(1965).
(27) F. Pietra, *Q. Rev., Chem. Soc.*, **23**, 504 (1969).
(28) (a) J. F. Bunnett and G. T. Davis, *J. Am. Chem. Soc.*, **82**, 665 (1960); (b) J. F. Bunnett and R. H. Garst, *ibid.*, **87**, 3875 (1965); (c) J. A. Orvik and J. F. Bunnett, *ibid.*, **92**, 2417 (1970).
(29) (a) C. F. Bernasconi, *MTP Int. Rev. Sci.: Org. Chem., Ser. One, 1973*, **3**, 33 (1973); (b) C. F. Bernasconi, personal communication.
(30) (a) Z. Rappoport and R. Ta-Shma, *J. Chem. Soc. B*, 871, 1461 (1971); (b) Z. Rappoport and N. Ronen, *J. Chem. Soc., Perkin Trans. 2*, 955 (1972); (c) Z. Rappoport and P. Peled, *ibid.*, 616 (1973).
(31) W. P. Jencks, "Catalysis in Chemistry and Enzymology", McGraw-Hill, New York, N.Y., 1969, p 463.
(32) R. F. Hudson and G. Klopman, *J. Chem. Soc.*, 1062 (1962).
(33) D. N. Kevill, P. H. Daum, and R. Sapre, *J. Chem. Soc., Perkin Trans. 2*, 963 (1975).
(34) W. P. Jencks, *J. Am. Chem. Soc.*, **94**, 4731 (1972).
(35) (a) G. Illuminati, *Adv. Heterocycl. Chem.*, **3**, 285 (1964); (b) Y. Ogata and A. Kawasaki, *J. Chem. Soc. B*, 325 (1971).
(36) H. H. Jaffe, *Chem. Rev.*, **53**, 191 (1953).
(37) For example, see C. A. Grob and G. Cseh, *Helv. Chim. Acta*, **47**, 194 (1974); Z. Rappoport and J. Kaspi, *J. Chem. Soc., Perkin Trans. 2*, 1102 (1972).
(38) D. J. Kroeger and R. Stewart, *J. Chem. Soc. B*, 217 (1970).
(39) Y. Ogata and A. Kawasaki, *J. Org. Chem.*, **39**, 1058 (1974).
(40) Z. Rappoport and D. Ladkani, *Chemica Scripta*, **5**, 124 (1974).
(41) D. D. Perrin, "Dissociation Constants of Organic Bases in Aqueous Solution", Butterworth, London, 1965.
(42) (a) B. Bariou and M. Kerfanto, *C. R. Hebd. Seances Acad. Sci., Ser. A*, **264**, 1134 (1967); (b) M. J. Gregory and T. C. Brulce, *J. Am. Chem. Soc.*, **89**, 4400 (1967).
(43) H. Shenhav, Z. Rappoport, and S. Patai, *J. Chem. Soc. B*, 469 (1970).
(44) R. F. Hudson and G. Loveday, *J. Chem. Soc.*, 1068 (1962).
(45) G. S. Hammond, *J. Am. Chem. Soc.*, **77**, 334 (1955).
(46) O. Rogne, *J. Chem. Soc. B*, 1855 (1971).
(47) E. D. Hughes, C. K. Ingold, S. F. Mok, S. Patai, and Y. Pocker, *J. Chem. Soc.*, 1265 (1957).
(48) H. M. R. Hoffmann, *J. Chem. Soc.*, 6753 (1965).
(49) C. G. Swain and C. B. Scott, *J. Am. Chem. Soc.*, **75**, 246 (1953).
(50) M. L. Bender and J. M. Jones, *J. Org. Chem.*, **27**, 3771 (1962).
(51) H. S. Venkataraman and C. Hinshelwood, *J. Chem. Soc.*, 4977 (1960).
(52) Z. Rappoport and A. Topol, *J. Chem. Soc., Perkin Trans 2*, 1823 (1972); 863 (1975).
(53) J. C. Chalchat, F. Théron, and R. Vessière, *Bull. Soc. Chim. Fr.*, 2501 (1973).
(54) For example, see Z. Rappoport and A. Gal, *J. Am. Chem. Soc.*, **91**, 5246 (1969); Z. Rappoport and Y. Apeloig, **97**, 821 (1975).
(55) O. Wallach and M. Hoffmann, *Chem. Ber.*, **8**, 313 (1875).
(56) K. Nakanishi, "Infrared Absorption Spectroscopy", Holden-Day, San Francisco, Calif., 1962.
(57) H. v. Pechman, *Chem. Ber.*, **28**, 2366 (1895).

Absence of Intramolecular Charge-Transfer Quenching in Photoexcited 4-Benzoylpiperidines[1]

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Abstract: The photochemistry of *N*-methyl- and *N*-benzyl-4-methyl-4-benzoylpiperidine (**1** and **2**) has been compared with that of 1-methyl-1-benzoylcyclohexane (**3**). Like **3**, **1** and **2** undergo competitive α cleavage (yielding benzaldehyde) and cyclization to bicyclo[3.1.1]heptan-6-ols. Sensitization and quenching studies both reveal that **1**, like **3**, forms two kinetically distinct triplets. These are assigned to separate chair conformers with the benzoyl group axial (**1**-a) or equatorial (**1**-e). Low-temperature ^{13}C NMR indicates a **1**-a/**1**-e ratio comparable with that for **3**. **1**-e has the same triplet lifetime as **3**-e and cleaves with the same quantum efficiency. The lack of intramolecular CT quenching in **1**-e indicates that such quenching requires through-space orbital overlap. Triplet decay of **1**-a is 100 times faster than in **3**-a. The enhancement is ascribed to stabilization of the γ-radical site by the nitrogen lone pair.

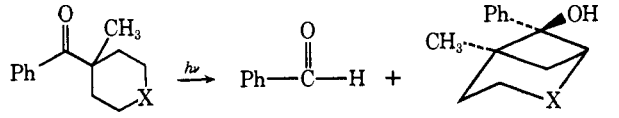
Some years ago we reported rates of intramolecular charge-transfer (CT) quenching of the electronically excited benzoyl group in several α-benzoyl-ω-dialkylaminoalkanes.[2] We assumed that CT quenching occurs in conformations in which the amino group has rotated close enough to the carbonyl for significant overlap of the nitrogen lone-pair orbital with the carbonyl n orbital. Therefore we were surprised to read a major annual review describing our results in terms of through-bond coupling![3] In this case differentiating between through-space and through-bond electronic coupling is far more important than usual because of the kinetics boundary conditions involved. Bimolecular CT quenching of triplet phenyl ketones by tertiary amines occurs at rates close to those of diffusion control.[2,4] Consequently the analogous intramolecular reaction should be rotation controlled provided that through-bond effects are negligible.[5] That is, the rate-determining step for intramolecular quenching may be rotation into proper conformations. Eisenthal was among the first to point out that the rapid intramolecular exciplex formation in an (ω-aminoalkyl) anthracene must be rotationally controlled[6] and picosecond spectroscopists are now well aware of this aspect of kinetics.[7]

If we can demonstrate that CT quenching in amino ketones involves only through-space interactions, then the kinetics of CT quenching in flexible amino ketones will provide valuable information regarding rates of bond rotations in large molecules. Consequently we have investigated the photochemistry of two *N*-alkyl-4-methyl-4-benzoylpiperidines, in which the nitrogen lone pair is fixed some 5–6 Å away from the carbonyl group. We find no evidence for any intramolecular CT quenching in these molecules.

Results

N-Methyl- and *N*-benzyl-4-methyl-4-benzoylpiperidine (**1** and **2**) were prepared as described in the Experimental Section and outlined in Scheme I. Each of these ketones undergoes two

Scheme I



1, X = N–CH_3
2, X = N–CH_2Ph
3, X = CH_2

4, X = N–CH_3
5, X = N–CH_2Ph
6, X = CH_2

competitive photoreactions, as might be anticipated from Lewis' work on the carbocyclic analogue **3**.[8] Benzaldehyde, formed by an α cleavage reaction, was identified by its characteristic odor and gas chromatographic (GC) retention time. No attempt was made to characterize the piperidine fragments which accompany the benzaldehyde. The bicyclic alcohol **4**,

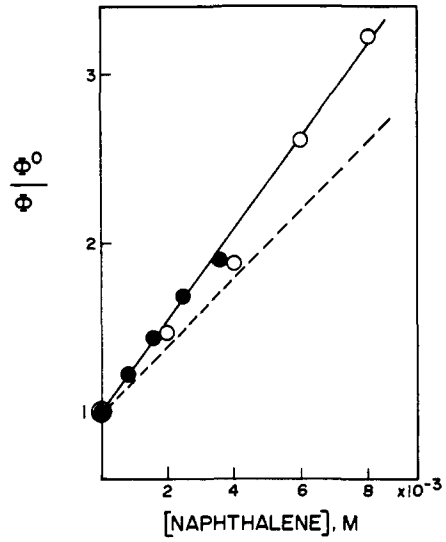


Figure 1. Stern–Volmer quenching of benzaldehyde formation from **1** (○) and **2** (●). Dashed line is reported plot for **3**.

Table I. Quantum Yields for Photoreactions of Ketones **1–3**[a]

Ketone	Solvent	ϕ_I[b]	ϕ_{II}[c]	Φ_{-k}[d]
1	Benzene	0.016	0.017	0.14
1	Benzene/0.01 M RSH[e]	0.06		
1	Benzene/0.04 M RSH	0.16	0.053	0.22
1	Benzene/0.1 M $C_{10}H_8$[f]	0	0.06	0.06
1	Benzene/0.1 M C_5H_5N[g]	0	0.01	0.05
1	Benzene/40% PrOH[h]	0.002	0.015	0.07
2	Benzene/0.02 M RSH	0.16		
3	Benzene/0.01 M RSH	(0.20)		
3	Benzene		(0.045)	
3	Benzene/0.5 M C_5H_5N		0.032	
3	PrOH		(0.18)	

[a] 0.04 M ketone irradiated at 313 nm; values in parentheses from ref 8. [b] Benzaldehyde formation. [c] Bicyclic alcohol formation. [d] Ketone disappearance. [e] *n*-$C_{12}H_{25}SH$. [f] Naphthalene. [g] Pyridine. [h] 1-Propanol.

formed by a type II cyclization, was isolated as a white solid by chromatography of an irradiated benzene solution of **1** and recrystallization from hexane. Its spectroscopic characteristics (see Experimental Section) are completely consistent with the assigned and expected[8] structure. The presence of two *C*-methyl and OH signals in the NMR spectrum indicates a 2:1 ratio of the two possible diastereomers with the *endo*-hydroxy compound drawn above predominating. Compound **5** was not characterized. Alcohol **6**, already reported as a product from **3**,[8] was identified merely by the appearance of a product with the expected GC retention time.

Quantum yields of ketone disappearance and benzaldehyde formation were measured under various conditions for **1–3**; those for bicyclic alcohol formation were measured only for **1** and **3**. In all cases, initial ketone concentration was 0.04 M. A 0.1 M valerophenone actinometer was employed to measure absorbed light intensity.[9] Table I reports the results, which for **3** compare favorably with those already reported.[8] Low concentrations of dodecyl mercaptan maximize benzaldehyde yields by trapping the free radicals.[10] Acetonitrile and 1-propanol enhance the type II quantum yield of **3** but have little effect on the value for **1**. We found that both **1** and **4** are highly reactive toward the radicals formed by α cleavage of triplet **1**. In the absence of mercaptan, material balances are only 20–25%. A host of long-retention-time products elute during high-temperature GC analysis. However, in the presence of

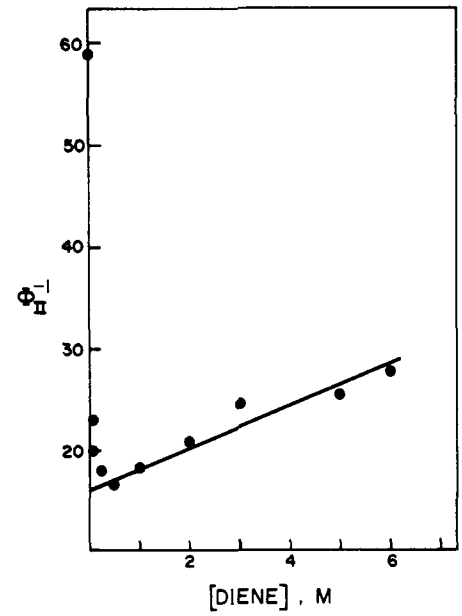


Figure 2. Effect of 2,5-dimethyl-2,4-hexadiene on quantum yield for formation of **4**.

Table II. Quenching Data for Ketones **1–3**[a]

Ketone	Quencher	$h\nu$, nm	$k_q\tau_I$, M^{-1},[b]	$k_q\tau_{II}$, M^{-1},[c]
1	Diene[d]	366		0.2 (0.4)[e]
1-RSH[f]	Naphthalene	366	270	
2-RSH[f]	Naphthalene	366	275	
3[g]	Naphthalene	313	200	29
3	*N*-Methylpiperidine	313	3.3	0.25[h]

[a] 0.04 M ketone in degassed benzene. [b] Quenching of benzaldehyde formation. [c] Quenching of bicyclic alcohol. [d] 2,5-Dimethyl-2,4-hexadiene. [e] Containing 50% 2-propanol. [f] 0.02 M dodecanethiol. [g] Data from ref 8. [h] In CH_3CN.

either 0.04 M mercaptan or 0.1 M naphthalene (which quenches >95% of the α cleavage), benzaldehyde and **4** account for 100% of reacted **1**. In a separate experiment, a degassed benzene solution 0.04 M in **1** and 0.0040 M in **4** was irradiated long enough for 0.0013 M **4** to be formed. Instead of increasing, the concentration of **4** had decreased to 0.0034 M.

Figure 1 compares Stern–Volmer quenching results on benzaldehyde formation for **1–3**. Degassed benzene solutions 0.04 M in ketone were irradiated at 365 nm. In the absence of mercaptan, the plots for **1** and **2** curve downward; addition of 0.02 M mercaptan produces linear plots indistinguishable from each other and only slightly different from that for **3**.

Low concentrations of naphthalene or conjugated dienes *enhance* the quantum yield for formation of **4**, apparently by quenching radical formation and thus preventing the destruction of **4** noted above. Above 1 M 2,5-dimethyl-2,4-hexadiene, the maximum yield of **4** is quenched, albeit very inefficiently. Figure 2 displays a plot of reciprocal quantum yield vs. quencher concentration. Irradiation was at 365 nm to preclude absorption by diene.

Since tertiary amines do quench triplet ketones very rapidly, it is possible that an excited molecule of **1** can be quenched by the amine functionality of another ground-state **1**. Consequently we measured the ability of *N*-methylpiperidine to quench both benzaldehyde formation from **1** and cyclization of **3**. All of the Stern–Volmer slopes are collected in Table II.

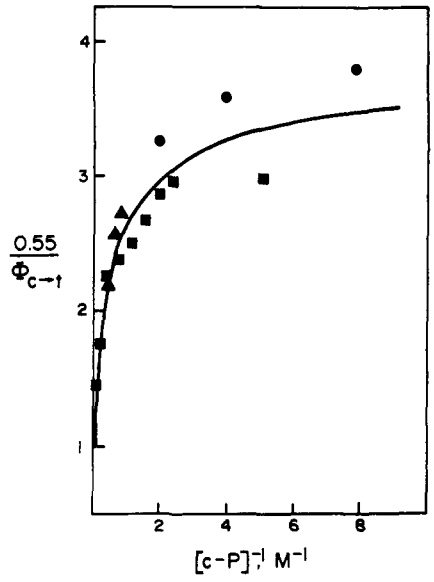


Figure 3. Dependence of the **1**-photosensitized cis-to-trans isomerization efficiency of *cis*-1,3-pentadiene (*c*-P) on *c*-P concentration.

The cis-trans isomerization of 1,3-pentadiene was sensitized with 0.04 M **1**.[11] At concentrations below 0.05 M, diene concentration decreased and radical adducts were apparent by GC analysis. Figure 3 displays the results above 0.20 M diene plotted in the usual[12] double reciprocal fashion. The acetophenone (ϕ_{isc} = 1)[11] sensitized isomerization was employed for actinometry. Results above 1 M pentadiene were corrected for enhanced isomerization.[13] Results were not as readily reproducible as usual, but it is clear that the plot has an initial large slope at high concentrations and curves down to a small slope at low concentrations. Moreover, the high-concentration results extrapolate to an intercept near unity. Such curved sensitization plots indicate the presence of two triplets, one long lived and one short lived.[14] The initial slope of Figure 3 is ~4 M, which indicates a $k_q\tau$ value of ~0.25 M^{-1} for the short-lived triplet. The data are too scattered to accurately measure $k_q\tau$ for the long-lived triplet; we estimate a value (intercept/slope) $\geq$100 M^{-1}.

Like **3**, **1** can exist in two major chair conformations, with the benzoyl group either axial (**1**-a) or equatorial (**1**-e). Low-temperature (−90 °C) ^{1}H NMR spectra of **1** in Freon 11 revealed broadening but no splitting of the *N*-CH_3 and *C*-CH_3 signals. However, the proton-decoupled ^{13}C NMR spectrum of **1** in Freon 12 does reveal both isomers. The carbonyl signal remains a sharp singlet down to −96 °C. Apparently the axial and equatorial carbonyl carbons of **1** coincidentally have the same chemical shift, unlike the situation in **3**.[8] Below −15 °C the *C*-methyl signal splits into two peaks at 19.8 and 28.1 ppm (δ 25.4, >−15 °C); below −50 °C the ring methylenes split into two peaks separated by 2.2 ppm. The *N*-methyl peak does not split even at −96 °C. Figure 4 depicts the observed temperature effects on the 90-MHz ^{13}C spectra of **1**. Comparison of the equilibrium chemical shifts of the *C*-methyl and the methylene signals with those of the separate conformers at −70 °C indicates a 3:1 ratio of the two conformers at *RT*. We presume that **1**-e is favored for the same reasons Lewis concluded that **3**-e is favored.[8]

Discussion

The curved sensitization plot and the totally different efficiencies for quenching the two photoproducts of **1** indicate that **1** forms two kinetically distinct triplets. We conclude that these two triplets correspond to the two chair forms of **1** which, as in **3**,[8] do not interconvert once excited. Type II cyclization

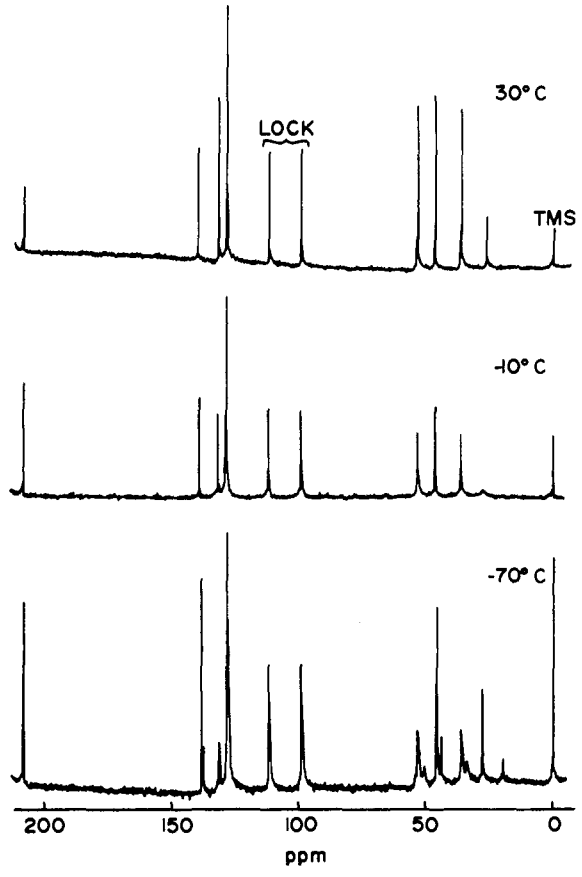
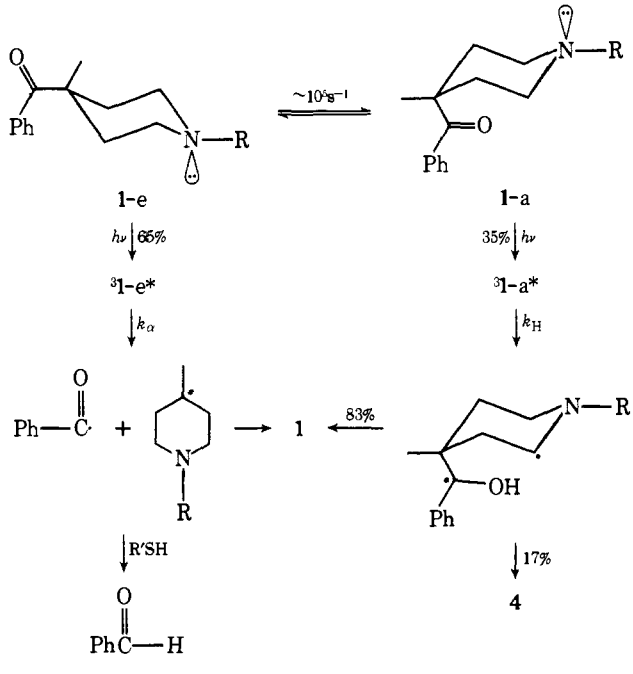


Figure 4. Proton-decoupled ^{13}C NMR spectra of **1** in $CFHCl_2$.

proceeds from **1**-a, while **1**-e undergoes only the much slower α cleavage, as shown in Scheme II. Thus **1** behaves much like

Scheme II



3. However, the very similarity between **1** and **3** allows us to draw several important conclusions regarding intramolecular CT interactions.

First, **1** and **2** are both γ-dialkylamino phenyl ketones. Figure 3 indicates that the quantum yield of intersystem crossing in **1** is close to unity. In the acyclic γ-dimethylaminobutyrophenone (**7**), Φ_{isc} is only 0.50.[2] Therefore we can

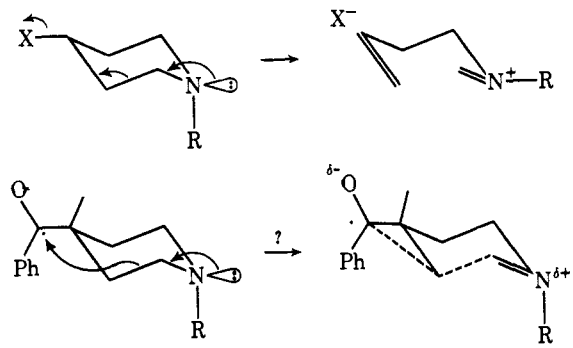
conclude that the process which lowers ϕ_{isc} in amino ketones requires molecular flexibility: presumably significant population of conformers with the amino function close to the carbonyl.

Second, the long-lived triplet of **1** is slightly longer lived than the corresponding triplet of **3**. If any intramolecular CT quenching were occurring in triplet **1**-e, both τ and Φ_{II} would be lower than in **3**. The quantum yield is slightly lower, but a small amount of intermolecular quenching is probably responsible. The ability of *N*-methylpiperidine to quench triplet **3** indicates a k_q value of 6×10^7 M^{-1} s^{-1}. This same value, which is only $1/50$ the value observed for less hindered ketones,[2,4] would presumably hold for **1**. At [**1**] = 0.04 M, intermolecular quenching contributes some 2.4×10^6 s^{-1} to $1/\tau$ for **1**-e, $1/8$ its total value. Energy transfer to **1**-a (irreversible because of the short τ_T for **1**-a) may also occur to a small degree.[8]

With $k_q = 5 \times 10^9$ M^{-1} s^{-1} under our conditions,[15] $1/\tau$ for **1** and **2** equals 1.8×10^7 s^{-1} and k_α equals 1.6×10^7 s^{-1}. This value compares favorably with those reported for pivalophenone,[16] α,α-dimethylvalerophenone,[10] and **3**:[8] 1.1×10^7, 1.3×10^7, and 2.1×10^7 s^{-1}, respectively. The rate constant for any competing CT quenching in triplet **1**-e cannot exceed 2×10^6 s^{-1}. This maximum value is only 0.025% the value of k_{CT} in the acyclic model **7**. Therefore we can conclude that *CT quenching in acyclic γ-amino ketones such as* **7** *occurs, to an extent exceeding 99.9%, solely by through-space interactions.*

In fact, **1** is a good compound in which to find through-bond interactions because of the well-known ability of piperidine lone pairs to participate in Grob fragmentations.[17] Halpern has reported intramolecular interactions in β-amino ketones and one case where the UV spectrum indicates a mixed chromophore.[18] However, the n,π* bands of **1** and **2** resemble that of **3** closely and the ^1L_a λ_{max} at 235 nm is characteristic of phenyl alkyl ketones.[19]

As evident in our low-temperature ^{13}C NMR results and as implied in Scheme II, inversion at nitrogen is faster than and independent of ring inversion in **1**. Although there was considerable uncertainty until recently about the conformational preference of the lone pair vis-a-vis the methyl in *N*-methylpiperidines, it now appears that there is at least a 20:1 preference for equatorial methyl.[20] Even if a through-bond coupling scheme such as shown below were possible, it would have to

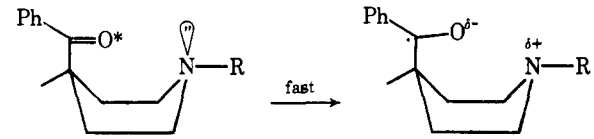


occur from a low equilibrium population of **1**-e with an equatorial lone pair. However, nitrogen inversion is fast enough to continuously populate such a conformer in the triplet lifetime of **1**-e.

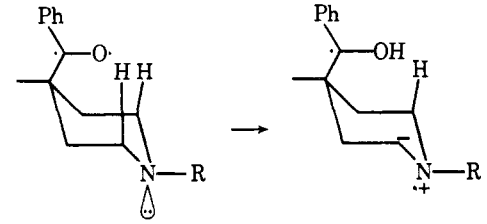
The only significant difference in excited-state behavior between **1** and **3** is the very rapid triplet decay of **1**-a. A $k_q\tau$ value on the order of 0.2 M^{-1} indicates a rate of triplet decay $\sim 2.5 \times 10^{10}$ s^{-1}, some 100 times faster than that observed for **3**-a.[8] Lewis reasonably equated $1/\tau$ with k_H in **3**-a.[8] We tentatively do the same for **1**-a.

Given comparable ground-state populations of the two chief chair conformers in **1** and **3** and a like ratio of extinction coefficients for **1**-a/**1**-e and **3**-a/**3**-e, we would expect comparable cyclization quantum yields for both **1** and **3** if (1) no CT quenching competes in **1**-a, and (2) the diradicals formed by γ-hydrogen abstraction proceed on to product with equal probability for both compounds. The type II quantum yields which we observe for **1** in benzene containing additives which either trap radicals or prevent their formation are, in fact, slightly higher than that reported for **3** in benzene. Unfortunately, the cyclization yield of **1** is lowered by the alcohol solvents which normally raise type II yields.[21] We cannot quantitatively explain this aspect of our results with **1**. The low material balances obtained in samples containing either propanol or pyridine indicate extensive loss of products.

Several other factors suggest very little CT quenching in triplet **1**-a. Protic solvents are known to lower k_{CT} values by an order of magnitude;[2,4] 50% added alcohol has comparable small effects on the $k_q\tau$ measured for **1**-a and on that for valerophenone.[2] Moreover, it is very difficult to visualize how the nitrogen lone pair can overlap appreciably with the carbonyl. Even in the flexible **7**, the measured k_{CT} value is only one-third the $1/\tau$ value of **1**-a. If **1**-a were in a boat conformation, CT interaction should be quite facile. However, only a negligible fraction of **1** molecules would be in a boat conformation when excited.



Although we cannot unequivocally rule out any CT quenching in triplet **1**-a, the slowness of CT quenching in **1**-e suggests that rapid decay of triplet **1**-a involves predominantly another process. The resulting conclusion that $1/\tau = k_H$ makes hydrogen abstraction in **1**-a the fastest yet recorded. Such a rapid rate is not unreasonable for the structure. A value of $k_H \sim 8 \times 10^8$ s^{-1} was measured for **7**,[2] some seven times larger than for triplet valerophenone. The enhancement by a γ heteroatom is expected, since atoms with lone pairs stabilize radicals.[9] In **1**-a, the nitrogen lone pair is trans coplanar to both γ hydrogens, the geometry of maximal conjugative stabilization of both the diradical and the transition state leading to it. Unlike **7**, **1**-a does not have to rotate around the C–N bond to achieve this favored geometry. The additional frozen rotation in **1** should enhance k_H by an order of magnitude.[22] If one multiplies k_H for **3**-a by 70, one gets 1.2×10^{10} s^{-1}, close to our measured value of $1/\tau$.



Finally we note that the extreme lability of the C–H bonds α to nitrogen in **1** may explain the observed destruction of **1** and **4** by radicals produced by α cleavage.

Summary. The similar cleavage quantum yields and triplet lifetimes for **1**-e, **2**-e, and **3**-e indicate that CT quenching is very slow in the benzoylpiperidines. Therefore it can be concluded that intramolecular CT quenching occurs through space and over rather short distances attainable only in flexible molecules.

Experimental Section

Preparation of 1. *N*-4-Dimethyl-4-cyanopiperidine (**8**) was prepared by appropriate modification of the method described by Grob and Renk for synthesis of the 4-propyl homologue.[23] Isonipecotamide (Aldrich, 40 g) in 150 mL of methanol was added to 25 mL of 40%

formalin and stirred for 4 h at room temperature. This mixture was added to Raney nickel (50% suspension in water; dry powder does not work) in a Parr apparatus and hydrogenated at 60 psi at room temperature. Hydrogen uptake ceased after 3 h. The resulting solution was filtered, evaporated, and then titrated with acetone to isolate 34 g (76%) of *N*-methylisonipecotamide **9** as a white solid: mp 193–196 °C (lit.[21] 196–198 °C); IR 3515, 3410, 1650 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.05–1.65 (m, 9 H, CH_2, CH), 2.30 (s, 3 H, N-CH_3), 6.30 (broad s, 2 H, NH_2).

9 (50 g) was added to 300 mL of chloroform, and 200 mL of thionyl chloride was added slowly. The solution was then refluxed until all solids had dissolved. Excess thionyl chloride was evaporated and the remaining brown oil neutralized with ammonium hydroxide. This mixture was extracted with chloroform; the extracts were dried over magnesium sulfate and distilled. A 50% yield was obtained of *N*-methyl-4-cyanopiperidine (**10**) as a colorless oil: bp 100 °C (20 Torr) [lit.[21] 85–88 °C (14 Torr)]; IR 2250 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.85–1.62 (m, 9 H, CH, CH_2), 2.24 (s, 3 H, N-CH_3); MS *m/e* 124, 123, 71, 70, 57.

Sodium sand[24] was prepared by adding 29 g of clean sodium (1.26 g-atom) to 400 mL of xylene and heating to reflux with stirring. The cooled xylene was poured off, and the resulting sand was washed twice with dry benzene. To this sodium was added 150 mL of benzene. The mixture was heated under nitrogen to 40 °C; 9 g of chlorobenzene was then added. After the exothermic reaction had subsided, 50 g more of chlorobenzene (0.5 mol total) was added dropwise over 6 h to the stirred mixture at 30–40 °C. This mixture of phenyl sodium was cooled to 5 °C and 41 g (0.33 mol) of **10** was added. The mixture was stirred 1 h; 65 g (0.40 mol) of methyl iodide was then added, and the mixture was stirred at 8–10 °C for 1 h more. Twelve milliliters of ethanol followed by 200 mL of water were then added. The quenched reaction mixture was filtered through Celite. The water layer was extracted several times with ether; the combined ether extracts were added to the benzene layer, and the whole was dried over magnesium sulfate. The solvent was then distilled off, and the residual oil was dissolved in ether. HCl gas was bubbled into the solution until no further precipitation occurred. The resulting **8**–HCl was recrystallized twice from 2-propanol, yielding 43 g (75%) of a white salt, mp 223–226 °C. Free **8** was regenerated by treating the salt with aqueous base and extracting into ether: IR 2240 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.38 (s, 3 H, C-CH_3), 2.17 (s, 3 H, N-CH_3), 2.90–1.38 (m, 8 H, CH_2); MS *m/e* 138, 137, 96, 71, 70, 57, 43.

8 (30 g) was added to $\frac{2}{3}$ mol phenyl magnesium bromide previously prepared in ether. The mixture was refluxed 8 h after which 50% aqueous sodium hydroxide was added until refluxing ceased. The separated aqueous layer was extracted with chloroform. The extract was added to the ether layer. The combined organic solvents were distilled off after the solution had first been dried over magnesium sulfate. The residual imine of **1** was dissolved in 7 N HCl and heated on a steam bath for 1 h. The solution was then neutralized with ammonium hydroxide and extracted with ether. The ether was dried and distilled off. The crude **1** (35 g, 75%) was dissolved in ether; HCl gas was bubbled in until precipitation ceased. **1**-HCl was recrystallized twice from 50:50 methanol–butanone, mp 217–219 °C. Free **1** was obtained as needed by neutralizing an aqueous solution of **1**-HCl with sodium hydroxide, extraction into ether, drying, evaporation of solvent, and vacuum drying: IR 1690 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.40 (s, 3 H, C-CH_3), 2.20 (s, 3 H, N-CH_3), 2.62–1.40 (m, 8 H, CH_2), 7.80–7.37 (m, 5 H, benzoyl); ^{13}C NMR ($CFHCl_2$) δ 25.4 (C-CH_3), 35.9 (C_3), 46.0 (C_4), 46.2 (N-CH_3), 53.0 (C_2), 128.1, 128.4, 131.1, 139.4 (phenyl), 208.5 (C=O); MS *m/e* 217, 202, 112, 105, 77, 71, 70; UV (EtOH) 318 nm (130), 275 (660), 235 (14 000).

Preparation of 2. *N*-Benzyl-4-methyl-4-cyanopiperidine (**11**) was prepared as reported by Kuhnis and Denss.[25] Isonipecotamide (50 g, 0.4 mol) in 285 mL of 3-pentanone was heated to reflux. To the boiling solution were added 66 g of sodium carbonate and a pinch of potassium iodide. Benzyl bromide (67 g, 0.4 mol) was added dropwise, and the mixture was refluxed 4 h. The solution was filtered while hot, and the solids were washed several times with hot acetone. The combined liquids were cooled, and solid *N*-benzylisonipecotamide **12** (72 g, 85%) was collected as a white solid, mp 145–147 °C, by evaporating off the ketone solvents and recrystallizing twice from ethanol–ether: IR 3515, 3410, 1650; ^1H NMR (CCl_4) δ 3.47 (s, 2 H, benzylic CH_2), 3.13–1.63 (m, 9 H, piperidine ring), 5.82 (s, 2 H, NH_2), 7.33 (s, 5 H, phenyl).

The amide **12** was reacted with thionyl chloride as described for **9** → **10** to yield *N*-benzyl-4-cyanopiperidine **13**: bp 138 °C (0.05 Torr); IR 2240 cm^{-1}; ^1H NMR (CCl_4) δ 2.90–1.60 (m, 9 H, piperidine ring), 3.47 (s, 2 H, benzylic CH_2), 7.33 (s, 5 H, phenyl).

Bromobenzene (39 g, 0.25 mol) and 1 g of lithium metal (0.25 g-atom) were refluxed for 2.5 h in 400 mL of ether; then 61 g of triphenylmethane (0.25 mol) dissolved in 250 mL of 1,2-dimethoxyethane was added, and the mixture was stirred for 20 min. The solution was cooled in an ice–salt bath, and 50 g (0.25 mol) of **13** was added slowly. The resulting solution was stirred 10 min and then 36 g of methyl iodide (0.25 mol) was added. After another 1.5 h of stirring, the solution was quenched with 25 mL of water. The organic solvents were evaporated off. The aqueous solution was extracted several times with ether; the combined ether extracts were in turn extracted four times with 4 N HCl. The combined acidic extracts were neutralized with ammonium hydroxide and then extracted with chloroform. The solution was dried and flash distilled, leaving 20 g (37%) of crude *N*-benzyl-4-methyl-4-cyanopiperidine (**11**). **11**–HCl was prepared as usual and recrystallized twice from 2-propanol, mp 288 °C. For neutral **11**, IR 2240 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.30 (s, 3 H, CH_3), 2.98–1.40 (m, 8 H, ring CH_2), 3.43 (s, 2 H, benzylic CH_2), 7.30 (s, 5 H, phenyl).

Ketone **2** was then prepared by reacting **11** with phenyl magnesium bromide as in **8** → **1**. The yield of **2**–HCl, which was recrystallized twice from methanol–butanone, was 70%, mp 185 °C. Free **2** was prepared as needed by neutralizing the salt and distilling: bp 175 °C (0.03 Torr); IR 1680 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.32 (s, 3 H, CH_3), 2.65–1.40 (m, 8 H, ring CH_2), 3.30 (s, 2 H, benzylic CH_2), 7.18 (s, 5 H, benzyl), 7.42 (m, 5 H, benzoyl); MS *m/e* 293, 278, 202, 188, 147, 146, 123, 105, 91, 77; UV (heptane) 315 nm (120), 275 (700), 235 (14 500).

Preparation of 3. Cyclohexanecarboxamide was prepared as described by Baumgarten.[26] It was converted to the nitrile by reluxing for 16 h in chloroform–thionyl chloride. Crude nitrile was collected by distillation (bp 95–97 °C) at water aspirator pressure. The nitrile was reacted with phenyl sodium at 5 °C as above and then with methyl iodide. After workup, 1-methylcyclohexylcarbonitrile was collected in 50% yield. Addition of phenyl magnesium bromide to this nitrile and the usual workup yielded 50% of crude **3**. The ketone was purified by recrystallizing its oxime from ethanol, yielding white needles, mp 146 °C. Pure **3** was regenerated by refluxing the oxime with 2 N HCl for 2 h, extraction into ether, and distillation: bp 97–100 °C (0.08 Torr); IR 1675 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.32 (s, 3 H, CH_3), 2.50–1.00 (m, 10 H, ring CH_2), 7.80–7.17 (m, 5 H, benzoyl); MS *m/e* 202, 105, 97, 81, 77, 55.

Photochemical Preparation of 2,5-Dimethyl-6-phenyl-2-azabicyclo[3.1.1]heptan-6-ol (4). 1 (3 g) was dissolved in benzene containing 0.1 M naphthalene. The solution filled a photolysis cell fitted with a nitrogen bubbler, magnetic stirrer, and water-cooled vycor immersion well containing a Hanovia 450-W mercury lamp. After 24 h irradiation, the benzene was distilled off and the residual oil was dissolved in a minimum volume of 50:50 benzene–hexane. This material was chromatographed on neutral alumina, with benzene–hexane as eluent. One fraction yielded 2 g of a yellow oil which had the GC retention time of the only photoproduct. A small portion of this oil was added to ether and precipitated as the HCl salt, mp 180 °C after two recrystallizations from 2-butanone. The major portion of the oil was allowed to sit in a few milliliters of hexane for several weeks, after which time it crystallized. It was recrystallized from hexane, yielding colorless crystals of **4**: mp 80 °C; IR 3425, 1470 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.25, 1.33 (each s, 2:1, total 3 H, C-CH_3), 2.10 (s, 3 H, N-CH_3), 2.60–1.50 (m, 7 H, CH, CH_2), 3.27, 3.35 (each s, 2:1, total 1 H, OH), 7.35 (s, 5 H, phenyl); MS *m/e* 217, 202, 199, 162, 110, 105, 77, 71, 70.

Other Chemicals. Benzene was purified by treatment with first sulfuric acid and then base. It was then dried and distilled from P_2O_5. Propanol was distilled from sodium. Alkane internal standards were vacuum distilled. Naphthalene was recrystallized three times from ethanol. 1-Methylnaphthalene (Aldrich) and *cis*-1,3-pentadiene (Chemical Samples Co.) were used as received. 2,5-Dimethyl-2,4-hexadiene was allowed to sublime in the refrigerator. *N*-Methylpiperidine was distilled before use. Valerophenone and acetophenone were available from previous studies.

Procedures. Samples were prepared, degassed, irradiated, and analyzed by GC as in our previous studies.[2] Dodecane was employed as internal standard to monitor benzaldehyde formation; octadecane or heptadecane for disappearance of **1** and **3** and for appearance of

4 and 6. Benzaldehyde formation was monitored at 100 °C on a 12 ft × ⅛ in. column containing 4% QF-1 and 1% Carbowax 20 M on 60/80 Chromosorb G. Formation of 6 was monitored on the same column at 150 °C. The formation of 4 and disappearance of ketones were monitored at 110–130 °C on a 3 ft × ⅛ in. column containing 5% SE-30 on Chromosorb W.

All IR spectra were recorded on a Perkin-Elmer 237 B spectrometer with either neat samples or Nujol films and were calibrated against polystyrene. ^{1}H NMR spectra were recorded on a Varian T-60 spectrometer. Mass spectra were recorded on a Hitachi-Perkin-Elmer RMU-6 mass spectrometer, with 70 V ionizing voltage. UV spectra were recorded on a Unicam SP800 or Cary 14 instrument. ^{13}C NMR spectra were measured by Dr. R. C. Schoening on a Brucker HFX-10 spectrometer set at 22.6 MHz with the usual Fourier Transform and broad band proton decoupling methods. Freon 21 solutions containing 40% 1 by volume were held in a 10-mm diameter sample tube containing a thermometer.

References and Notes

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(2) P. J. Wagner, T. Jellinck, and A. E. Kemppainen, *J. Am. Chem. Soc.*, **94**, 7512 (1972).
(3) W. M. Horspool, *Photochemistry*, **4**, 455 (1973).
(4) S. G. Cohen, A. Parola, and G. H. Parsons, *Chem. Rev.*, **73**, 141 (1973).
(5) (a) P. Avouris, J. Kordas, and M. A. El-Bayoumi, *Chem. Phys. Lett.*, **26**, 373 (1974); (b) Y.-C. Wang and H. Morawetz, *J. Am. Chem. Soc.*, **98**, 3611 (1976).
(6) T. J. Chuang, R. J. Cox, and K. B. Eisenthal, *J. Am. Chem. Soc.*, **96**, 6828 (1974).
(7) E. Lippert in "Organic Molecular Photophysics", Vol. 2, J. B. Birks, Ed., Wiley, London, 1975, p 1.
(8) F. D. Lewis, R. W. Johnson, and D. E. Johnson, *J. Am. Chem. Soc.*, **96**, 6090 (1974).
(9) P. J. Wagner and A. E. Kemppainen, *J. Am. Chem. Soc.*, **94**, 7495 (1972).
(10) (a) P. J. Wagner and J. M. McGrath, *J. Am. Chem. Soc.*, **94**, 3849 (1972); (b) F. D. Lewis and J. G. Magyar, *ibid.*, **95**, 5973 (1973).
(11) A. A. Lamola and G. S. Hammond, *J. Chem. Phys.*, **43**, 2129 (1965).
(12) P. J. Wagner in "Creation and Detection of the Excited State", Vol. 1A, A. A. Lamola, Ed., Marcel Dekker, New York, N.Y., 1971, p 173.
(13) (a) R. Hurley and A. C. Testa, *J. Am. Chem. Soc.*, **92**, 211 (1970); (b) J. Saltiel, D. E. Townsend, and A. Sykes, *ibid.*, **95**, 5968 (1973).
(14) P. J. Wagner and C.-P. Chen, *J. Am. Chem. Soc.*, **98**, 239 (1976).
(15) (a) P. J. Wagner and I. Kochevar, *J. Am. Chem. Soc.*, **90**, 2232 (1968); (b) W. D. K. Clark, A. D. Litt, and C. Steel, *ibid.*, **91**, 5412 (1969); (c) G. Porter and M. R. Topp, *Proc. R. Soc. London, Ser. A*, **315**, 163 (1970).
(16) F. D. Lewis and J. G. Magyar, *J. Org. Chem.*, **37**, 2102 (1972).
(17) C. A. Grob, *Angew. Chem., Int. Ed. Engl.*, **8**, 535 (1969).
(18) A. M. Halpern and A. L. Lyons, Jr., *J. Am. Chem. Soc.*, **98**, 3242 (1976).
(19) H. Suzuki, "Electronic Absorption Spectra and Geometry of Organic Molecules", Academic Press, New York, N.Y., 1967, p 446.
(20) E. L. Eliel and F. W. Vierhapper, *J. Am. Chem. Soc.*, **97**, 2424 (1975).
(21) P. J. Wagner, I. Kochevar, and A. E. Kemppainen, *J. Am. Chem. Soc.*, **94**, 7489 (1972).
(22) F. D. Lewis, R. W. Johnson, and D. R. Kory, *J. Am. Chem. Soc.*, **96**, 6100 (1974).
(23) C. A. Grob and E. Renk, *Helv. Chim. Acta*, **37**, 1672 (1954).
(24) G. Ehrhart, *Chem. Ber.*, **96**, 2042 (1963).
(25) H. H. Kuhnis and R. Denss, U.S. Patent 3 551 431 (1970).
(26) H. E. Baumgarten, F. A. Bower, and T. T. Okamoto, *J. Am. Chem. Soc.*, **79**, 3148 (1957).

Mechanistic Aspects of the Wolff–Kishner Reaction. 7.[1] The W–K Reaction of Benzophenone Hydrazone in Dimethyl Sulfoxide

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Abstract: The kinetics and activation parameters of the W–K reaction of benzophenone hydrazone were determined in absolute Me_2SO in the presence of potassium *tert*-butoxide, sodium dimsyl, and other base catalysts. Results are presented concerning the solvation of hydrazones by Me_2SO, their ionization to hydrazone anions, and the roles of protic and basic solvents in the W–K reaction are elucidated. Also, the kinetics of the homogeneous W–K reaction in Me_2SO is compared with the heterogeneous reaction described in the literature[2] and with the conventional W–K reaction in hydroxylic solvents.

Introduction

The report of Cram, Sahyun, and Knox[2] concerning the room-temperature W–K reaction of benzophenone hydrazone (I) in a mixture of Me_2SO and potassium *tert*-butoxide (II) prompted a detailed study of the process under the reported and related experimental conditions. In the course of this study it became necessary to examine the role of protic and basic reagents that can be present in the reaction mixture.

Results and Discussion

Repetition of the experiments described by Cram and coworkers[2] revealed that one is dealing with a heterogeneous mixture of I, II, and Me_2SO, and this condition is obviously unsuitable for the determination of the kinetics and of the activation parameters of the W–K reaction. However, larger volumes of Me_2SO did give homogeneous solutions of I and II, but then it was found that the use of rigorously dried Me_2SO and of a large molar excess of freshly sublimed II converted I to its corresponding anion, and this process was accomplished by a very sluggish W–K reaction. Because of the very slow W–K reaction under these experimental conditions, it was possible to examine the spectrum of the anion of I and to demonstrate that it exhibited a characteristic maximum at 393 nm. The addition of solutions of sodium dimsyl to I gave identical results. The use of a 100-fold excess of II produced satisfactory Beer–Lambert plots for the hydrazone anion derived from I, as well as for those derived from the *p,p'*-dimethoxy- and *p,p'*-dichlorobenzophenone hydrazones (Figures 1 and 2). The maxima of the latter anions were located at 375 and 404 nm, respectively, in accord with the expected effect of these substituents on the excitation energies in delocalized anions. The molar absorptivities of the three hydrazone anions were found to be 24 000, 20 300, and 26 700, respectively, and were calculated on the assumption that the hydrazones were completely ionized in a 100-fold excess of base.

Attempts to determine the equilibrium constant for the ionization of I to its corresponding anion were only partially successful because of the sensitivity of the solutions to atmospheric oxygen and moisture. The latter caused a deterioration