reaction showed a temporary surge of *dextrorotation*, followed by a slower decay to zero rotation at final equilibrium. These results suggest that in enzymatic hydration, the (−) enantiomer of pteridine hydrate is more rapidly synthesized, giving rise to a spectrophotometric burst and a corresponding levorotation; slower synthesis of the (+) enantiomer results in decay of the *net* optical rotation until the final equilibrium mixture, equimolar in the two enantiomeric hydrates, is reached. In dehydration, the (−) enantiomer is rapidly consumed, leaving in its wake the positive optical rotation of the slower reacting (+) enantiomer; equilibration of the latter leads eventually to the optically inactive equilibrium mixture. The enzymatic hydration of pteridine, as well as the dehydration of pteridine hydrate, thus appears to be stereospecific. However, it should be noted that careful analysis shows that the relatively slow reactions of the (+) enantiomer are also subject to enzyme catalysis; these reactions appear to be approximately one order of magnitude slower than the reactions involving the (−) enantiomer.

The initial rates of enzymatic hydration and dehydration were examined spectrophotometrically as a function of substrate concentration; these rates referred mainly to the reaction of the favored enantiomer. Double reciprocal plots of the observed rates (corrected for a very minor contribution from the nonenzymatic reaction amounting to no more than 5% of the observed rates) were linear, yielding the apparent kinetic parameters listed in Table I. For comparison, the observed kinetic parameters for enzymatic deamination of 4-aminopteridine[3] are shown. It is of interest that the limiting rate constants for hydration and dehydration are somewhat larger than those for hydrolysis of 4-aminopteridine, the analogous substrate.

Table I. Enzymatic Reactions in the Pteridine Ring, in 0.1 *M* Potassium Phosphate Buffer, pH 7.5, at 25°

Substrate	4-Amino-pteridine	Anhydrous pteridine	Pteridine hydrate (racemic)
Reaction	Deamination[a]	Hydration	Dehydration
$\Delta\epsilon$ for complete reaction	−3900	+7400	−7400
Wavelength, nm	350	318	318
V_{max}, μmol/(min mg of enzyme)	1.26	3.56	5.00
K_m, m*M*	0.105	0.163	0.071

[a] Reference 3.

Although these experiments were carried out with the enzyme from calf duodenum, we have obtained similar results with the fungal enzyme from *Aspergillus oryzae*, which differs considerably from the mammalian enzyme in molecular weight and amino acid composition.[7]

The fact that these enzymes are efficient hydratases suggests that hydration is a partial reaction in the normal *hydrolytic* sequence of reactions (Scheme I). Hydration of pteridine proceeds slightly more rapidly than the overall hydrolysis of I; however, in the case of pteridine, reaction can proceed no further than the hydrate. It is of interest that the presumed reaction intermediate II, like pteridine hydrate (IV), contains a chiral center not present in the substrate or products of hydrolysis. The stereoselectivity of the hydration reaction suggests that water attack from one side of the heterocyclic ring is preferred, and this is also consistent with steric effects previously observed[2] for inhibitory analogs of the presumed intermediate in adenosine hydrolysis.

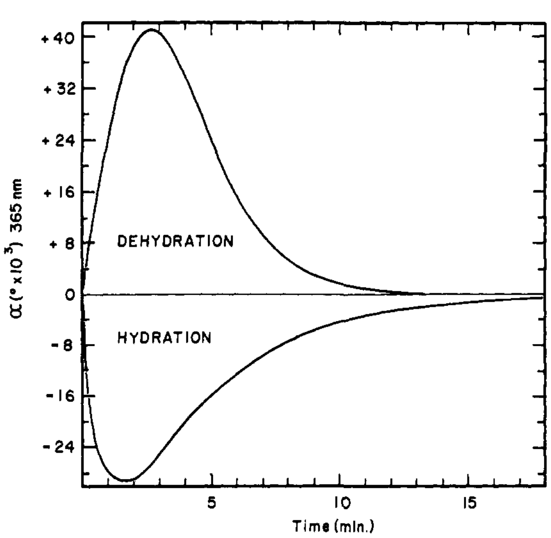

Figure 1. Polarimetric time course for hydration of pteridine (10^{-2} *M*) (lower curve), and dehydration of pteridine 3,4-monohydrate (10^{-2} *M*) (upper curve) in the presence of calf duodenal adenosine deaminase (150 μg/ml) in 0.1 *M* potassium phosphate buffer, pH 7.5 at 25°. Reactions were followed with a Cary Model 60 spectropolarimeter at 365 nm.

These findings suggest that water attack on substrates for hydrolysis by adenosine deaminase is direct, in contrast with many hydrolytic enzymes which act through double displacement mechanisms. An optically active hydrate of pteridine has been generated for the first time, in a reaction which illustrates the versatility of this enzyme and offers promise as a starting point for the further elucidation of its catalytic function.

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[7] R. Wolfenden, Y. Tomozawa, and B. Bamman, *Biochemistry*, 7, 3965 (1968).

Temperature and Viscosity Effects on the Decay Characteristics of *s-trans*-1,3-Diene Triplets

Sir:

1,3-Diene triplets at room temperature in solution undergo facile rotation about the 1,2 and 3,4 bonds while maintaining geometric integrity with respect to rotation about the 2,3 bond.[1-3] The benzophenone-sensitized interconversion of 2,4-hexadienes can be explained by assuming that twisting at both ends of the diene system gives a common triplet having 1,4 birad-

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[1] H. L. Hyndman, B. M. Monroe, and G. S. Hammond, *J. Amer. Chem. Soc.*, **91**, 2852 (1969).

[2] J. Saltiel, L. Metts, and M. Wrighton, *ibid.*, **91**, 5684 (1969).

[3] J. Saltiel, L. Metts, A. Sykes, and M. Wrighton, *ibid.*, **93**, 5302 (1971), and references cited therein.

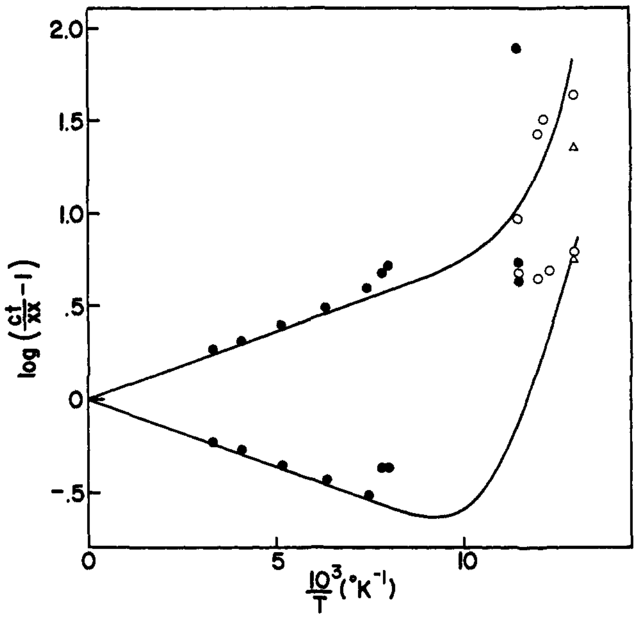


Figure 1. Temperature dependence of isomerization quantum yield ratios starting with tt (upper) and with cc (lower): solid circles, MP; open circles, IPMP; triangles, IP.

Table I. One Bond to Two Bond Quantum Yield Ratios for the 2,4-Hexadienes[a]

T, °K	Solvent[b]	ϕ_{ct}/ϕ_{cc}	ϕ_{ct}/ϕ_{tt}
300.7	MP	2.85	1.60
243.8	MP	3.07	1.54
194.8	MP	3.52	1.45
158.8	MP	4.11	1.39
134.2	MP	4.95	1.30
127.8	MP	5.73	1.42
125.0	MP	6.16	1.43
87.0	IPMP	9.20	5.70
87.0	MP	76.5	5.81
83.0	IPMP	27.8	6.40
81.0	IPMP	32.7	5.90
77.0	IPMP	42.3	7.07
77.0	IP	23.5	6.70

[a] Conversions are corrected for back reaction. [b] Solvents: MP, 3-methylpentane; IPMP, isopentane-3-methylpentane, 6:1 by volume; IP, isopentane.

ical type geometry or that twisting at one end gives allylmethylene type triplets which undergo rapid equilibration.[1,2] Theoretical calculations suggest that the 1,4-biradical geometry represents an energy maximum in the torsional potential energy curve of 1,3-diene triplets and support the allylmethylene geometry.[4-7] We report effects of temperature and viscosity on the benzophenone-sensitized cis–trans photoisomerization of the 2,4-hexadienes which favor the allymethylene description of *s-trans*-1,3-diene triplets.

Degassed sample tubes were irradiated in a small cylindrical merry-go-round attached to a stirring motor and immersed in a Pyrex dewar containing either a liquefied gas or a low melting hydrocarbon solvent, cooling coils, and an iron–constantan thermocouple. Light from an Osram HBO 200-W super-pressure mercury lamp was collimated, then made to converge on the sample tubes using a Bausch and Lomb housing and appropriate lenses. Other experimental procedures have been described.[2] One bond to two bond isomerization quantum yield ratios were determined using several temperatures and solvents starting with *trans,trans*-2,4-hexadiene (tt) and *cis,cis*-2,4-hexadiene (cc). Representative values are shown in Table I. Isomerization quantum yields, determined by irradiating IPMP solutions under the same or similar conditions, were not diminished within experimental uncertainty (±20%) throughout the temperature range investigated, 300–159°K. Minimum values obtained at 159°K are $\phi_{cc\rightarrow tt} = 0.30 \pm 0.01$, $\phi_{cc\rightarrow ct} = 0.41 \pm 0.02$, $\phi_{tt\rightarrow ct} = 0.39 \pm 0.07$, and $\phi_{tt\rightarrow cc} = 0.11 \pm 0.02$.[8] Even at 77°K, where the high medium viscosity prevented deactivation of all benzophenone triplets by dienes, observed minimum quantum yields are $\phi_{cc\rightarrow ct} = \phi_{tt\rightarrow ct} \geq 0.24$.[8]

One bond to two bond isomerization ratios are solvent independent down to ~135°K. Changes in these ratios in the 300–135°K range show that decreasing the temperature favors decay to trans double bonds, while the sum of the isomerization quantum yields remains ~2.[1,2] At lower temperatures a viscosity-dependent shift from a two bond to a one bond isomerization mechanism is observed [compare ratios in MP (η = 2 × 10^7 P) at 87°K and in IP (η = 10^6 P) at 77°K, with ratios obtained in IPMP at these temperatures (η = 10^5 and 5 × 10^6 P at 87 and 77°K, respectively)].[9]

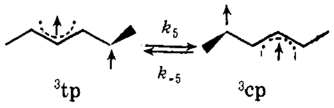
The observations are readily interpreted using the allylmethylene triplet mechanism, shown for tt in eq 1–7, where B represents benzophenone and the other

$$\mathrm{B} \xrightarrow{h\nu} {}^1\mathrm{B} \longrightarrow {}^3\mathrm{B} \tag{1}$$

$$^3\mathrm{B} + \mathrm{tt} \xrightarrow{k_2} {}^3\mathrm{tt} + \mathrm{B} \tag{2}$$

$$^3\mathrm{tt} \xrightarrow{k_3} \mathrm{tt} \tag{3}$$

$$^3\mathrm{tt} \xrightarrow{k_4} {}^3\mathrm{tp} \tag{4}$$



(5)

$$^3\mathrm{tp} \xrightarrow{k_6} 0.50\mathrm{tt} + 0.50\mathrm{ct} \tag{6}$$

$$^3\mathrm{cp} \xrightarrow{k_7} 0.50\mathrm{ct} + 0.50\mathrm{cc} \tag{7}$$

symbols have their usual meanings.[2,3] The decay fractions in eq 6 and 7 are supported by the temperature independence of the tc content of photostationary states (50% tc, 300–77°K). The mechanism gives eq 8 and 9 for the ratios of ct/cc and ct/tt obtained from tt

$$\frac{\mathrm{ct}}{\mathrm{cc}} - 1 = \frac{k_6}{k_7}\left(\frac{A_{-5}}{A_5}e^{(E_5 - E_{-5})/RT} + \frac{k_7}{A_5}e^{E_5/RT}\right) \tag{8}$$

$$\frac{\mathrm{ct}}{\mathrm{tt}} - 1 = \frac{k_7}{k_6}\left(\frac{A_5}{A_{-5}}e^{-(E_5 - E_{-5})/RT} + \frac{k_6}{A_{-5}}e^{E_{-5}/RT}\right) \tag{9}$$

and from cc, respectively, in which Arrhenius equations describe allylmethylene triplet interconversion. At high temperatures the second terms in the parentheses

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[4] R. Hoffmann, *Tetrahedron*, **22**, 521 (1966).

[5] E. M. Evleth, *Chem. Phys. Lett.*, **3**, 122 (1969).

[6] N. C. Baird, *Mol. Photochem.*, **2**, 53 (1970).

[7] N. C. Baird and R. M. West, *J. Amer. Chem. Soc.*, **93**, 4427 (1971).

[8] At the lower temperatures experimental difficulties, such as cloudy solutions, ice formation in the dewar, and benzophenone precipitation, may have given observed values which are lower than the actual quantum yields.

[9] For medium viscosities see A. C. Ling and J. E. Willard, *J. Phys. Chem.*, **72**, 1918 (1968).

of eq 8 and 9 are negligible and logarithmic plots of (ct/cc) − 1 and (ct/tt) − 1 *vs.* T^{-1} are predicted to be linear. The data are plotted in this fashion in Figure 1, with points down to 159°K giving $E_5 - E_{-5} = \Delta H_5 = 324 \pm 22$ cal/mol and $k_6A_{-5}/k_7A_5 = k_7A_5/k_6A_{-5} = 1.00 \pm 0.01$. The fit of the observations to the mechanism is illustrated by the lines drawn in Figure 1 which were calculated using $E_5 - E_{-5} = 333$ cal/mol, $k_6/A_5 = k_7/A_{-5} = 10^8$, and $E_5 = 3450$ cal/mol. The latter parameters were somewhat arbitrarily selected so that the calculated lines pass close to the low-temperature points for the low-viscosity media. Solvent barriers to interconversion of ^{3}cp and ^{3}tp are expected in temperature regions for which the twisting process is slower than solvent relaxation, and it is likely that a large portion of the activation energies E_5 and E_{-5} is medium derived.[10]

Small thermal[7] and/or solvent barriers to twisting from planar triplets will not affect isomerization quantum yields provided that decay of planar triplets directly to the ground state remains slow relative to twisting, *e.g.*, $k_3 \ll k_4$. Starting with tc in IPMP at 77°K, $\phi_{\text{tc}\rightarrow\text{tt}}/\phi_{\text{tc}\rightarrow\text{cc}} = 2.9$. Since these conditions inhibit allyl methylene triplet interconversion, this ratio reflects mainly a preference for twisting of cis over trans double bonds in the planar triplet.

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[10] J. Saltiel and J. T. D'Agostino, *J. Amer. Chem. Soc.*, submitted for publication.

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The Role of Ion Pairing in Reactions of Metal Carbonyl Anions. I. Cation-Assisted Alkyl-Acyl Migratory Insertions

Sir:

Disodium tetracarbonylferrate(−II) is an inexpensive, selective reagent converting aliphatic halides into aldehydes[1] and unsymmetrical ketones.[2] These reactions involve anionic alkyl and acyl intermediates[3] **1** and **2**. The fullest synthetic application of these reagents requires a detailed understanding of the reaction mechanisms. We have investigated the alkyl-acyl insertion (eq 1) and found the rate to be dramatically

$$\underset{\mathbf{1}}{\mathrm{Na(RFe(CO)_4)}} \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} \mathrm{Na((RCO)Fe(CO)_3)} \xrightarrow{\mathrm{L},k_2} \underset{\mathbf{2}}{\mathrm{Na((RCO)Fe(CO)_3L)}} \qquad (1)$$

influenced by the nature of the gegencation and added solvents. We interpret these results as arising from ion pairing and conclude that ion-pairing phenomena may have hitherto unrecognized importance in the chemical reactivity of many metal carbonyl anions.[4]

The usual mechanism for alkyl-acyl insertion[5] involves a reversible migration followed by reaction with a ligand, L, to form the coordinatively saturated product (eq 1). Depending on the relative rate constants k_{-1} and k_2 and [L], such reactions can exhibit rate laws having first, second, or intermediate order. Using the complex **1**, R = *n*-nonyl, the rates of alkyl loss and acyl gain, determined by quenching with acid affording nonane and decanal, respectively (glc analysis), are equivalent within experimental error. Tertiary phosphines were employed as L, usually in tenfold or greater excess, affording pseudo-first-order behavior. The reaction obeyed the second-order rate law (eq 2) which is consistent with either a rapid prior equilibrium (eq 1, $k_{-1} \gg k_2$) or a simple concerted second-order reaction. In accordance with previous observations[5] we have assumed eq 1. The observed pseudo-first-order rate constant was found to be linearly dependent on the phosphine concentration (0.03–0.4 *M*), with apparent second-order rate constants $Kk_2 = 0.066$ M^{-1} sec^{-1}, L = triphenylphosphine; and $Kk_2 = 0.23$ M^{-1} sec^{-1}, L = dimethylphenylphosphine; both at 25°, R = *n*-nonyl.

$$-\mathrm{d[NaRFe(CO)_4]}/\mathrm{d}t = Kk_2[\mathrm{L}][\mathrm{Na(RFe(CO)_4)}]$$
$$K = k_1/k_{-1} \qquad (2)$$

Polar solvents often act[5] as transient ligands in alkyl-acyl insertions and affect the rate by increasing k_1. However, in the present case certain solvents produce a different but dramatic effect. For example, addition of a few per cent of *N*-methylpyrrolidone (MP) or hexamethylphosphoric triamide (HMPA) to $\mathrm{Na(RFe(CO)_4)}$ in tetrahydrofuran (THF) strongly inhibits the rate. The rate is also remarkably dependent on the nature of the cation, $\mathrm{Li^+ > Na^+ \gg (Ph_3P)_2N^+}$, spanning a range of at least three orders of magnitude (Table I).

Table I. Effect of Cation on Rate of Allyl Migration[a]

Complex	Kk_2, M^{-1} sec^{-1}
$\mathrm{LiRFe(CO)_4}$	0.24
$\mathrm{NaRFe(CO)_4}$	0.065
$\mathrm{(Ph_3P)_2NRFe(CO)_4}$	$<1.5 \times 10^{-4}$
Na(dicyclohexyl-18-crown-6)RFe(CO)$_4$	$<7 \times 10^{-4}$

[a] Data taken at $T = 25°$, with THF as solvent and R = nonyl.

These results are consistent with a mechanism in which a sodium or lithium ion pair is the kinetically reactive species. Apparently migration of the alkyl to an adjacent terminal carbonyl is facilitated by electrostatic interaction of small polarizing cations which are probably associated with the electron-rich carbonyl oxygens and help stabilize the extra negative charge which accompanies the migrating alkyl group (mechanism I). Larger more diffuse cations or solvent-separated cations are less effective. This mechanism

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[1] M. P. Cooke, *J. Amer. Chem. Soc.*, **92**, 6080 (1970).

[2] J. P. Collman, S. R. Winter, and D. R. Clark, *ibid.*, **94**, 1788 (1972).

[3] These intermediates have been isolated and characterized: W. O. Siegl and J. P. Collman, *ibid.*, **94**, 2516 (1972).

[4] Ion pairing is known to be of importance in the reactions of carbanions: see for example M. Shinohava, J. Smid, and M. Szwarc, *ibid.*, **90**, 2175 (1968); T. E. Hogen-Esch and J. Smid, *ibid.*, **89**, 2764 (1967).

[5] R. W. Glyde and R. J. Mawby, *Inorg. Chem.*, **10**, 854 (1971), and references contained therein.