orbitals, eliminating the possibility of a $p^\dagger \rightarrow e_g(\pi^*)$ transition.

Our orbital mechanism for the origin of *hyper* spectra in CO-P-450 and in the CO model compounds leads to the prediction that other low spin ferrous porphyrin mercaptide complexes could exhibit *hyper* spectra. Indeed, Chang and Dolphin have synthesized O_2 mercaptide heme complexes which also clearly exhibit *hyper* absorption spectra.[4b] IEH calculations on O_2-mercaptide and O_2-mercaptan complexes give results similar to the CO complexes.[21] There is considerable mixing of mercaptide, but not mercaptan, sulfur orbitals with the porphyrin π system, indicating a similar mechanism for the *hyper* spectra observed in the O_2 mercaptide complex.

The possibility exists that "CO-P-450 type" spectra can occur in the absence of a mercaptide ligand. Chaing et al.[23] find that CO-chloroperoxidase has a spectrum very similar to CO-P-450, yet they report that the protein contains no cysteines. Our orbital mechanism specifically requires, however, that both CO-P-450 and CO-chloroperoxidase have electron donating ligands which can play the same role in causing *hyper* spectra as the mercaptide sulfur in the model compounds.

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Palladium Assisted Intramolecular Amination of Olefins. A New Synthesis of Indoles

Sir:

We recently reported the palladium assisted amination of simple monoolefins by secondary amines to produce tertiary amines. We report herein the development of an *intra*molecular version of this reaction for the cyclization of *o*-allylanilines to 2-methylindoles in high yield under remarkably mild conditions. The synthetic approach is outlined in Scheme I. The requisite *o*-allylanilines were prepared in high yield by the reaction of *o*-bromoanilines with π-allylnickel bromide,[2] a reaction which proceeds under mild conditions, tolerates a wide range of functionality, and allows the facile preparation of a variety of differently substituted *o*-allylanilines.

Addition of the *o*-allylaniline to a THF solution of $PdCl_2(CH_3CN)_2$ produced a yellow-brown precipitate. Upon addition of triethylamine the solid dissolved and the resulting cherry red solution began to deposit metallic palladium. After deposition was complete (~2 h), the solution was filtered and evaporated to dryness. The crude material was essentially the