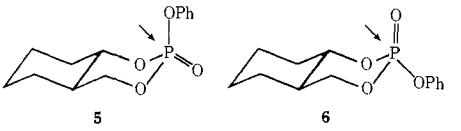

5 6

the equatorial phenoxide leaving group, hydrolyzes considerably faster than isomer **5**. Since addition of $-OH$ is rate limiting, the two app long pairs on the endocyclic ester oxygens require hydroxide attack from the top side of both isomers. This will force an O^- into an apical position of the trigonal bipyramid intermediate in **5**. Since this is unfavorable according to pseudorotation theory, isomer **6** is the more reactive although sterically isomer **5** should be the more reactive for attack from the bottom side in an "in-line" mechanism (Unpublished work, D. G. Gorenstein and J. B. Findlay).

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A Synthetic Biomimetic Model of Special Pair Bacteriochlorophyll a

Sir:

Evidence relating to the molecular organization of chlorophyll in the photoreaction centers of both green plants and photosynthetic bacteria strongly suggests that special pairs of chlorophyll molecules are oxidized in the primary light conversion event in photosynthesis.[1-4] Satisfactory models for green plant photoreaction center special pair chlorophylls have been successfully prepared by the synthesis of covalently bound, dimeric derivatives of pyrochlorophyll a[5] and chlorophyll a (Chl a).[6] These linked dimers, when dissolved at room temperature in nonnucleophilic solvents containing an excess of water or alcohol, assume a folded conformation which has optical properties very similar to photoreaction center P700 chlorophyll in plants. Moreover, the oxidized linked dimeric derivative of chlorophyll a in its folded conformation gives an ESR signal closely resembling that of $P700^+$.[6-9]

We now report the synthesis of a model for special pair bacteriochlorophyll a (Bchl a) in photosynthetic bacteria, the dimeric ethylene glycol diester of bacteriochlorophyllide a, **2**. The well-known reactivity of the Bchl a ring system required the development of a synthetic scheme differing substantially from that previously employed in the synthesis of Chl a linked dimers.[10] Bchl a, obtained from *R. spheroides*, was treated with trifluoroacetic acid to obtain bacteriopheophorbide a (Bphide a), which was esterified at 25 °C with ethylene glycol using benzotriazole *N*-methanesulfonate and Et_3N in dry THF.[11] The glycol monoester was coupled with an equivalent of Bphide a using the same esterification method, but substituting 4-dimethylaminopyridine as the base and CH_2Cl_2 as the solvent. The diester **1**, obtained in 30% overall yield based on Bchl a, exhibited a mass spectrum (*m/e* 1246, M^+), ^1H NMR, and electronic spectrum consistent with **1**. The reinsertion of the magnesium atoms was accomplished by a modification of the method of Eschenmoser to yield diester **2** (Figure 1).[12,13]

The electronic transition spectrum of **2** in nucleophilic solvents is indistinguishable from that of monomeric Bchl a recorded under identical conditions (Figure 2). Similarly, the ^1H NMR spectrum of **2** is consistent with the assigned spectrum of Bchl a,[14] except that the phytyl resonances are replaced by a sharp singlet at δ 4.00 assigned to the glycol protons (Figure 1). The electronic transition spectrum of 10^{-5} M covalent dimer in dry benzene (Figure 2) displays an intense absorption at 780 nm and a shoulder at 812 nm, which are very similar to those observed for self-aggregated Bchl a.[15] The ^1H NMR spectrum of a 10^{-3} M solution of **2** in dry benzene displays severely broadened resonances, as is typical of anhydrous aggregated chlorophylls.[16]

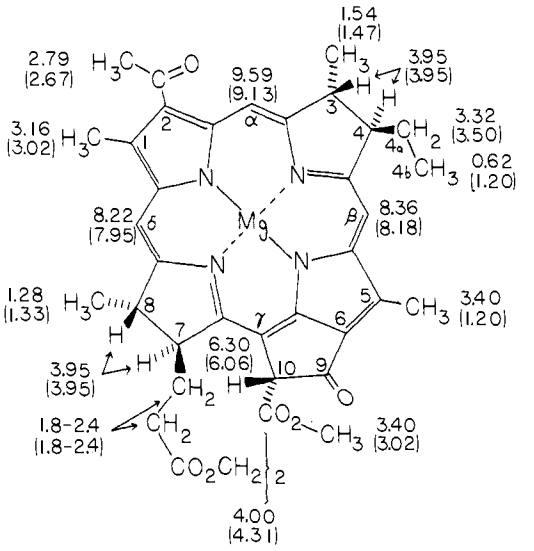


Figure 1. The proton chemical shifts for a 10^{-3} M solution of diester **2** in 10% pyridine-d_5 in benzene-d_6 solution, δ (ppm), and in D_2O saturated benzene-d_6 solution, (δ (ppm)).

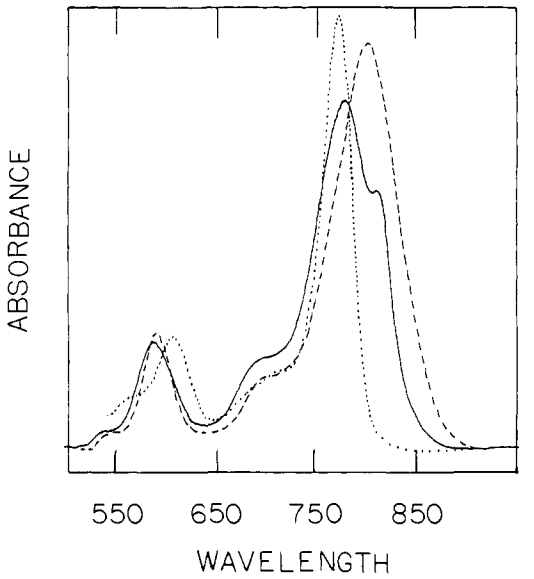
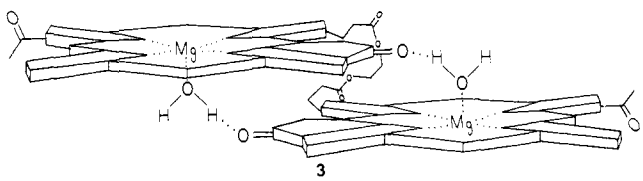


Figure 2. The electronic transition spectrum of a 10^{-5} M solution of diester **2** in 10% pyridine in benzene (·····), in dry benzene (—), and in water-saturated benzene (- - - -).

When the benzene solution of **2** is saturated with water, the absorption maximum at 780 nm is replaced by a broad band centered at 803 nm (Figure 2).[17] This change is accompanied by a sharpening of the ^1H NMR lines, yielding a spectrum indicative of a single macrocyclic species in the solution. A comparison between the two sets of chemical shifts given in schematic form in Figure 1 reveals that several resonances of **2** in the water-saturated solution are substantially shifted from their respective positions in the fully disaggregated species. These chemical shift changes closely parallel those observed by Boxer and Closs in the pyrochlorophyll linked dimer.[5] Since **2** displays only one set of resonances in the wet benzene solution, the two rings of the dimer must be equivalent on the ^1H NMR time scale. The 5-methyl group and the 10 proton experience substantial upfield shifts, 2.20 and 0.24 ppm, respectively, while the 4b methyl group shifts downfield 0.58 ppm. The methyl resonance of the acetyl groups shifts very

little from its position in the unfolded, linked dimer.[18] As the changes in chemical shift are due to the influence of the ring current of one macrocycle on its dimeric partner, the ^1H NMR data suggest that the macrocycles are, on the average, parallel to each other with the III and V rings of each macrocycle experiencing the greatest interannular overlap, and that the acetyl groups do not participate in folding the dimer through hydrogen-bonding interactions. Thus, the evidence suggests that the Bchlide a covalent dimer folds into a structure, **3**, essentially similar to that previously proposed for the special pair of Chl a.[5,6,19]



3

Illumination of a 10^{-5} M solution of **2** in water-saturated toluene containing an equivalent of I_2 with red light ($\lambda > 648$ nm) resulted in complete bleaching of the 803-nm band in <30 s and the appearance of a new absorption band at 1150 nm. This behavior closely mimics the in vivo bleaching of P865,[20] which results in a species absorbing at 1250 nm.[1-3,21] This long wavelength absorption is usually ascribed to the cation radical of the Bchl a special pair. If the same experiment using 10^{-3} M covalent dimer is performed in the cavity of an ESR spectrometer, a Gaussian photo-ESR signal with a linewidth of 10.6 ± 0.3 G is observed at $g = 2.0027$. An identical ESR signal is obtained by oxidation of **2** in water-saturated toluene with $ZnTPP^+ \cdot ClO_4^-$ according to the method of Fajer et al.[22] Since the line width of the ESR signal of monomeric Bchl a^+ is ~13 G, the narrowing of the signal of the folded cation radical of **2** indicates that the folded structure of the linked Bchl a model special pair has the ability to delocalize an unpaired spin over both macrocycles, as does the in vivo special pair.[7-9]

While our covalently linked Bchl a model mimics the properties of oxidized bacterial photoreaction center special pair chlorophyll, it nevertheless absorbs at 803 nm instead of 865 nm. It is known that reaction center preparations contain at least four bacteriochlorophyll and two bacteriopheophytin molecules.[1-3] Interaction of the in vivo bacteriochlorophyll special pair with additional Bchl a and Bpheo a molecules may shift the special pair transition to longer wavelength. Our model bacterial special pair does not use its two acetyl groups in folding into its photoactive conformation, and these groups could interact with additional Bchl a molecules either through direct acetyl C=O···Mg coordination or via hydrogen bonding to yield an aggregate with an environmentally shifted optical transition. *The additional Bchl a molecules need not be involved in the delocalization of the unpaired spin in the oxidized special pair.* Thus, an important consequence of the work reported here is that the ESR and optical properties of bacterial reaction center probably involve different numbers of Bchl a molecules.

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Synthesis of a Chiral Pyridoxal Analogue as a Potential Catalyst for Stereospecific Nonenzymatic Reactions

Sir:

Many reactions of amino acids that are catalyzed by pyridoxal phosphate containing enzymes have been duplicated by nonenzymatic model reactions in which pyridoxal (**1**) and a suitable metal salt serve as catalysts.[1] It is generally accepted that these enzymatic and nonenzymatic reactions proceed by closely similar mechanisms.[2]

The stereochemical aspects of these two types of reactions are, however, quite different. While enzymes carry out stereospecific reactions due to their apoenzymes, the nonenzymatic model reactions are not stereospecific. The only reported instance of apparent stereospecificity in model reactions has been attributed to the asymmetry in the substrate.[3] If chirality can be introduced into the pyridoxal molecule without loss of the catalytic activity, we might have a useful novel catalyst for stereospecific reactions that can differentiate between enantiomeric substrates.

From this point of view, we have tried to derive an ansa compound which has planar chirality from **1**, using the methyl group at position 2 and the hydroxymethyl group at position 5 for formation of the "ansa chain", since neither of these groups seems to play any role for the catalytic activity in **1**.[4] Here we report the synthesis of (−)-15-formyl-14-hydroxy-2,8-dithia[9](2,5)pyridinophane (**2b**), which proved to be potential catalyst for stereospecific nonenzymatic reactions.

3,4′-*O*-Isopropylidene-2′-hydroxypyridoxine (**3**) prepared from pyridoxine in 55% overall yield by modifications of a known procedure[5] was treated with thionyl chloride at 0 °C. Removal of excess thionyl chloride followed by neutralization with sodium bicarbonate gave **4**, mp 89–91 °C, in 67% yield.