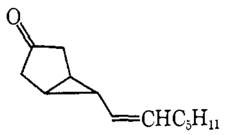
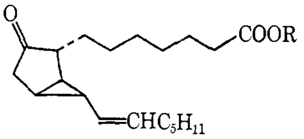
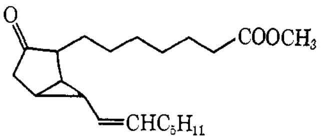


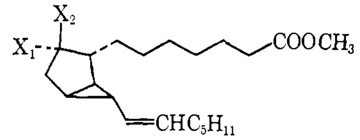
1 (*cis*)
2 (*trans*)



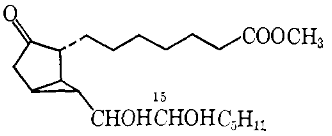
3a, R = CH_3 (*cis*)
b, R = H
5 (*trans*)



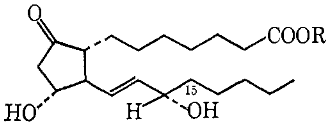
4 (*cis*)
6 (*trans*)



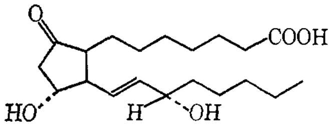
7 (*cis*), $X_1 = OH; X_2 = H$
8 (*cis*), $X_1 = H; X_2 = OH$



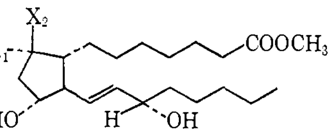
9, **10** (*erythro*)
11, **12** (*threo*)



13a, R = CH_3
b, R = H
c, R = CH_2CCl_3



14



15a, $X_1 = OH; X_2 = H$
b, $X_1 = H; X_2 = OH$

clohexylcarbodiimide, to the 2,2,2-trichloroethyl esters. Bismesylation and solvolysis of these glycol esters, without prior separation of isomers, gave *dl*-PGE_1 trichloroethyl ester (**13c**) in 4% yield. Removal of the trichloroethyl group by zinc in acetic acid[7] gave *dl*-PGE_1 (**13b**), mp 113.5–115°, in 70% yield. This is essentially the same melting point as the natural isomer, but the synthetic material showed no optical rotation between 475 and 230 mμ and the mixture melting point was slightly depressed. The fragmentation pattern of the mass spectrum was identical with that of natural PGE_1, and the synthetic material had about 60% of the biological activity of the natural isomer in two assays.[6] It showed the same tlc mobility and color reactions in several systems as natural PGE_1 and on treatment with base gave λ_{max} 278 mμ (ϵ 26,000).

The β-alkylated ketones **4** and **6** were also treated with osmium tetroxide to give four glycol racemates analogous to **9–12**, but with the β-oriented carboxyl side chain. Each of these gave, after mesylation and solvolysis, up to 10% yields of the *dl*-methyl ester of 8-iso-PGE_1 (**14**), mp 52–53° (*Anal.* Found: C, 67.80; H, 9.98). The nmr, ir, and mass spectra were identical with those of the methyl ester prepared from 8-iso-PGE_1 isolated from enzymatic conversions of bishomo-γ-linolenic acid using sheep seminal vesicles (the subject of a separate communication).[8]

dl-8-Iso-PGE_1, mp 101–102° (*Anal.* Found: C, 67.56; H, 9.60), was prepared from **4** *via* the same series of reactions as were used above for the preparation of *dl*-PGE_1 from **3** *via* trichloroethyl esters. The product showed nmr, ir, and mass spectra identical with those of authentic material[8] and their tlc mobilities were indistinguishable in several systems.

We have also found that epoxidation of **7** under mild conditions gave a mixture of isomeric epoxides. These, without separation, on treatment with formic acid at room temperature overnight followed by selective hydrolysis of formates, gave a complex mixture from which *dl*-prostaglandin $F_{1}\alpha$ methyl ester (**15a**), mp 70–73°, was isolated in 2–3% yield. Approximately the same amount of the 15 epimer[9] was also formed. In the same way, **8** was converted to epoxides which gave a 10% yield of *dl*-$PGF_{1}\beta$ methyl ester (**15b**), mp 101–102° (*Anal.* Found: C, 67.68; H, 10.71). Characterization of these products rests on the identity of infrared, nmr, and mass spectra with those of natural materials, identical mobility and color reactions in several thin layer chromatographic systems, and biological activity of at least 50% of the natural material in two systems.[6,10]

---

(7) R. B. Woodward, K. Heusler, J. Gosteli, P. Naegeli, W. Oppolzer, R. Ramage, S. Ranganathan, and H. Vorbrueggen, *J. Am. Chem. Soc.*, **88**, 852 (1966).

(8) E. G. Daniels, W. C. Kreuger, F. P. Kupiecki, J. E. Pike, and W. P. Schneider, *ibid.*, **90**, 5894 (1968).

(9) This was compared with a sample of (15*R*)-$PGF_{1}\beta$ methyl ester prepared from (15*S*)-$PGF_{1}\alpha$ as described in ref 5.

(10) We thank Dr. M. F. Grostic for the mass spectra, Dr. W. A. Struck and associates for other analytical data, and R. A. Morge, J. H. Kinner, and J. M. Baldwin for technical assistance.

W. P. Schneider, U. Axen, F. H. Lincoln
J. E. Pike, J. L. Thompson
Chemistry Department, The Upjohn Company
Kalamazoo, Michigan 49001

Received May 22, 1968

Is There Any Correlation between Quantum Yields and Triplet-State Reactivity in Type II Photoelimination?[1]

Sir:

We present some results which are particularly novel in that certain γ substituents which markedly increase the reactivity of phenyl ketones in type II photoelimination actually reduce the over-all quantum efficiency of the process, while others decrease triplet-state reactivity but increase quantum yields.

The various ketones listed in Table I were irradiated at 3131 Å as 0.10 *M* benzene solutions. Quantum yields of acetophenone formation (Φ_{II}) were determined by parallel irradiation of benzophenone–piperylene

---

(1) This work was generously supported by a grant from the National Science Foundation.

Table I. Kinetic Data for Photoelimination of Phenyl Alkyl Ketones

Ketone[a]	Φ_{II}[b]	$k_q\tau$, M^{-1}	k_r, 10^8 sec^{-1}
$PhCOCH_2CH_2CH_3$	0.35	670	0.075
$PhCOCH_2CH(CH_3)_2$	0.36	245	0.20
$PhCOCH_2CH_2CH_2CH_3$	0.33	36	1.4
$PhCOCH_2CH_2CH(CH_3)_2$	0.25	11	4.5
$PhCOCH_2CH_2CH(CH_3)OCH_3$	0.21	7	7.0
$PhCOCH_2OCH_3$	0.51	3	17.0
$PhCOCH_2CH_2CH_2Ph$	0.49[c]	12.5	4.0
$PhCOCH_2CH_2CH_2COOCH_3$	0.46[c]	440	0.11
$PhCOCH_2CH_2CH_2CH_2COOH$	0.55	185	0.27
$PhCOCH_2CH_2CH_2CH_2COOCH_3$	0.63	125	0.40

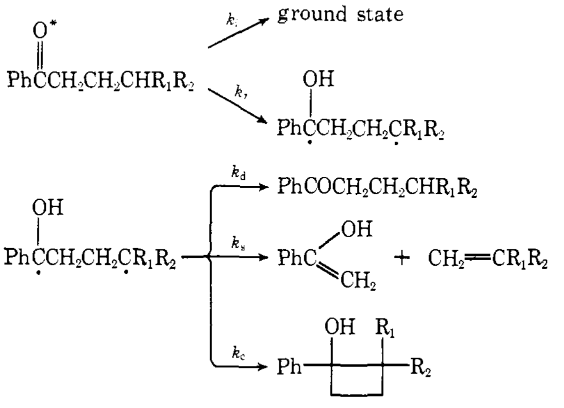
[a] Originally 0.10 M in benzene. [b] Usually at 5% conversion, precision ±0.01. [c] Extrapolated to zero conversion.

actinometer solutions.[2] With various concentrations of 2,5-dimethyl-2,4-hexadiene as quencher, linear Stern–Volmer plots were obtained with the slopes listed in Table I as $k_q\tau$ values.[3] Values of τ were estimated on the basis that k_q equals $5 \times 10^9\ M^{-1}\ \text{sec}^{-1}$.[4,5]

The total quantum yield for the disappearance of the various ketones rises to near unity when irradiation is carried out in *t*-butyl alcohol as solvent. Consequently, it is assumed[6] that $1/\tau = k_r$, the rate constant for intramolecular hydrogen abstraction by the ketone triplet. This conclusion is based on previous proposals[4,6] that quantum yields for photoelimination normally are low because of reversible γ-hydrogen transfer. The total quantum yield must be the product of two separate probabilities, where ϕ_{BR} is the probability that the triplet will react to give a biradical and ϕ_P is the probability that the biradical will proceed on to product. The solvent effect suggests that $\phi_{BR} \approx 1$ for all these ketones.

$$\Phi_{II} = \phi_{BR}\phi_P$$

$$\Phi_{II} = \left(\frac{k_r}{k_r + k_i}\right)\left(\frac{k_s}{k_s + k_c + k_d}\right)$$



There exists a very close parallel between the relative k_r values and the known reactivity of the various kinds of γ C–H bonds toward attack by electrophilic ketone triplets.[7] The lower the bond energy, the higher k_r. Superimposed on this order is the rate enhancement afforded by the radical-stabilizing oxygen atom and the rate decrease caused by the electron-withdrawing carbonyl groups.

These results dramatize how fortuitous is any correlation between quantum yield and reactivity of the ketone triplet. An alternative explanation of the low quantum yields, based on fast rates of radiationless decay, would demand that k_i be proportional to k_r for most of the ketones. But the behavior of methoxyacetophenone and of γ-phenylbutyrophenone would then be exceptional. *All* the results are consistent, however, with the biradical mechanistic hypothesis. If ϕ_{Br} is very nearly unity for all these ketones, quantum yields are determined almost completely by the values ϕ_P. Since ϕ_P is determined by the competition between three reactions of very similar rates, it is not surprising that changes in the structure of the biradical intermediate might change ϕ_P and thus Φ_{II}. The observed variations in Φ_{II} can be explained as follows.

The first five ketones in Table I demonstrate that Φ_{II} decreases as the γ C–H bond goes from primary to secondary to tertiary. It was also observed that yields of 1-phenylcyclobutanols decreased from 20 to 15 to <5%. These effects parallel the well-documented increase in disproportionation:coupling ratios of free radicals as they change from primary to tertiary.[8] The corresponding decrease in the percentage of elimination may reflect some steric interference in the cleavage reaction of the biradical. The preferred conformation for this reaction must require the four carbon atoms to be coplanar and arranged for maximum overlap between the developing p orbitals and the p orbitals at the radical positions. With phenyl cyclobutyl ketone, in which such overlap is very difficult, the elimination: cyclization ratio has the remarkably low value of 0.40.[9]

The last five ketones in Table I all display high quantum yields no matter what their triplet lifetimes. For the first three, the formation of strong double bonds such as in formaldehyde, styrene, and methyl acrylate might be expected to slightly increase k_s in relation to k_d and k_c. Addition of 0.10 M alcohol or acetic acid to hexane solutions of valerophenone produces almost the same Φ_{II} as obtained with 0.10 M δ-benzoylvaleric acid; moreover, the quantum yield for the keto acid increases with its concentration. Consequently, the relatively high quantum yield for this ketone probably reflects intermolecular hydrogen-bonding effects.[6] The high quantum yield for the methyl δ-benzoylvalerate is not concentration dependent and must be caused by some particularly efficient intramolecular perturbation of the biradical.

In summary, it would appear that the quantum efficiency of type II photoelimination normally is not directly related to triplet-state reactivity for phenyl ketones.[10] Such behavior may well be common to all triplet-state photoreactions which involve biradical intermediates (*e.g.*, cycloadditions, rearrangements).

---

(2) A. A. Lamola and G. S. Hammond, *J. Chem. Phys.*, **43**, 2129 (1965).

(3) The Φ_{II} and $k_q\tau$ values for butyrophenone and valerophenone are lower than originally reported.[4]

(4) P. J. Wagner and G. S. Hammond, *J. Am. Chem. Soc.*, **88**, 1245 (1966).

(5) P. J. Wagner and I. Kochevar, *ibid.*, **90**, 2232 (1968).

(6) P. J. Wagner, *ibid.*, **89**, 5898 (1967).

(7) C. Walling and M. J. Gibian, *ibid.*, **87**, 3361 (1965).

(8) S. W. Benson and W. B. DeMore, *Ann. Rev. Phys. Soc.*, **16**, 412 (1965).

(9) A. Padwa and E. Alexander, *J. Am. Chem. Soc.*, **89**, 6376 (1967).

(10) D. R. Coulson and N. C. Yang, *ibid.*, **88**, 4511 (1966), have reported results consistent with this conclusion for 2-hexanone.

Peter J. Wagner, Allen E. Kemppainen
Department of Chemistry, Michigan State University
East Lansing, Michigan 48723

Received April 18, 1968