Table II. Pulsed Laser Excitation of Rhodopsin

Detergent[a]	Φ[b]	Bleaching products[c,d]
Triton X-100	0.64	Trans
A-LO	0.62	Trans, 2% 9-cis
CTAB	0.69	Trans, 10% 9-cis, 3% 13-cis
NaDOC	0.55	Trans, 5% 9-cis, 15% 13-cis

[a] See Table I. Digitonin was not studied because the chromophore could not be extracted with methylene chloride from a digitonin solution. [b] Reproducibility ±5%, 50 mM $NH_2OH \cdot HCl$. The relative bleaching rates were the same in the absence of $NH_2OH \cdot HCl$. [c] Conversion yields are 50–75%, 23°C. The percent are approximate because the detergents broadened the HPLC peaks. The 11-cis isomer, the chromophore in rhodopsin, is omitted in the estimations of product distribution. [d] The methylene chloride extraction procedure does not induce isomerization of retinals as shown by the liberations of only 11-cis and 9-cis retinals, respectively, from rhodopsin and isorhodopsin (ref 13).

and products were analyzed by high pressure liquid chromatography (HPLC), Waters ALC-100, 6000 psi pump, two 1-ft μ-porasil columns,[18] 1% ether in hexane, 1.5 ml/min, 350-nm detector. The HPLC peak areas were corrected for detector response by dividing by $\epsilon_{350\ nm}$ of the respective retinal isomer. Quantum yields were determined by monochromatic excitation at 500 ± 5 nm and monitoring the 500-nm rhodopsin absorption in the presence of 50 mM hydroxylamine hydrochloride. The lamp flux was calibrated by ferrioxalate actinometry.[19]

Extraction of nonirradiated rhodopsin via the methylene chloride process afforded exclusively the 11-cis retinal,[13] while all-trans retinal was the only product when rhodopsin is bleached by pulsed laser excitation in Triton X-100 (Table II). In contrast to the nonionic micelles (Triton X-100, A-LO), excitation of rhodopsin in the cationic detergents (CTAB, NaDOC) gave relatively large amounts of cis retinals, 9-cis and 13-cis, as primary photoproducts resulting from simultaneous isomerization about two double bonds. It should be noted that 9,13-isorhodopsin (isorhodopsin II),[13] upon pulsed excitation, also yields primary products resulting from a one-photon two-bond isomerization, i.e., a 15:1 mixture of all-trans and 11-cis retinals.[20] Although the question of multiple photon events is a relevant one since rhodopsin is isomerized within 6 ps of photon irradiation,[21] it should be pointed out that the number of absorbing molecules was approximately equal to the photons per flash, and that rhodopsin gave no cis retinal products when flash irradiation was carried out under identical conditions in Triton X-100; however, upon prolonged excitation in Triton X-100 some cis products were formed.

Of the detergents used in this study, only CTAB has been thoroughly investigated. Molecules such as benzene, *N,N*-dimethylaniline, and hexanol are solubilized at the micelle–water interface, while cyclohexane is located in the micelle interior.[22] The location of rhodopsin in CTAB is unknown, although ultracentrifugation studies conclude that three rhodopsin–opsin molecules can be contained in a single CTAB micelle.[23] Even though we cannot elaborate upon specifics of the protein–micelle interaction, we know that the location of the protein in the micelles, interior or interface, and the shape of the micelles are important,[24] due to the structural and electronic features of the different detergents and the fact that rhodopsin is thought to have an elongated shape.[25]

It is evident that the protein–chromophore interactions alter the photochemical properties of the polyene. These photochemical variations may be caused either by different twists of the chromophore in the different micelles, and/or different electronic interactions between the protein and chromophore due to varying protein conformations. These would affect: (i) the energy levels of the 11-cis chromophore and its photoproducts, or (ii) the pathway of photoisomerization, i.e., singlet or triplet. Multiple bond photoisomerization in polyenes usually occur via a triplet state pathway.[26,27] Since interactions with the protein could alter the photochemistry of the chromophore and thus result in two-bond isomerizations via the singlet, it is not possible to determine the isomerizing state from the nature of the photoproducts.

Finally, in view of the differences in the circular dichroism spectra, quantum yields of bleaching, and bleaching products of rhodopsin in the various detergents, caution should be exercised in comparing the spectral and photochemical properties of rhodopsin in different micelle environments where some consideration of the chromophore microenvironment must be made.

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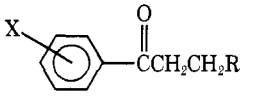
Walter H. Waddell,[28] Anthony P. Yudd, Koji Nakanishi*
Department of Chemistry, Columbia University
New York, New York 10027
Received September 26, 1975

A Rotation-Controlled Excited-State Reaction. The Photoenolization of Ortho Alkyl Phenyl Ketones[1]

Sir:

We wish to report evidence that the well-known and much studied photoenolization of ortho methyl ketones[2-5] is dominated by hitherto unsuspected conformational factors,

Table I. Photokinetic Parameters for Ortho Alkyl Ketones[a]



Ketone	X	R	Solvent	Φ_{II}[b]	Φ_T[c]	$k_q\tau$, M^{-1}[d]	$1/\tau$ $10^7\ s^{-1}$[e]	k_γ, $10^7\ s^{-1}$	k_e, $10^7\ s^{-1}$
3	2-CH_3	CH_3	Benzene	0.0014	0.21	150	3.4	0.4	3.0
4	2-CH_3	CH_2CH_3	Benzene	0.016	0.21	90	5.6	3.0	2.6
5	2-CH_3	$CH(CH_3)_2$	Benzene	0.033	0.21	27	18.0	15.0	3.0
6	2-CH_2CH_3	CH_2CH_3	Benzene	0.021	0.12	94	5.3	~3.0	~2.3
3	2-CH_3	CH_3	*t*-BuOH	0.015	0.11	340	0.68	0.08	0.6
4	2-CH_3	CH_2CH_3	*t*-BuOH	0.060	0.11	156	1.5	0.9	0.6
5	2-CH_3	$CH(CH_3)_2$	*t*-BuOH	0.095	0.11	40	5.7	5.0	0.7
6	2-CH_2CH_3	CH_2CH_3	*t*-BuOH	0.048	0.07	120	2.0	1.3	0.7
7-h	2,4-$(CH_3)_2$	$CH(CH_3)_2$	Benzene	0.024	0.27	137	3.6	~1.8	~1.8
7-d	2,4-$(CD_3)_2$	$CH(CH_3)_2$	Benzene	0.039	0.27	102	4.9	~3.0	~1.9

[a] 0.05 M in benzene, 313-nm irradiation, 20–24 °C. [b] Acetophenone formation; cyclobutanols are formed in negligible yields. [c] Triplet yield measured by extrapolation of low concentration pentadiene data in plots such as for 1 in Figure 1 to [pentadiene]$^{-1}$ = 0. [d] Slopes of linear Stern–Volmer plots with 2,5-dimethyl-2,4-hexadiene as quencher. [e] $k_q = 5 \times 10^9\ M^{-1}\ s^{-1}$ in benzene, $2.3 \times 10^9\ M^{-1}\ s^{-1}$ in *tert*-butyl alcohol (C. Steel and L. Giering, unpublished work).

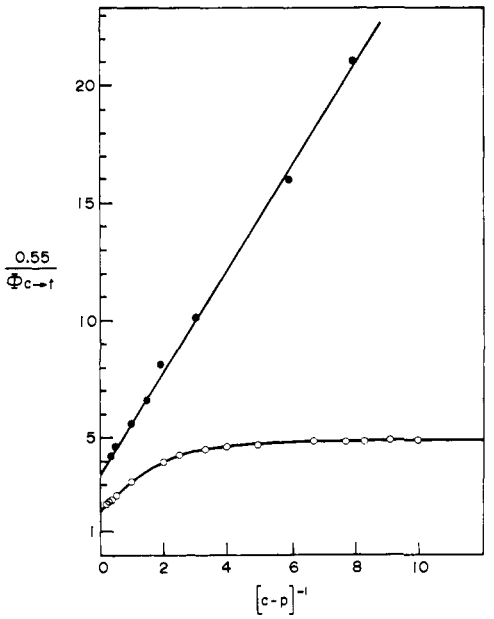
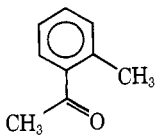


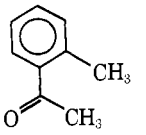
Figure 1. Concentration dependence of the cis–trans isomerization of *cis*-1,3-pentadiene (C-P) in benzene photosensitized by 0.05 M *o*-methylacetophenone (○) and by 0.05 M 8-methyl-1-tetralone, **2** (●).

especially by the syn/anti ground-state ratio and by the rate of triplet state anti → syn rotation.

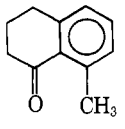
In agreement with the recent report[5] that only 80% of the photoenolization of *o*-methylacetophenone (**1**) can be quenched by 0.5 M 1,3-pentadiene, we find that several *o*-tolyl alkyl ketones are only 21% as efficient as benzophenone at sensitizing the cis → trans photoisomerization of 0.2 M 1,3-pentadiene in benzene. The quantum yield for production of a long-lived triplet is thus only 21%.[6] However, a conclusion[5] that 80% of the enolization occurs from the singlet is not warranted. As shown in Figure 1, the usual plot of Φ(cis → trans)$^{-1}$ vs. reciprocal diene concentration is *not* linear for **1** but has a steep slope at high (>1 M) diene concentrations[7] and a very low slope at low (<0.2 M) diene concentrations. Proper kinetic analysis of this plot[8] yields $k_q\tau$ values of 150 M^{-1} for the triplet formed in 21% yield and 1.0 M^{-1} for a triplet formed in 31% yield. The two triplets are thus calculated[9] to have decay rates of 3×10^7 and $5 \times 10^9\ s^{-1}$, respectively. The former apparently is the one observed by Lindqvist.[5] No subnanosecond triplet has been detected previously. The following evidence suggests that the two triplets are kinetically independent anti and syn conformers, respectively.[11]



syn-**1**



anti-**1**



2

First, 8-methyl-1-tetralone (**2**), a model for *syn*-**1**, also sensitizes the cis–trans isomerization of 1,3-pentadiene but displays a linear reciprocal quantum yield plot. The intercept of 3.5 and slope of 2.2 M indicate a triplet yield of 0.28 and a triplet lifetime of 0.3 ns.[9] If we make the reasonable assumption that only rapid enolization can be responsible for the unusually rapid triplet decay of both **1** and **2**, we conclude that the very short-lived triplet of **1** is the syn conformer. Both *syn*-**1** and **2** apparently do undergo significant singlet-state enolization, a fact which is less surprising now that the very rapid rate of triplet-state enolization is evident.[12]

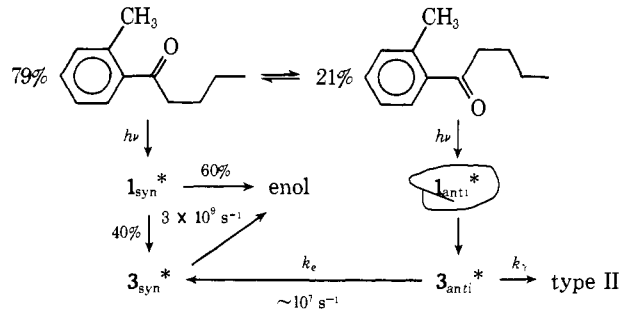
If indeed the longer-lived triplet from **1** is an anti conformer (the only way in which **1** can differ significantly from **2**), rotation over a substantial barrier[15] to a syn conformation must precede enolization. Study of the type II photoelimination of various ortho alkyl ketones[16] provides evidence that this rotation is probably rate determining. Table I lists quantum yield and quenching data for several ketones in both benzene and in *tert*-butyl alcohol. Type II quantum yields are low and depend on γ-hydrogen lability, as expected if another triplet-state reaction (enolization, rate = k_e) is competitive with γ-hydrogen abstraction (rate = k_γ). We have analyzed our results in benzene by assuming that an ortho methyl, besides lowering the yield of long-lived triplet, introduces only two changes in the decay rate of that triplet: (1) a constant factor α decreasing the known unsubstituted[17] k_γ^0 values; and (2) a constant additional rate of enolization.[18] Solution of the simultaneous equations

$$1/\tau = \alpha k_\gamma^0 + k_e \quad (1)$$

$$\phi_{II} = \phi_T k_\gamma \tau P \quad (2)$$

which result from putting the lifetime data for ketones **3–5** into eq 1 yields a value of 0.3 for α[19] and $3 \times 10^7\ s^{-1}$ for k_e, the same triplet decay rate already observed for the long-lived triplet of **1**. The low type II quantum yields result from a combination of low yield of long-lived triplet, low

Scheme I



probability for product formation from the diradical intermediate (P = 0.08–0.18), and competing enolization, not just from the latter as previously assumed.[16]

Addition of large concentrations of *tert*-butyl alcohol causes type II yields to maximize, as previously noted.[16] However, the effect represents a combination of P maximizing while ϕ_T, k_γ,[20] and k_e[5] all decrease. Analysis of the data in *tert*-butyl alcohol on the basis that P = 1 gives further self-consistent results, in that α = 0.10 and $k_e = 0.6 \times 10^7$ for ketones **3–5.**

These type II results are important for two reasons. First, they establish that the long-lived triplet detected by sensitization experiments is a ketone triplet and not, say, a triplet enol,[3,21] which would not be expected to undergo type II elimination. Second, the value of k_e appears to be independent of C–H bond strength! *o*-Ethylvalerophenone (**6**) has the same triplet lifetime as *o*-methylvalerophenone (**4**). In *tert*-butyl alcohol, exact kinetic analysis yields the same value of k_e for both ketones. In benzene, where the value of P cannot yet be ascertained, assumption of comparable k_γ values for **4** and **6** produces comparable values of k_e. Equally interesting is the behavior of ketones **7h** and **7d,** which also display comparable triplet lifetimes in benzene. Since the low type II quantum yields indicate that k_e is a major contributor to triplet decay, it must be concluded that there is no significant isotope effect on k_e. A k_H/k_D value of 4.8 obtains in type II γ-hydrogen abstraction.[22]

Since k_e is independent of C–H bond strength, we must conclude that the rate determining step for enolization of the long-lived triplet is not hydrogen abstraction. This conclusion is almost demanded by the model of discrete syn and anti triplet conformers and does not fit any other scheme that we can think of. Scheme I summarizes what we believe to be the mechanism for photoenolization of *o*-tolyl alkyl ketones. The process competing with normal triplet reactions of the anti triplet is irreversible rotation into a syn conformation which enolizes so rapidly that other reactions cannot compete. The Φ_T values in fact measure the percentage of anti ground states in what is presumably a rapid conformational equilibrium. NMR chemical shift data have been interpreted as indicating that *syn*-**1** predominates over *anti*-**1**,[23] but no quantitative analysis has been reported. The various percentages and rates depend on solvent and on the ortho alkyl group in ways which only further work can explain. The $\sim 10^7$ s^{-1} rate which we ascribe to rotation in the triplet would indicate a barrier of some 8 kcal. Because of severe nonbonded interactions in the totally planar forms, this barrier would certainly be expected to be smaller than that in excited benzaldehyde, for which a value of some 20 kcal has been calculated.[15]

Finally, we note that we have purposely ignored some important questions, such as the energetic proximity of n, π^* and π,π^* triplets in these compounds[20,24] and the possible formation of triplet enols,[3] in order to emphasize the importance of previously unsuspected conformational factors and the rapidity of enolization of triplets with syn conformations. Although the importance of ground-state conformations in photochemical processes is now well documented,[25] this photoenolization is a rare case[26] where an excited-state conformational change appears to be rate limiting.

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Peter J. Wagner,* C.-P. Chen[27]

Department of Chemistry, Michigan State University
East Lansing, Michigan 48824

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Enhanced Photocyclization of α-Fluoro Ketones[1]

Sir:

We have studied the photochemistry of α-fluorovalerophenone (**1**) and α,α-difluorovalerophenone (**2**) and find that the α-fluorines greatly enhance the efficiency of type II cyclization, such that a cyclobutanol is the only significant product formed from **2.**

The monofluoro ketone was prepared by treatment of α-bromovalerophenone with potassium fluoride in glycerol;[2]