Lifetimes of Simple Ketocarbenes

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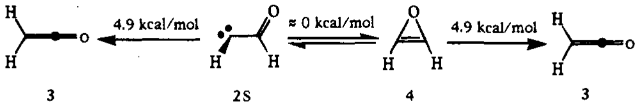
Received December 2, 1994

Decomposition of α-diazoketones (**1**, Scheme 1) readily produces ketocarbenes (**2**) and ketenes (**3**, Scheme 1) which can be intercepted with typical traps.[1,2] Oxirene species have also been implicated as intemediaries on the basis of labeling studies,[3] and evidence for dimethyloxirene has been obtained in cryogenic matrices.[4]

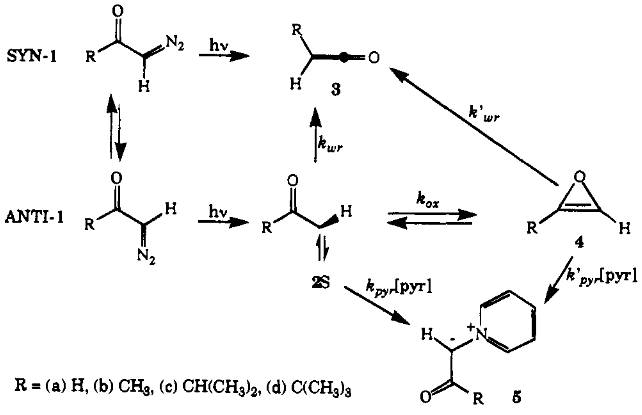
Kaplan, Meloy, and Mitchell have reported convincing evidence that the photochemistry of α-diazoketones is highly dependent on their conformation.[5] Photolysis of the *syn* isomer is believed to lead directly to ketene and nitrogen, whereas photolysis of the *anti* isomer releases carbene and nitrogen which can subsequently isomerize to ketene (**3**) or oxirene (**4**) or react with external trapping agents. Increasing steric bulk of the substituent R (Scheme 1) leads to a decrease in the extent of the *anti* conformer at equilibrium and a decrease in the yield of carbene. These rules are widely used, but other interpretations have been advanced.[6]

Scott *et al.* have recently calculated the ketocarbene–ketene–oxirene potential surface at several levels of *ab initio* theory.[7] They conclude that there is little or no energy barrier separating carbene and oxirene **2S** and **4** but that both species must pass over a barrier of 4.9 kcal/mol to form ketene (**3**).



The singlet carbene is predicted to be nonplanar.[7] It is presumed that the ground state of the carbene has triplet spin multiplicity, as certain substituted ketocarbenes have been detected by matrix EPR spectroscopy. The triplet carbenes are thought to be planar because EPR spectroscopy indicates that many carbonyl-substituted carbenes exist in two rotomeric forms (*syn* and *anti*).[8]

Scheme 1



Herein we report our studies of ketocarbenes by laser flash photolysis (LFP) techniques.[9] Our findings are consistent with the Kaplan–Meloy–Mitchell[5] rules, but we find no evidence for significant (>3–4 kcal/mol) barriers protecting ketocarbenes from rearrangement. Our experiments neither implicate nor disqualify oxirene (**4**) as an intermediate.

LFP of diazoketones **1a–d** in alkanes, acetonitrile, or Freon solvents produces no UV–vis active transient species. LFP in the presence of pyridine produces transients (Figure 1) whose yield (A_y) is a function of pyridine concentration (Figure 1, inset). Transient spectra were also observed upon LFP of **1** in neat acetone (supplementary material). The transients are assigned to pyridine and acetone ylides, respectively, by analogy to our studies of other carbenes.[10,11] These ylides can, in principle, be derived from capture of either a carbene or an oxirene (Scheme 1).

When [pyridine] exceeds ~2 M, the yield of ylide (A_y) is saturated, and every trappable intermediate generated in the laser

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(11) In principle, one may be concerned that it is ketene **3** that is reacting with pyridine. These same issues arose in the study of carbethoxycarbene (Toscano, J. P.; Platz, M. S.; Nikolaev, V.; Popic, V. *J. Am. Chem. Soc.* **1994**, *116*, 1165; **1994**, *116*, 8146). Although small ring and aryl ketenes react with pyridine to give UV–vis active ylides [(a) Boate, D. R.; Johnston, L. J.; Kwong, P. C.; Lee-Ruff, E.; Scaiano, J. C. *J. Am. Chem. Soc.* **1990**, *112*, 8858. (b) Barra, M.; Fisher, T. A.; Cerniglìaro, G. J.; Sinta, R.; Scaiano, J. C. *J. Am. Chem. Soc.* **1992**, *114*, 2630. (c) Andraos, J.; Chiang, Y.; Huang, C.-G.; Kresge, A. J.; Scaiano, J. C. *J. Am. Chem. Soc.* **1993**, *115*, 10605], simple ketenes apparently do not. Furthermore, the trappable intermediates of this work are too short lived to be ketenes, and ketene is not expected to react with acetone to form UV–vis active ylides.

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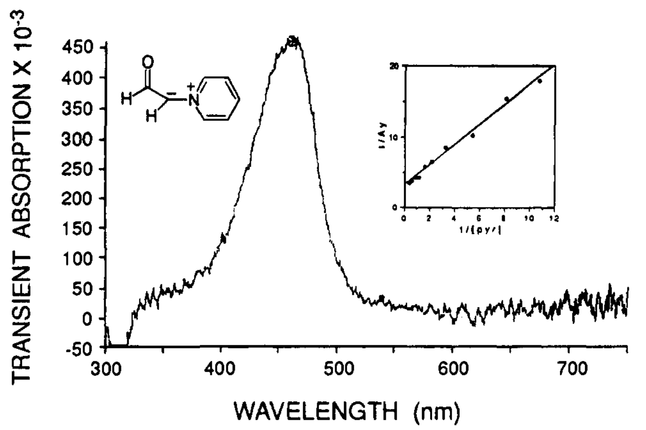

Figure 1. Transient spectrum of ylide **5a** produced by LFP (308 nm, 17 ns) of **1a** in Freon-113 containing 0.84 M pyridine at ambient temperature. The spectrum was recorded 50 ns after the laser flash over a window of 400 ns. Inset: double reciprocal treatment of the yield of ylide (A_y) versus [pyridine].

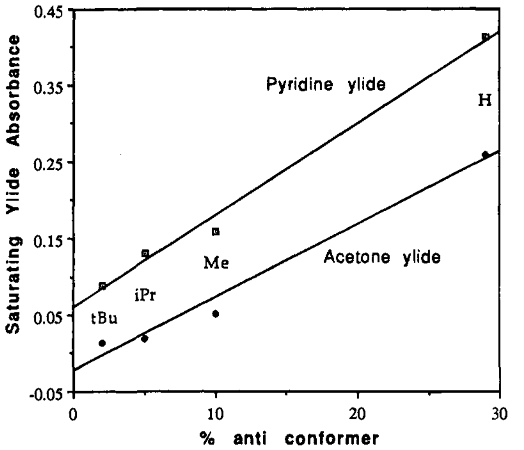

Figure 2. Plot of the yield of ylide (saturating [pyridine] or in neat acetone) produced by LFP versus the equilibrium concentration of the *anti* conformation of diazo precursor deduced by NMR.

pulse is captured ($A_y = A_y^\infty$, [pyridine] > 2 M). A plot of A_y^∞ for either the pyridine or acetone ylides versus percent *anti* conformation of precursor at equilibrium (Figure 2) shows a clear relationship consistent with the predictions of Kaplan, Meloy, and Mitchell.[5] Of course, this analysis assumes that the ylide extinction coefficient does not vary significantly with the R group. We believe that this assumption is well-founded since the ylide absorption maximum is constant within each series.

Standard[12] double reciprocal analysis of A_y as a function of [pyridine] (Figure 1, inset) yields estimates (Table 1) of the lifetimes of the trappable intermediate. These lifetimes are deduced on the basis of two assumptions: that k_{pyr} ($k_{pyr'}$, Scheme 1) = (1−5) × 10^9 M^{-1} s^{-1}, as per other carbenes,[10,12] and that the singlet ketocarbenes have not relaxed to the presumably lower energy triplet states.[8] Product studies have shown that this second assumption is clearly valid in the case of carboethoxycarbene and bis(carbomethoxy)carbene.[2a,13] The lifetimes we deduce are about 10 times longer than that of the planar singlet ketocarbene derived from 2-diazo-1-naphthoquinone, a precursor that is rigidly held in the *syn* conformation.[14]

The lifetime of the trappable species produced upon LFP of **1a–d** is the same in cyclohexane and in cyclohexane-d_{12} at ambient temperature. This demonstrates that the lifetimes of the trappable species produced under these conditions is controlled by the rate of an intramolecular rearrangement rather than by its reaction with solvent. The carbene lifetime appears to be slightly longer in Freon and slightly shorter in acetonitrile than in cyclohexane. This may reflect small solvent variation in k_{wr}, k_{ox}, k_{pyr}, or two of these rate constants.[15]

Table 1. Deduced Lifetime of Ketocarbenes at Ambient Temperature[a]

ketocarbene	solvent	lifetime (ns)
2a	Freon-113[b]	2.3−0.5
	cyclohexane	1.0−0.2
	cyclohexane-d_{12}	1.2−0.2
	acetonitrile	0.2−0.04
2b	Freon-113[b]	1.2−0.2
	cyclohexane	1.4−0.3
	cyclohexane-d_{12}	1.4−0.3
	acetonitrile	0.2−0.04
2c	Freon-113[b]	0.9−0.2
	cyclohexane	0.8−0.2
	cyclohexane-d_{12}	0.8−0.2
2d	Freon-113[b]	0.7−0.1
	cyclohexane	2.1−0.4
	cyclohexane-d_{12}	2.2−0.4

[a] Assuming k_{pyr} = (1−5) × 10^9 M^{-1} s^{-1} and that intersystem crossing is slower than trapping of the singlet carbene. [b] CCl_2FCF_2Cl.

The value $k_{pyr}\tau$ was determined by LFP methods for **1a** as a function of temperature (from −26 to 20 °C) in pentane. Analysis of product mixtures following photolysis at −25 °C reveals that very little heptanal type product is formed (<3%), consistent with intramolecular rather than intermolecular decay of this carbene in pentane. If the Arrhenius *A* factor and the activation energy (E_a) for ketocarbene reaction with pyridine are comparable ($E_a \pm 1$ kcal/mol) to those of phenylchlorocarbene ($A = 10^{9.7}$ M^{-1} s^{-1}; $E_a = 1.3$ kcal/mol),[16] then we estimate that an activation barrier of approximately 2.3 ± 1 kcal/mol (with an *A* factor of $10^{10.2}$ M^{-1} s^{-1}) protects the reactive intermediate from rearrangement.

These experiments were also repeated in Freon-113, where solvent reaction should be even less important than in pentane. For this solvent, we deduce, as before, $E_a = 2.0 \pm 1$ kcal/mol and $A = 10^{10}$ M^{-1} s^{-1}.

If theory correctly predicts the rapid isomerization of **2S** and **4**, then the barrier to Wolff rearrangement of one or both of these species is somewhat less than 4.9 kcal/mol ($1/\tau = k_{wr} + k_{wr'}$).[17] We prefer this interpretation even though it requires that hydrogen and alkyl groups have the same migratory aptitudes at ambient temperature. Thus, if tunneling is responsible for an activation energy smaller than predicted by theory, it must involve heavy atom motion of the carbene and carbonyl carbons rather than the R group in Scheme 1.

However, another interpretation is possible which states that carbene **2S** is the sole trappable species produced upon LFP and that its lifetime is controlled by cyclization ($1/\tau = k_{ox}$). If this is true, then the barrier to interconversion of **2S** and **4** must be larger than predicted by theory. Experiments are in progress to distinguish these possibilities.

Acknowledgment. Support of this work by the NSF (CHE-8814950) is gratefully acknowledged. J.P.T. gratefully acknowledges NIH postdoctoral fellowship support. We also thank Dean E. Rende for assistance with low-temperature NMR experiments.

Supplementary Material Available: Figure showing the transient spectrum produced by LFP (351 nm, 17 ns) of **1a** in neat acetone (1 page). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, can be ordered from the ACS, and can be downloaded from the Internet; see any current masthead page for ordering information and Internet access instructions.

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(17) If **2S** and **4** are rapidly interconverting relative to the rate of Wolff rearrangement, the kinetic analysis does not depend on whether it is **2S**, **4**, or both species that are reacting with pyridine.