A laser flash photolysis study of *p*-tolyl(trifluoromethyl)carbene

Atnaf Admasu,[a] **Anna D. Gudmundsdóttir,**[a] **Matthew S. Platz,**[*,a]
David S. Watt,[*,b] **Stephan Kwiatkowski**[b] **and Peter J. Crocker**[b]

[a] *Department of Chemistry, The Ohio State University, 100 W. 18th Avenue, Columbus, Ohio 43210, USA*
[b] *Department of Chemistry, The University of Kentucky, Lexington, Kentucky 40506, USA*

3-*p*-Tolyl-3-trifluoromethyldiazirine was studied by laser flash photolysis (LFP) to obtain the absolute kinetics of *p*-tolyl(trifluoromethyl)carbene 1. The absolute rate constants for the reactions of 1 with pyridine, ketones and quenchers of biological interest were obtained. The implications of the data for photoaffinity labeling experiments are discussed.

I. Introduction

As detailed elsewhere in this issue, Paul Dowd made extremely important contributions to the study of biradicals.[1] In these species, issues of spin multiplicity are of paramount importance. The same issues dominate any discussion of carbene chemistry and are discussed at length in this paper. It is a privilege to be able to dedicate this paper to the memory of an outstanding physical organic chemist.

Photoaffinity labeling is a widely used tool in biochemistry for identifying the binding sites of biological receptors.[2] Using this technique, a light-sensitive moiety is appended to a ligand of a biological molecule. Upon photolysis of the enzyme–ligand complex, a highly reactive intermediate, such as a carbene, is released. In an ideal experiment, the carbene will react with the first bond of the biomolecule that it encounters, even an unactivated CH bond. Furthermore, it is important that the newly created bond be sufficiently robust to survive analysis and/or partial degradation of the labeled biomolecule.[3]

3,3-Disubstituted diazirines are widely used in this regard[3] because their syntheses are straightforward.[4] Aryl(trifluoromethyl)diazirines are particularly popular reagents because the trifluoromethyl group is not prone to the rearrangements that plague the excited states of alkyl diazirines[5] and alkyl carbenes[6] (Scheme 1). The absence of these rearrangements
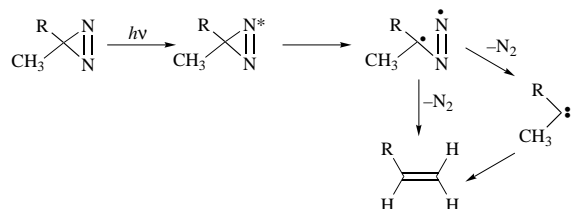
Scheme 1

dramatically increases the efficiency of photoaffinity labeling experiments. Fluorine does not migrate as readily as hydrogen because of the greater strength of the CF bond relative to the CH bond.[7] Despite the widespread use of 3-trifluoromethyldiazirines in photolabeling,[3] few mechanistic details of their photochemistry and no information on the kinetics of trifluoromethylcarbenes are available. This study was undertaken to measure the absolute rate constants of *p*-tolyl(trifluoromethyl)carbene 1 in solution (*via* diazirine 2).
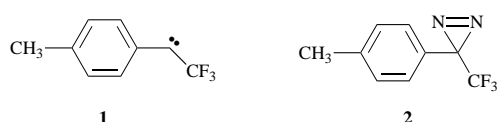
II. Results

Low temperature EPR spectroscopy
A solution of diazirine **2** in perfluoro-2-*n*-butyltetrahydrofuran was cooled to −196 °C and photolyzed with 350 nm radiation from a Rayonet Reactor. The photolysis generated new signals at 2300, 4600 and 6000 G that are typical for an arylcarbene. A free radical signal was detected at 3250 G. The triplet EPR spectrum was analyzed to yield zero field parameters: $|D/hc| = 0.5215$ cm^{-1} and $|E/hc| = 0.0305$ cm^{-1}. These parameters are comparable to those of triplet phenylcarbene:[8] $|D/hc| = 0.5098$ cm^{-1}, $|E/hc| = 0.0249$ cm^{-1}; and methylphenylcarbene: $|D/hc| = 0.4957$ cm^{-1}, $|E/hc| = 0.0265$ cm^{-1}.[9] Thus, the observed spectrum is assigned to ^{3}**1** which has either a ground triplet state or a triplet state within a few kcal mol^{-1} of the ground state.

Chemical analysis of photolysis mixtures
Photolysis of **2** in cyclohexane cleanly produces the product of formal C–H insertion, 1-(4-tolyl)-2,2,2-trifluoroethylcyclohexane (**3**). Conspicuous by their absence are products **4** and **5**
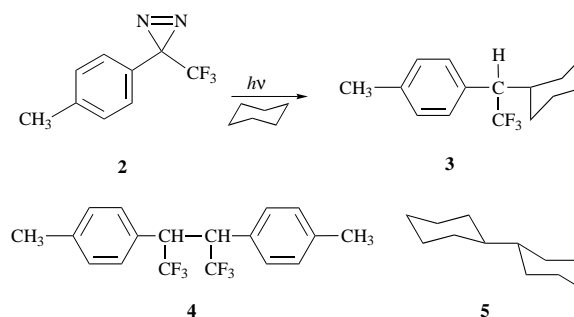
derived from radical–radical coupling. Thus, the product analysis observed upon photolysis of **2** in cyclohexane is consistent with singlet carbene insertion into an unactivated C–H bond. Although the triplet is the ground state of the carbene, its chemistry is not observed in this solvent.

Singlet carbene ^{1}**1** can also be trapped with benzene to form **6**, with methanol to form **7**, or with acetone to form **8**, after
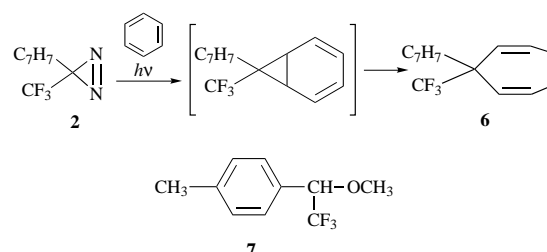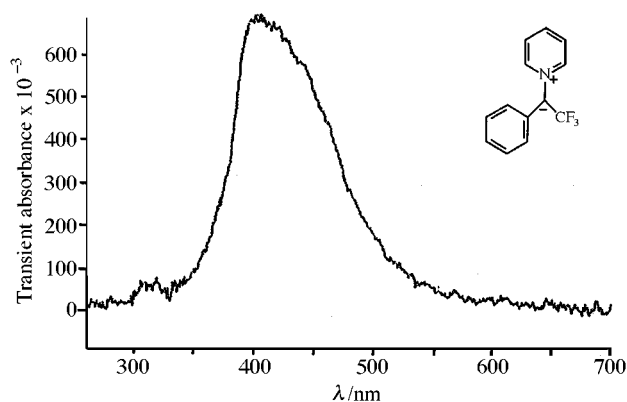
Fig. 1 The transient spectrum of ylide **10** produced by LFP of diazirine **2** in pentane containing pyridine
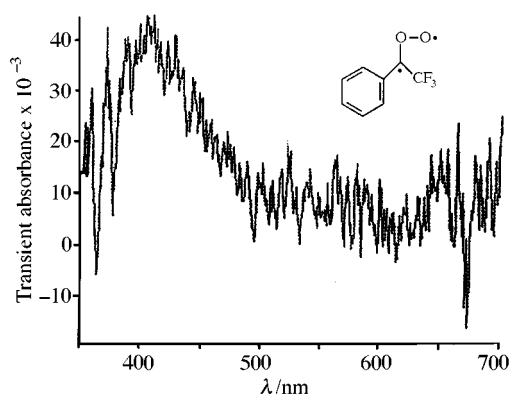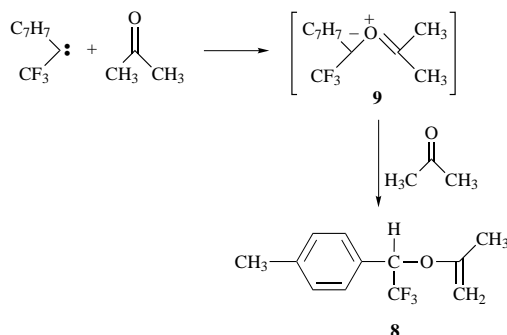

Fig. 2 The transient spectrum of carbonyl oxide **11** in pentane containing oxygen


reaction of ylide intermediate **9** with a second molecule of ketone.[10]

Triplet carbene derived products were not observed in these solvents upon photolysis of **2**. These results are highly reminiscent of phenylcarbene, another species with a triplet ground state which reacts predominantly through its low lying singlet state.[11]

Laser flash photolysis studies

LFP (XeCl, 308 nm, 150 mJ, 17 ns) of 3-*p*-tolyl-3-trifluoromethyldiazirine (**2**) in *n*-pentane does not produce any significant transient absorption. In hexafluorobenzene, a small transient is observed at 321 nm which likely[12] is carbene ³**1** in its triplet ground state, but it is too weak to be of use in dynamical studies. However, LFP of diazirine **2** in pentane containing pyridine produces an intense transient spectrum attributed to ylide **10** (Fig. 1).
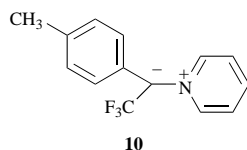

EPR spectroscopy indicated a triplet ground state for this carbene and raised the immediate question of whether or not the singlet state of the carbene (¹**1**) was intercepted prior to relaxation to the triplet ground state (³**1**) (Scheme 2). The fact that oxygen, a specific quencher of triplet carbene, completely quenched the yield of pyridine ylide demonstrated that ¹**1** and ³**1** had equilibrated completely on the timescales of these experiments. In this regard, carbene **1** resembles other carbenes such as diphenylcarbene, phenylcarbene and 1-phenylethylidene.[11–14]

The transient carbonyl oxide **11** formed by reaction of ³**1** with oxygen can be detected upon LFP of diazirine **2** in pentane (Fig. 2) or dichloromethane in the presence of oxygen.

The formation of pyridine ylide **10** was resolved in CH$_2$ClCFCl$_2$ but not in pentane even when diazirine **2** was excited with a 0.15 ns Nd/YAG laser (355 nm, 35 mJ). Ylide **10** is

Scheme 2

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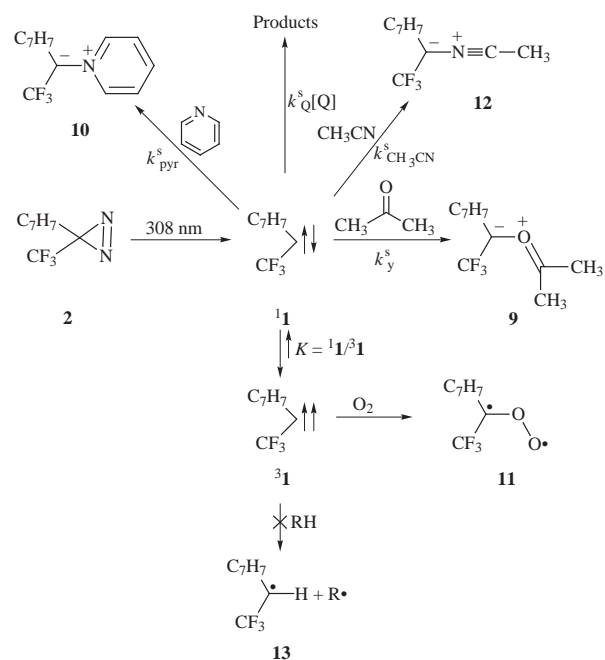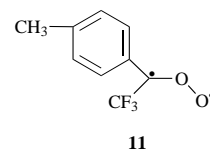
formed in an exponential process which can be analyzed to obtain k_{obs}, the observed rate constant of ylide formation. The observed rate constant can be related to the carbene lifetime (τ), eqn. (1),[15] where k_{pyr} is the absolute rate constant of reaction of

$$k_{obs} = 1/\tau + k_{pyr}[\text{pyr}] \qquad (1)$$

the spin equilibrated carbene with pyridine. As predicted from eqn. (1) a plot of k_{obs} *versus* the concentration of pyridine ([pyr]) is linear (Fig. 3). In Freon-113 at ambient temperature, $k_{pyr} = 4 \times 10^8 \text{ M}^{-1} \text{ s}^{-1}$ and $\tau = 190$ ns.

The transient spectrum of nitrile ylide **12** is observed upon LFP of **2** in acetonitrile (Fig. 4). The transient spectrum of

12
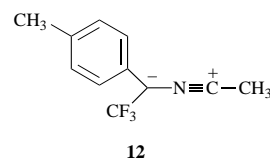
Fig. 3 A plot of k_{obs} of the formation of pyridine ylide **10**, following LFP of **2**, in Freon-113 at ambient temperature

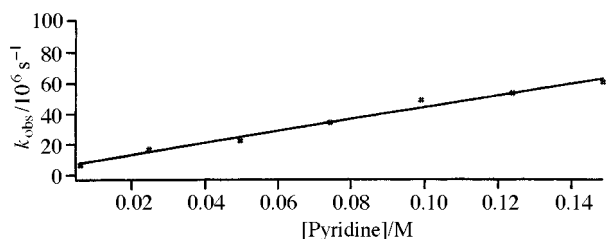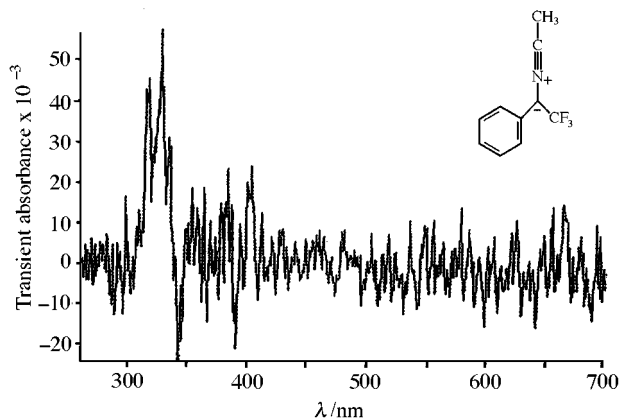**Fig. 4** The transient spectrum of ylide **12** in CH_3CN

[$^2H_3$]**12**, produced by LFP of **2** in CD_3CN, is more than twice as intense as that of ylide **12**. This demonstrates that the carbene inserts into the CH bond of acetonitrile in competition with ylide formation. The isotope effect in the reaction with the CH/CD bond of the solvent is ≈2. The magnitude of the kinetic isotope effect (KIE) suggests that it is ^{1}**1** rather than ^{3}**1** which is reacting with solvent as the isotope effect to bond insertion of singlet phenylcarbene and singlet 1-naphthylcarbene with cyclohexane is also 1.9–2.0.[16] This conclusion is also consistent with the fact that there is no evidence for the formation of radical **13** (Scheme 2) upon LFP of diazirine **2** in pentane

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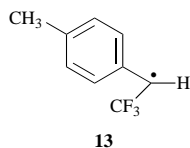
or acetonitrile. A benzylic radical of this type would be expected to have a strong absorbance around 312 nm.[17] These findings are completely consistent with the product analysis of photolysis mixtures of **2** in cyclohexane, as discussed previously.

It is possible to resolve the formation of **12** upon LFP (Nd/YAG, 355 nm, 0.15 ns) of **2** in neat acetonitrile (Fig. 5). Analysis of the exponential rise of **12** reveals that the lifetime of **1** in neat acetonitrile is 2 ns at ambient temperature. Given that intersystem crossing (ISC) rate constants[18] of arylcarbenes are 10^{9-10} s^{-1}, spin equilibration of singlet and triplet **1** seems assured in this solvent.

To verify the lifetime in acetonitrile, the formation of **12** was monitored in Freon-113. The observed rate constant of formation of **12** was linearly dependent on the concentration of acetonitrile (Fig. 6). The lifetime of **1** in Freon-113 is found to be 162 ns, in good agreement with the earlier work with pyridine. The lifetime of phenylcarbene under these conditions is about 200 ns.[19] The absolute rate constant of spin-equilibrated carbene with acetonitrile is 3.4×10^7 M^{-1} s^{-1}. As neat acetonitrile is 19.2 M, τ can be predicted to be 1.5 ns, in neat acetonitrile, in excellent agreement with the direct measurement.
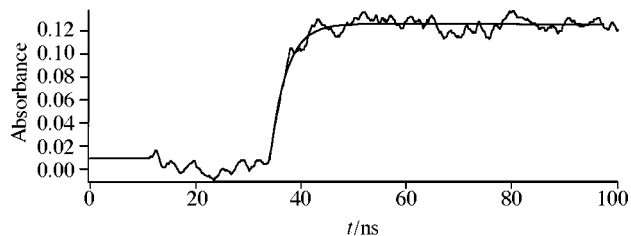

Fig. 5 The formation of ylide **12** following LFP of **2** in neat CH_3CN at ambient temperature
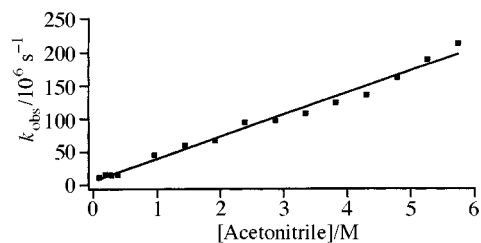

Fig. 6 A plot of k_{obs} of the formation of acetonitrile ylide **12**, following LFP of **2**, in Freon-113 at ambient temperature
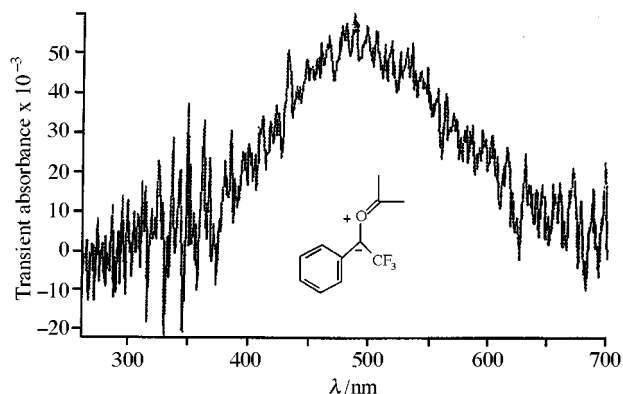

Fig. 7 The transient spectrum of ylide **9** in C_6F_6 containing acetone

It is customary to assume that it is the singlet state of the carbene which is trapped by pyridine or acetonitrile to form ylides **10** and **12**. Thus, under the conditions of rapid equilibrium (Scheme 2), k_{pyr} can be related to equilibrium constant K as shown in eqn. (2), where k_{pyr}^s is the absolute rate constant

$$k_{pyr} = k_{pyr}^s K \qquad (2)$$

of reaction of singlet **1** with pyridine. This quantity is likely in the range $1-5 \times 10^9$ M^{-1} s^{-1} thus $K = 0.08-0.4$ at 293 K. This corresponds to a singlet–triplet gap (ΔG_{ST}) of 0.5 to 1.5 kcal mol^{-1}.[20] This is slightly smaller than the calculated singlet–triplet gap of phenylcarbene (4 kcal mol^{-1})[21] and the value estimated by similar types of experiment (2.3 kcal mol^{-1}).[19] It is possible, of course, that ground state triplet **1** reacts directly with pyridine by a surface-crossing mechanism.[22] Thus, ΔG_{ST} in these experiments measures the accessibility of the singlet surface and not necessarily the vertical separation of singlet and triplet states. These issues were first addressed by Dowd and Chow in their classic study of trimethylenemethane.[23]

Particularly intense ylide spectra are generated upon LFP of **2** in hexafluorobenzene containing ketones (Fig. 7, Table 1). The combination of growth and decay of the transient absorption of ylides (*e.g.* **9**) were easily resolved in hexafluorobenzene solution containing a ketone (Fig. 8).
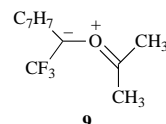

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Table 1 The transient absorption maxima of ylides formed from carbene **1**

Solvent	Carbene trap	Ylide	λ_{max}/nm
CH_3CN	CH_3CN	**12**	325
CD_3CN	CD_3CN	$[^2H_3]$**12**	326
CH_2Cl_2	O_2	**11**	390
C_5H_{12}	O_2	**11**	403
C_5H_{12}	Pyridine	**10**	410
C_6F_6	Acetone	**9**	485
C_6F_6	Cyclopentanone	**14**	464
C_6F_6	Cyclobutanone	**15**	460
C_6F_6	2-Norcamphor	**16**	464
C_6F_6	Camphor	**17**	472
C_6F_6	Trimethylacetaldehyde	**18**	407

Table 2 The absolute rate constant of reaction of carbene **1** with ketones at ambient temperature in hexafluorobenzene

Quencher	Ylide	$k_y^s K$/M^{-1} s^{-1}
Acetone	**9**	1.7×10^8
Cyclopentanone	**14**	1.5×10^8
Cyclobutanone	**15**	5.5×10^8
Norcamphor	**16**	9.8×10^8
Camphor	**17**	3.2×10^8
Trimethylacetaldehyde	**18**	8.2×10^8

Table 3 The absolute rate constants of reaction of carbonyl ylides with ketones in hexafluorobenzene

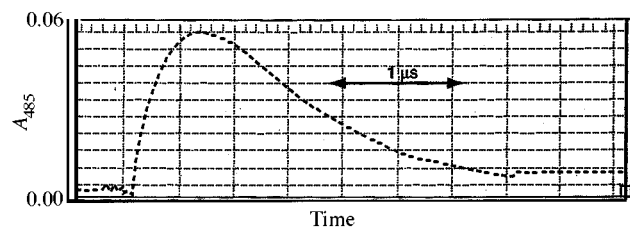| Ylide	Ketone	k_{KET}/M^{-1} s^{-1}
9	Acetone	1.8×10^8
14	Cyclopentanone	1.5×10^8
15	Cyclobutanone	4.8×10^7
16	Norcamphor	8.0×10^7
17	Camphor	3.2×10^7
18	Trimethylacetaldehyde	1.6×10^6

Fig. 8 The growth and decay of ylide **9** produced by LFP of diazirine **2** in hexafluorobenzene containing acetone

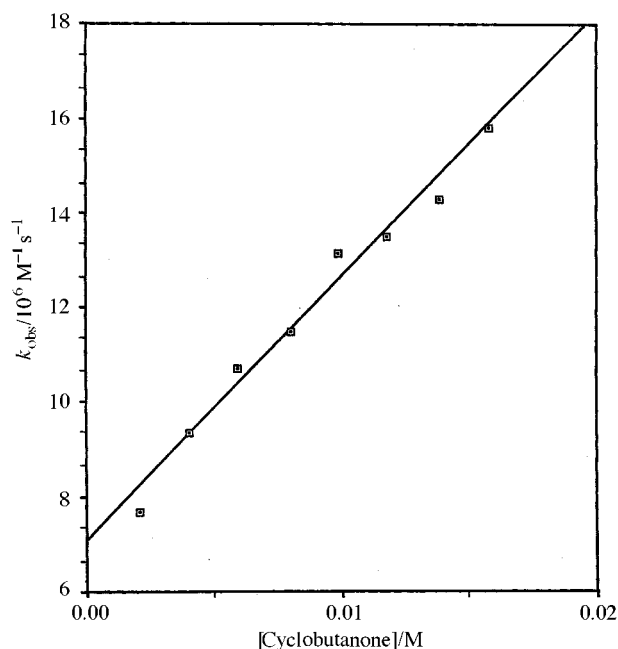**Fig. 9** A plot of the observed rate of formation of carbene–cyclobutanone ylide as a function of [cyclobutanone]
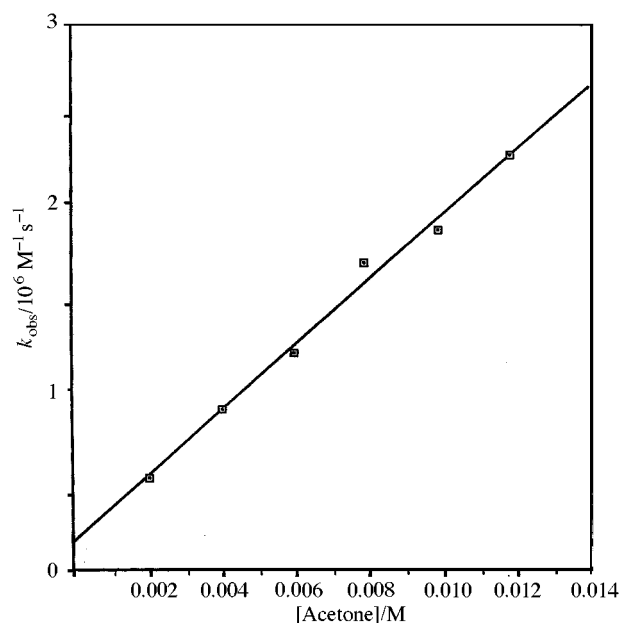
Fig. 10 A plot of the observed rate of decay of ylide **9** in hexafluorobenzene as a function of [acetone]

Both the rates of formation and decay of ylide **9** are linearly dependent on the concentration of ketone (Figs. 9 and 10, respectively). The slope of Fig. 9 is equal to $k_y^s K$ where k_y^s and K are defined in Scheme 2. Values of $k_y^s K$ for several ketones are given in Table 2. As k_y^s must be less than or equal to the rate of a diffusion-controlled process (10^{10} M^{-1} s^{-1}), the equilibrium constant K must be bracketed as $0.1 \leq k < 1.0$. This again demonstrates that the singlet–triplet gap in carbene **1** is extremely small, as per phenylcarbene.[19,21]

The intercept of the plot of Fig. 9 is $1/\tau$, where $\tau = 150$ ns is the lifetime of **1** in hexafluorobenzene in the absence of acetone. The lifetime of **1** in hexafluorobenzene is comparable to that of other carbenes such as fluorenylidene (80 ns).[24]

A plot of the rate of decay of ylide **9** *versus* [ketone] has slope equal to k_{KET} (Scheme 3), the absolute rate constant for reaction of the ylide with acetone. Values of k_{KET} are given in Table

3. The intercept of this plot is the inverse of the lifetime of ketone-ylide **9** in the absence of ketone.

It was possible to isolate compound **8** upon preparative photolysis of **2** in acetone. We speculate that **8** is formed in the reaction shown in Scheme 3. This is consistent with the observed isotope effect ($k_H/k_D = 9$) to the decay of **9** in the presence of $(CD_3)_2CO$ and the fact that the reaction of the carbene-
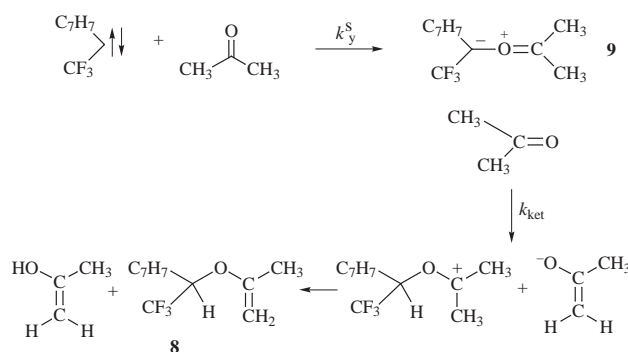
Scheme 3

Table 4 The absolute rate constant of reaction of spin-equilibrated carbene **1**, with quenchers of biological interest at ambient temperature in acetonitrile [a,b] (see Scheme 4)

Quencher	$k_Q\tau$ [a]	$k_Q^s K/\mathrm{s}^{-1}$
H_2O	0.62	3.1×10^8
CH_3OH	0.46	2.3×10^8
$CH_3(CH_2)_3NH_2$	0.74	3.7×10^8
Et_2NH	3.00	1.5×10^8
CH_3SCH_3	2.56	1.3×10^8
$CH_3(CH_2)_7SH$	33	17×10^9
CH_3SSCH_3	45	23×10^{10}
C_6H_{12}	6.2	3.1×10^9
C_6H_6	8.7	4.4×10^9
$CH_3CONHCN_3$	0.30	0.15×10^7
$CH_3CON(CH_3)_2$	0.61	0.30×10^8

[a] $\tau = 2$ ns in neat acetonitrile. [b] [pyr] = 1.236 M.

Fig. 11 Stern–Volmer treatment of the quenching of the yield of carbene acetonitrile ylide with methanol in acetonitrile solvent at 20 °C
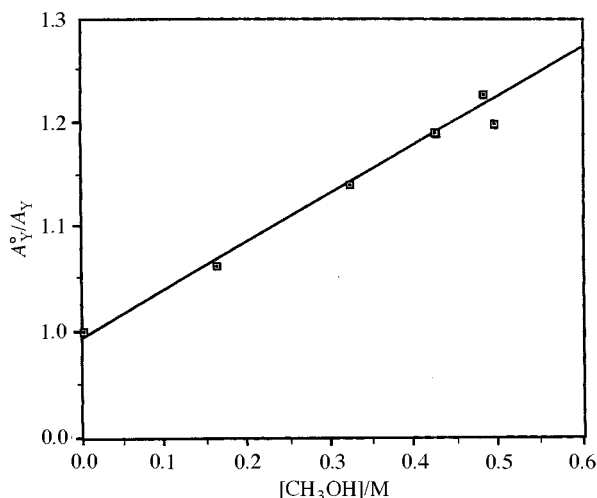
trimethylacetaldehyde ylide **18** with the hindered aldehyde, which lacks alpha protons, is particularly slow (Table 3). Many carbonyl ylides are known which readily react with carbonyl compounds.[10] Other carbonyl ylides are known whose lifetimes are controlled by the rate of cyclization to form an epoxide. These lifetimes are also in the order of a few microseconds.[25]

Stern–Volmer quenching studies

As mentioned previously, LFP of **2** in neat acetonitrile produces ylide **12**. The yield of ylide (A_y°) is reduced to (A_y) upon LFP of diazirine **2** in the presence of a competitive carbene quencher (Scheme 4). A Stern–Volmer treatment of the quenching data is linear (Fig. 11) with slope $k_Q\tau$ where τ is 2 ns and k_Q is the absolute rate constant of spin equilibrated carbene with quencher. As before, $k_Q = k_Q^s K$.[20]

It is clear from Table 4 that *p*-tolyl(trifluoromethyl)carbene reacts rapidly with a wide variety of functional groups and thereby meets the requirements of a valuable photoaffinity labeling reagent. Although **1** will be scavenged by water, this carbene reacts ten times more rapidly with the unactivated CH bonds of cyclohexane than with the OH bond in water. In fact, carbene **1** reacts with dimethylformamide (a model of a peptide bond) and water with about equal rates. Carbene **1** reacts with free amino groups and with benzene. Thus, lysine, tryptophan and tyrosine residues should all be labeled with carbene **1**. *p*-Tolyl(trifluoromethyl)carbene reacts most rapidly with traps containing sulfur; therefore, this carbene scavenges for cysteine and cystine. It is unclear whether these ylide adducts lead to stable products useful in photoaffinity labeling.
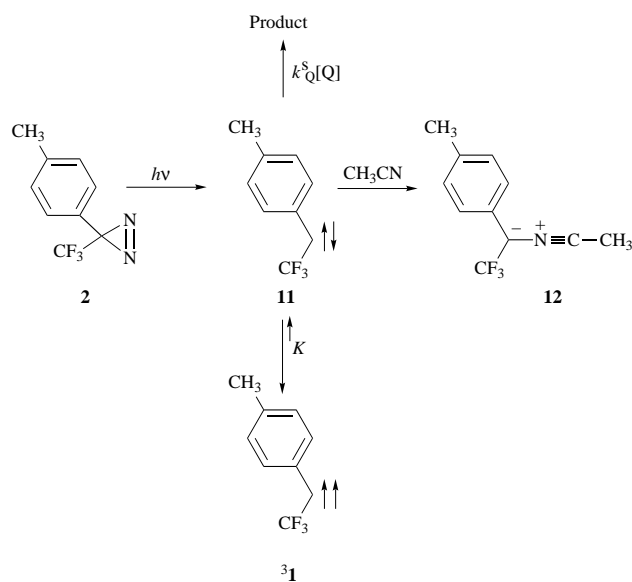
Scheme 4

Conclusions

p-Tolyl(trifluoromethyl)carbene **1** has been shown to have a triplet ground state by low temperature EPR spectroscopy. Chemical trapping studies reveal, however, that this carbene reacts primarily through its low-lying singlet state. Laser flash photolysis studies demonstrate that **1** reacts with pyridine, acetonitrile, oxygen and ketones to form spectroscopically detectable ylides. The lifetime of spin equilibrated **1** in neat acetonitrile is 2 ns. The absolute rate constants of reaction of spin-equilibrated **1** with pyridine and acetonitrile, in Freon-113 at ambient temperature, are 4×10^8 M^{-1} s^{-1} and 3.4×10^7 M^{-1} s^{-1}, respectively. The singlet–triplet gap of **1** is 0.5–1.5 kcal mol^{-1}. Stern–Volmer quenching studies demonstrate that carbene **1** reacts rapidly with functional groups commonly encountered in photoaffinity labeling experiments and reacts most rapidly with sulfur-containing residues.

Experimental

General
Melting points were taken with an Electrothermal capillary melting point apparatus and are uncorrected. ^{1}H NMR spectra were recorded with a Bruker AM-200 (200 MHz) or Varian AM-250 (250 MHz) instrument. ^{1}H and ^{13}C NMR shifts are reported in units of ppm relative to tetramethylsilane (0 ppm). Infrared spectra were recorded on a Perkin-Elmer model 1710 infrared Fourier transform spectrometer and are given in cm^{-1}. UV–VIS spectra were taken using a Perkin-Elmer Lambda 3B UV–VIS Spectrophotometer and recorded on a Perkin-Elmer 3700 data station or a Hewlett-Packard 8452A diode array spectrophotometer interfaced with an IBM portable personal computer. Gas chromatograph–Fourier transform infrared–mass spectra were taken on a Hewlett-Packard 5890 gas chromatograph with infrared and mass detection. Gas chromatography was performed on a Perkin-Elmer 8500 gas chromatograph with a flame ionization detector using a 30 m × 0.254 mm column (DB-1). Preparatory gas chromatography was performed on a Varian Aerograph Series 1400 with a thermal conductivity detector using 5% SE-30 GC, W-HP 80/100 and 5% OV-17, W-HP 80/100 columns.

Tetrahydrofuran, benzene, hexafluorobenzene and toluene were purified by distillation from sodium–benzophenone. Acetonitrile and methylene chloride were purified by being shaken over 4 Å molecular sieves and distilled from calcium hydride. Methanol and ethanol were distilled from sodium metal. Pyridine was distilled from barium oxide and stored over

potassium hydroxide pellets. Triethylamine and diethylamine were purified by distillation over barium oxide and stored over potassium carbonate. Olefinic quenchers were purified by distillation and stored over 4 Å sieves. All solvent distillations were performed under a dry nitrogen atmosphere. Deuterated solvents and other solvents were purchased from Aldrich and used as received. Diazirine **2** was prepared as described previously.[26]

EPR measurements

EPR measurements were made with a Varian E-112 X-band EPR spectrometer. Carbene spectra were obtained at 10 mW of microwave power. All samples were prepared in 4 mm Suprasil quartz sample tubes. Samples of 15 mmol were sealed under vacuum after three freeze–thaw cycles to remove traces of oxygen and photolyzed for 3–5 min using 300 or 350 nm lamps. Samples were stored in liquid nitrogen between measurements.

Laser flash photolysis studies

The laser flash photolysis apparatus for transient absorption and kinetic studies consisted of a Lumonics TE-816-4 excimer laser (351 nm or 249 nm) or a Lambda Physik LPX-100 excimer laser (308 nm) or an Nd:YAG laser (Continuum PY62 C-10, 150 ps, 355 nm).[26] Stock solutions of the photolabile carbene precursors were prepared in the solvents of interest. Hexafluorobenzene, acetonitrile, [^{2}H$_3$]acetonitrile and pentane were commonly used as solvents. Pyridine and various nitrile solvents were used as ylide-forming carbene traps. The concentration of each solution of carbene precursor was adjusted to an absorbance of 0.6–1.0 at 351, 308 or 249 nm depending upon which laser pulse was employed.

The solutions of samples to be studied by laser flash photolysis were contained in quartz cells for excitation at either 308 nm or 249 nm. For excitation at 351 nm the samples were contained in Pyrex cells. The cells were fitted with rubber septa, and the samples were degassed by bubbling with dry, oxygen-free nitrogen for three minutes. The sample cells were then irradiated at ambient temperature with laser pulses that impinged on the sample at a right angle to a Xe arc lamp monitoring beam. The monitoring beam was focused on a 1/4 meter grating monochromatometer (Oriel 77200) that was selected to be the wavelength of interest. Signals were obtained and converted into a digitized form by a Tektronix 7912 transient digitzer. These signals were finally transformed and analyzed by means of a Macintosh computer.[27]

Transient absorption spectra were obtained using an EG and G Princeton Allied Research model 1460 optical multichannel analyzer (OMA). The three laser systems (351 nm, 308 nm and 249 nm) were used as excitation sources. In a typical OMA experiment, a cell containing a solution of carbene precursor and/or any additional reagent (usually ylide trap) was placed in the path of the laser pulse and xenon arc beam, and four backgrounds (no laser pulse) and three active laser pulse signals in an alternating manner were collected with the OMA. The average spectrum was recorded and the most favorable transient absorption obtained from this spectrum was used as a monitoring wavelength in the subsequent kinetic studies.

During time resolved kinetic studies, two types of measurement were conducted. These were direct measurement of a rate constant and Stern–Volmer quenching. In a typical direct measurement, an aliquot of fixed volume of a stock solution of the carbene precursor was syringed into a given number of laser cells. The required ylide-forming reagent was then added in successively larger increments to each cell. Each cell was capped with a septum, degassed and pulsed with laser radiation, and the data were recorded.

In a typical Stern–Volmer quenching experiment, the samples were prepared in a number of cells by adding a fixed amount of stock solution and a constant volume of ylide-forming reagent. To these solutions, a known amount of the quencher of interest was added in successively larger increments to each cell. The quencher concentration in each sample was calculated based on the amount present in the total volume of the solution. The capped, degassed cell was pulsed with laser irradiation, and the data were recorded.

Product studies

Product studies were performed as follows: solutions of photolabile carbene precursors (0.015 M) were placed in 4 mm Pyrex tubing which had been thoroughly washed with ammonium hydroxide and dried prior to use. Solvents used in these studies were purchased from Aldrich (99+%) and were used without further purification. Deuterated solvents were 99.5% atom purity. The samples were sealed under vacuum after three freeze–thaw cycles and photolyzed for 30–120 min using four Rayonet RPR-3500 lamps (3500 Å) in a home-built photochemical reactor. When the photolysis was complete, the sealed tube was opened, and 0.10 ml of acrylonitrile was added to remove residual diazo precursor. The samples were allowed to stand in the dark for two hours prior to analysis to allow for complete reaction with acrylonitrile.

Gas chromatographic analysis of product mixtures was accomplished using a Perkin-Elmer 8500 gas chromatograph equipped with a flame ionization detector and a 30 m × 0.254 mm column (DB-1). Typical chromatography times were 60–120 min over a temperature range of 70–225 °C. Products of the photolysis mixture were isolated in their pure state from some of the reaction mixtures either by use of a Varian Series 1400 preparatory gas chromatograph or by preparatory thin layer chromatograph (prep-TLC). In both product isolation methods, the reaction mixtures were concentrated by pumping off most of the solvent prior to injection into the prep-GC or application to the prep-TLC plates.

Product assignments were made on the basis of mass spectra data obtained with a Hewlett-Packard 5890 GC/IR/MS. Those reaction products which were isolated were characterized by their ^{1}H NMR, ^{13}C NMR or ^{19}F NMR spectra and by their mass spectra.

8: Photolysis product of 3-(4-tolyl)-3-trifluoromethyldiazirine in neat acetone. m/z 230 (M$^+$, 2%), 210 (10), 173 (100), 123 (60); δ_H(200 MHz; CDCl$_3$) 7.15–7.35 (m, 4 H), 5.15 (q, *J* 7 Hz, 1 H), 3.95 (d, *J* 1 Hz, 1 H), 3.75 (d, *J* 1 Hz, 1 H), 2.35 (s, 3 H, *p*-CH$_3$), 1.95 (s, 3 H); δ_F(250 MHz; CDCl$_3$) −78.0; δ_C(50 MHz; CDCl$_3$) 158.0, 140.0, 132.0, 128.0, 125.0, 121.0, 85.0, 77.0 (m, buried under the CDCl$_3$ triplet) 21.0, 20.0.

6: Photolysis product of 3-(4-tolyl)-3-trifluoromethyldiazirine in neat benzene. m/z 250 (M$^+$, 70), 181 (100), 165 (85); δ_H(200 MHz; CDCl$_3$) 7.2 (d, *J* 7 Hz, 2 H), 6.95 (d, *J* 7 Hz, 2 H), 6.45 (m, 2 H), 6.35 (m, 2 H), 5.75 (d, *J* 7 Hz, 2 H), 2.35 (s, 3 H); δ_F(250 MHz; CDCl$_3$) −75.6; δ_C(50 MHz; CDCl$_3$) 138.0, 132.0, 130.0, 129.0, 127.0, 126.0, 125.0, 117.0 (s), 53.0 (t, *J* 21 Hz), 21.0 (s).

3: Photolysis product of 3-(4-tolyl)-3-trifluoromethyldiazirine in neat cyclohexane. m/z 256 (M$^+$, 55), 174 (65), 83 (100), 55 (85); δ_H(200 MHz; CDCl$_3$) 7.15 (s, 4 H), 3.04 (quintet, *J* 7 Hz, 1 H), 2.35 (2, 3 H), 2.1–0.8 (m, 11 H); δ_F(250 MHz; CDCl$_3$) −64.6; δ_C(50 MHz; CDCl$_3$) 138.0, 132.0, 129.0, 125.0 (s), 56.0 (q, *J* 21 Hz), 39.0, 31.5, 30.5, 25.6, 21.0 (s).

7: Photolysis product of 3-(4-tolyl)-3-trifluoromethyldiazirine in neat methanol. m/z 204 (M$^+$, 14), 173 (6), 135 (100), 91 (31); δ_H(200 MHz; CDCl$_3$) 7.35 (d, *J* 8 Hz, 2 H), 7.20 (d, *J* 8 Hz, 2 H), 4.50 (q, *J* 7 Hz, 1 H), 3.40 (s, 3 H), 2.35 (s, 3 H); δ_F(250 MHz; CDCl$_3$) −77.8; δ_C(50 MHz; CDCl$_3$) 139.5, 129.5, 128.0, 126.0, 122.0 (s), 81.0 (q, *J* 25 Hz), 58.0, 21.5 (s).

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