

On the Thermal Decomposition of Diazirines

Michael T. H. Liu* and Michal Tencer

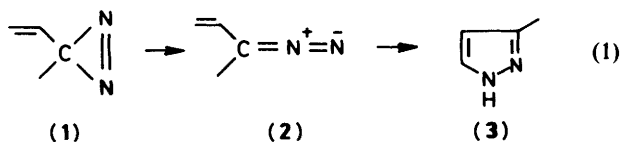
Department of Chemistry, University of Prince Edward Island, Charlottetown, Prince Edward Island, Canada C1A 4P3

Ian D. R. Stevens

Department of Chemistry, The University, Southampton SO9 5NH

Kinetic data for the thermal decomposition of 3-phenyl-3-trifluoromethyldiazirine, 1-phenyl-2,2,2-trifluorodiaoethane, and 3-methyl-3-vinyldiazirine are reported. Detailed analysis of the previously studied diazirine decompositions suggest a mechanism in which a carbene-nitrogen complex is formed as the first intermediate. This complex, depending on the relative rates and stabilities of intermediates and products, may collapse to a diazo compound and/or form a free carbene. Thus for different diazirines the isomerization to a diazo compound may or may not be observed.

The isomerization of 3-methyl-3-vinyldiazirine (1) to 3-methylpyrazole (3) has been investigated by Schmitz *et al.*¹ The kinetics of the thermal isomerization of this reaction were subsequently studied by Liu and Toriyama.² Both groups suggested that (1) will ring open to diazobutene (2) prior to its isomerization to 3-methylpyrazole [equation (1)].



The question of whether the above reaction can best be described as a concerted rearrangement not requiring the intermediacy of (2) was brought forth in a recent review.³ In this paper, we would like to demonstrate that the vinyldiazirine system prefers ring opening to the diazo species instead of following either the pericyclic or pseudopericyclic pathways. In addition, the thermal decompositions of 3-phenyl-3-trifluoromethyldiazirine (4) and 1-phenyl-2,2,2-trifluorodiaoethane (5) will be examined in order to gain some further insight into the nature of the process of the ring rupture.

Results and Discussion

In the present experiments, a 0.1M solution of (1) in diethylene glycol monoethyl ether (DEGME) in the presence of *m*-chloroperbenzoic acid [(1):MCPBA = 1:2] was used for all the kinetic measurements. The thermal decompositions were carried out over the 45–80 °C temperature range and were monitored by following the disappearance of the u.v. absorption of (1) at 374 nm. The first-order rate constants are given in Table 1 and represented in equation (2). These parameters compare

$$k = 10^{12.92 \pm 0.27} \exp[-102.12 \pm 1.70 \text{ kJ mol}^{-1}/RT] \text{ s}^{-1} \quad (2)$$

favourably with those² for the isomerization of (1) to (3) (log *A* 13.70, *E_a* 106 kJ mol⁻¹). Although the rate constants compare favourably, there is a small discrepancy in log *A*; this could be a medium effect due to the presence of MCPBA. The similarity in the two sets of data implied that the rate-determining step was involved in the process of ring-opening to give the diazo compound (2). In the absence of MCPBA, (2) is isomerized to (3) whereas, in the presence of MCPBA, (2) is oxidized to methyl vinyl ketone with the liberation of nitrogen [equation (3)]. The

Table 1. First-order rate constants for the decomposition of (1) in DEGME in the presence of MCPBA

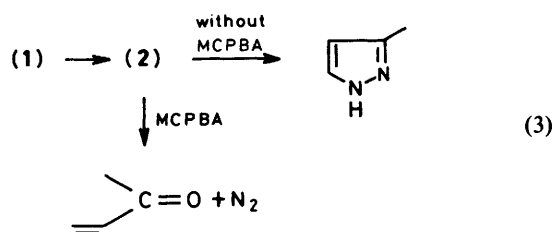
Temperature (°C)	10 ⁴ k/s ⁻¹
45.1	1.52
50.0	2.51
54.8	4.64
60.0	8.51
63.8	11.8
65.0	12.8
70.0	24.6
75.8	43.3

First-order rate constants for the decomposition of (4) in cyclohexane

Temperature (°C)	10 ⁵ k/s ⁻¹
82.4	0.7995
85.5	1.075
86.6	1.176
88.5	1.539
90.5	1.884
93.2	2.692
95.5	3.473
97.7	4.753

First-order rate constants for the decomposition of (5) in cyclohexane

Temperature (°C)	10 ⁵ k/s ⁻¹
73.0	1.625
81.3	4.150
87.0	8.408
93.2	14.89
97.5	24.67



reaction of (2) with MCPBA is instantaneous such that all (2) will be intercepted at this stage.

Following the recent observation⁴ that photolysis of 3-phenyl-3-trifluoromethyldiazirine (4) is accompanied by the

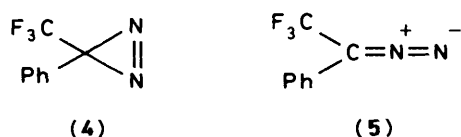
Table 2. First-order rate constants for the decompositions of some diazirines and their diazo isomers

R ¹	R ²	Conditions	10 ⁴ k _i /s ⁻¹	10 ⁴ k _d /s ⁻¹	Reference
Ph	Bu	100.2 °C, DMSO	6.75	2.23	5
Ph	CF ₃	97 °C, cyclohexane	0.48	2.47	This work
Ph	Cl	90 °C, DMSO	15.8	k _d ≫ k _i	6

formation of 1-phenyl-2,2,2-trifluorodiazoethane (5), we have studied the kinetics (Table 1) of the thermal decomposition of (4) in order to ascertain whether or not it follows the pattern of diazirine to diazo isomerization we had previously observed for 3-butyl-3-phenyldiazirine.⁵ The first-order rate constants for the decomposition of (4) in cyclohexane gave a linear Arrhenius plot with the rate constants given by equation (4).

$$k_{(4)} = 10^{13.93 \pm 0.53} \exp [(-129.66 \pm 3.64) \text{ kJ mol}^{-1}/RT] \text{ s}^{-1} \quad (4)$$

However, when studying this decomposition thermally, no isomerization to the diazo compound (5) could be detected.* In order to clarify the situation (5) was independently synthesized.



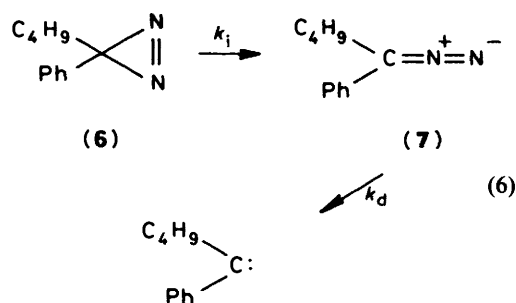
Its decomposition was studied over a similar temperature range and activation parameters were obtained [equation (5)].

$$k_{(5)} = 10^{13.02 \pm 0.34} \exp [(-117.92 \pm 2.30) \text{ kJ mol}^{-1}/RT] \text{ s}^{-1} \quad (5)$$

The data in Table 1 show that for any given temperature, the rate of decomposition of (5) is several times faster than that of (4), hence it is not at all surprising that (5) is not detected during the decomposition of (4). The nature of the substituents at the diazirine ring will determine the stability of the diazo compound isomeric with the diazirine precursor, and thus also determine the chances that such compounds will be formed and/or detected (Table 2). With R¹ = Ph, R² = Cl (and the other chlorodiazirines studied) formation of a diazo compound has never been detected⁶ and, in fact, 1-chlorodiazo compounds are very elusive species. So far, all the reports on chlorodiazirine decomposition point to the direct formation of chlorocarbenes. In addition, no diazo intermediates have been detected in flash photolysis experiments on arylchlorodiazirines.^{7,8} With R¹ = Ph, R² = CF₃, the diazo compound is stable but due to its faster decomposition its presence cannot be detected in

* A 0.3M solution of (4) was refluxed in cyclohexane for 2 h. The solution did not turn pink nor show an absorption due to a diazo group. If (4) produces (5), calculations indicate that ca. 20% of (5) should be present at steady state. This amount should be detectable under the present analytical system but it is not. This implies that the encounter complex (Scheme) decomposes directly to carbene rather than collapsing to diazo compounds.

thermolysis, whereas for 3-butyl-3-phenyldiazirine (6) thermal decomposition occurs with build up of 1-phenyldiazopentane (7). Detailed analysis of the kinetics of this reaction showed that in an inert solvent, and taking into account the experimental error, all the diazirine (6) is transformed to (7) before butylphenylcarbene is formed.⁵ A simple consecutive pattern emerged [equation (6)].



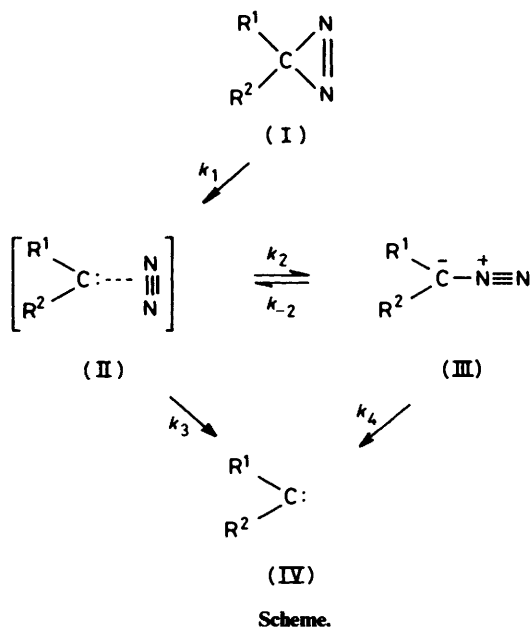
A survey of the literature on diazirine decompositions⁹ reveals that it is extremely difficult to explain all the experimental results within the confines of a single mechanism and indeed that either the carbenic or the diazo or both pathways for the thermal decomposition of diazirine depend on (i) the nature of the diazirine ring substituents, (ii) the stability of the intermediate diazo compound, and (iii) the ability of the solvent molecules to stabilize the carbene or diazo intermediate.

The possibility of two competitive paths seems unlikely on the basis of the constancy of the observed activation entropies for all types of substituents, which show that the transition state has almost the same increase in freedom for all types of substituents, despite the large differences in rate. This would require that the substituent exert a parallel influence on the A factor for the two transition states, while at the same time having a markedly different influence on the stability of the products and the ratio of the two paths. This argument therefore requires a dichotomy between the rate- and product-determining steps of the reaction.

A single path of opening to the diazo compound, followed by nitrogen loss, could account for most of the thermal decompositions, with the diazo compound not being observable when its rate of breakdown is much greater than that of the diazirine. However, diazoketones are in general much more stable than α -ketodiazirines and yet, in the decomposition of the latter, the formation of diazoketones is not observed.^{1,10} Further, particularly when the diazo compound is less stable than the diazirine, photolysis should produce observable quantities of

the diazo compound, as is observed for (4) and for many alkyl- and aryl-diazirines, if the mechanism is that of opening followed by nitrogen loss. Nevertheless, no observable diazo compound is formed from the chlorodiazirines by flash photolytic methods, nor do such techniques nor other photolytic studies suggest the intermediacy of short lived diazo compounds. In fact they point to carbenes as the first intermediates of sufficient lifetime to be detected and trapped.

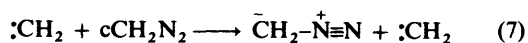
We would now suggest that all the known data on diazine decomposition can be reconciled by the postulate of a carbene-nitrogen encounter complex as an intermediate in the process (Scheme).



The formation of encounter complexes between nitrogen and an organic species is already known. Complexes between aryl cations and nitrogen are proven intermediates in the thermal decomposition of arenediazonium salts.¹¹

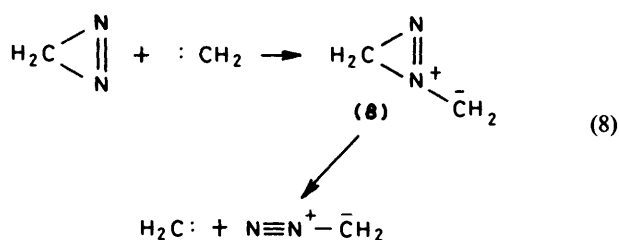
Labelling experiments¹² have shown that methylene, generated by the photolysis of either diazomethane or diazine, reacts with nitrogen in a nitrogen matrix to give diazomethane, showing that carbenes are sufficiently reactive to interact with molecular nitrogen even at 20 K. Similarly, in the gas phase, photolysis of diazomethane or diazine in ¹⁵N₂ affords low conversions into labelled diazomethane.¹³

When diazine is the sole quenching molecule present, photolysis of diazine in the gas phase results in the formation of diazomethane. This has been shown to occur by the process of equation (7),¹⁴ thus accounting for the observed quantum yield of just over 2.



This catalysed isomerization can reasonably be envisioned as proceeding *via* an adduct (8), followed by chelotropic extrusion of methylene [equation (8)].

Flash photolytic studies on the reaction of carbenes with alkenes have provided strong evidence for the intermediacy of a reversibly formed complex of singlet carbene with alkene before collapse occurs to the cyclopropane.¹⁵ Microscopic reversibility requires that the extrusion of carbene (from a cyclopropane)



should also pass *via* this complex. The decomposition of diazines is a direct analogue of this extrusion reaction.

The entropies of activation for diazine decompositions are very small and slightly positive, indicating that no additional free rotations are developed in the transition state and that the transition state resembles the diazine in structure.¹⁶ This would indeed be the case if the transition state lies between (I) and (II).

The kinetic studies of Liu and Chien¹⁷ on the thermolysis of 3-aryl-3-chlorodiazirines has provided evidence for the effect of substituents. The very low ρ value of -0.13 for the *meta*-substituted aryl compounds shows that inductive effects are minimal, while the concave upcurve for the *para*-substituted compounds with both *p*-MeO and *p*-NO₂ reacting faster than the unsubstituted compound is most readily accommodated in terms of a two-bond cleavage, where formation of a singlet carbene with both filled and vacant orbitals would be stabilized by either electron-donating or -withdrawing groups.

For different substituents R¹ and R² on the diazine, the encounter complex mechanism of the Scheme would give results which would depend on the interplay of the rate constants and compound stabilities. Thus, with chlorodiazirines (R¹ = Cl), the chlorodiazomethane (III) is so highly energetic that its rate of formation is negligible when compared with the rate of formation of a free carbene and, therefore, its formation cannot be observed, even in flash-photolysis experiments. The case of phenylbutyldiazirine (I; R¹ = Ph, R² = C₄H₉) is on the opposite side of the reactivity spectrum. The rate of formation of (III) is here much faster than that of carbene and in the absence of a reagent capable of removing the complex (II), the qualitative build up of (III) can be observed. For an intermediate case such as 3-phenyl-3-trifluorodiazirine (I; R¹ = Ph, R² = CF₃), the possibility of the formation of the diazo compound depends on the method of decomposition. In the photochemical experiments, the rates and photoequilibria can be controlled by the light quanta and are not necessarily the same as the thermal rates and equilibria. Thus, in the photochemical decomposition of (4) the formation of the diazo compound could be observed, whereas we have failed to do so in thermolysis. Similarly, photochemical formation of diazo compounds as intermediates has been observed with some aryl (R¹ = Ar)¹⁸ and spirodiazirines [R¹, R² = -(CH₂)₈].¹⁹

An ultimate case of the photoequilibrium shift when compared with the thermal equilibrium is provided by the photochemical isomerization of diazocarbonyl compound to diazines.²⁰ Thus the collapse of the complex (II) to diazine cannot be neglected, although due to the high energy content of diazines this is not a likely process in thermal experiments.

Product analysis and kinetic data give no insight as to the actual structure of complex (II). However, frontier orbital interactions suggest that it should resemble the transition state of a chelotropic reaction of a carbene with an alkene (Figure).²¹ Such a 'non-linear' geometry will give rise to suitable bonding interactions, as discussed by Voigt and Meier²⁰ and also by Snyder *et al.*²² for the transition state in the decomposition of diazine. The latter authors concluded that this structure lies on a thermally allowed reaction path and provides the lowest

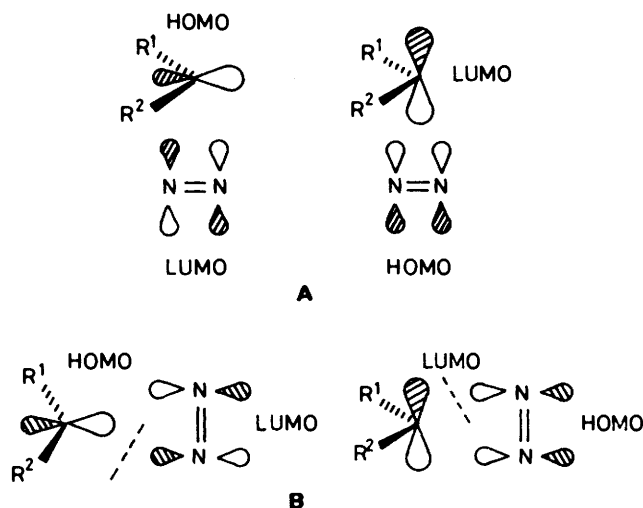


Figure. Frontier orbital interactions in carbene–nitrogen complex

energy pathway for the methylene extrusion. The more complete *ab initio* SCF-CI calculations of Devaquet *et al.*²³ for the diazine–diazomethane–methylene potential energy surface confirm that this path, involving rotational opening to a structure like A, is preferred. In addition, however, they found that there is a very definite minimum for singlet CH₂ coordinated to a nitrogen molecule at a separation of 2.8–3 Å and that this is not only more stable than free singlet (¹A₁) methylene, but also more stable than ground-state (³B₁) methylene.

Although Snyder's results suggest that there is no maximum between A and diazine, no account was taken of any possible solvent interactions and these have been shown to occur in the reactions of carbenes. The *ab initio* work gives a very definite maximum (*ca.* 50 kJ mol⁻¹) for return from complex either to diazomethane or to diazine, and Devaquet suggests that the stability of this complex might be strongly medium dependent.

In conclusion, we feel that the totality of the experimental results also points to the encounter complex (II) being an intermediate (not a transition state) and would anticipate that its stability would be enhanced both by suitable solvent interaction and by the influence of substituents.

Photochemically, the same intermediate (II) may be reached by way of excitation to the ¹n–π* state, an allowed crossing to the dissociative triplet D_{σσ} state [facilitated by the 90° rotation of the electron in space (from n– to π) compensating the spin inversion] and then back to the singlet D_{σσ} state as the methylene to nitrogen distance increases and the two surfaces, singlet and triplet, cross.²³

Experimental

3-Methyl-3-vinyldiazirine (1) was prepared by reacting methyl iodide in the presence of silver nitrate with 3-methyl-3-(β-diethylaminoethyl)diazirine according to the method of Schmitz *et al.*²⁴

3-Phenyl-3-trifluoromethyldiazirine (4) was synthesized according to Brunner *et al.*⁴ 1-Phenyl-2,2,2-trifluorodiazoethane (5) was prepared by methods reported previously.²⁵ The spectral data for (1), (4), and (5) are in excellent agreement with published results.^{24,4,25}

A solution (0.1M) of (1) in diethylene glycol monoethyl ether was heated in the presence of *m*-chloroperbenzoic acid [(1):MCPBA = 1:2] to give methyl vinyl ketone in greater than 90% yield. This product was identified by n.m.r. and i.r.

analysis and by comparison with the spectrum of the authentic sample. The decomposition of (4) and (5) in cyclohexane gave the expected C–H insertion product of the trifluoromethylphenyl carbene.⁴

The detailed procedure for kinetic studies has been described elsewhere.⁶ Reaction rates were measured by following the disappearance of the characteristic absorption: (1) (10⁻³M), λ 374 nm; (4) (10⁻³M), λ 354 nm, and (5) (10⁻²M), λ 465 nm. The first-order rate coefficients were determined graphically from the plot of log (A_t – A_∞) against time.

Note added in proof: Irradiation (320–380 nm) of phenylchlorodiazirine in argon at 10 K gave phenylchlorocarbene (i.r. bands at 1 590, 1 225, 1 170, 848, 735 cm⁻¹; λ_{max} at 300 nm) as well as small amounts of phenylchlorodiazo-methane (small i.r. band at 2 050 cm⁻¹) (G. A. Ganzer, R. S. Sheridan, and M. T. U. Liu, unpublished results).

Acknowledgements

M. T. H. L. thanks the Natural Sciences Engineering Research Council of Canada for financial support, and W. Y. Kwan for technical assistance.

References

- E. Schmitz, 23rd Int. Congress of Pure and Applied Chemistry, Boston, 1971; Butterworth, London, 1971, vol. 2, 283.
- M. T. H. Liu and K. Toriyama, *Can. J. Chem.*, 1973, **51**, 2393.
- E. C. Taylor and I. J. Turchi, *Chem. Rev.*, 1979, **79**, 181.
- J. Brunner, H. Senn, and F. M. Richards, *J. Biol. Chem.*, 1980, **255**, 3313.
- (a) B. M. Jennings and M. T. H. Liu, *J. Am. Chem. Soc.*, 1976, **98**, 6416; (b) M. T. H. Liu and B. M. Jennings, *Can. J. Chem.*, 1977, **55**, 3596.
- M. T. H. Liu and K. Toriyama, *J. Phys. Chem.*, 1972, **76**, 797.
- D. Griller, M. T. H. Liu, and J. C. Scaiano, *J. Am. Chem. Soc.*, 1982, **104**, 5549.
- N. J. Turro, J. A. Butcher, R. A. Moss, W. Guo, R. C. Munjal, and M. Fedorynski, *J. Am. Chem. Soc.*, 1980, **102**, 7576.
- M. T. H. Liu, *Chem. Soc. Rev.*, 1982, **11**, 127.
- (a) E. Schmitz, A. Stark, and Ch. Hörig, *Chem. Ber.*, 1965, **98**, 2509; (b) E. D. Langanis, D. S. Janik, T. J. Curphey, and D. M. Lemal, *J. Am. Chem. Soc.*, 1983, **105**, 7457.
- H. Zollinger, *Angew. Chem., Int. Ed. Engl.*, 1978, **17**, 141 and references cited therein.
- C. B. Moore and G. C. Pimentel, *J. Chem. Phys.*, 1964, **41**, 3504.
- A. E. Shilov, A. A. Shteinmann, and M. B. Tjabui, *Tetrahedron Lett.*, 1968, 4177.
- F. Lahmani, *J. Phys. Chem.*, 1976, **80**, 2623.
- N. J. Turro, G. F. Lehr, J. A. Butcher, R. A. Moss, and W. Guo, *J. Am. Chem. Soc.*, 1982, **104**, 1754.
- N. P. Smith and I. D. R. Stevens, *J. Chem. Soc., Perkin Trans. 2*, 1979, 213.
- M. T. H. Liu and D. H. T. Chien, *J. Chem. Soc., Perkin Trans. 2*, 1974, 937.
- R. A. G. Smith and J. R. Knowles, *J. Chem. Soc., Perkin Trans. 2*, 1975, 686.
- G. F. Bradley, W. B. L. Evans, and I. D. R. Stevens, *J. Chem. Soc., Perkin Trans. 2*, 1977, 1214.
- E. Voigt and H. Meier, *Chem. Ber.*, 1975, **108**, 3326.
- I. Fleming, 'Frontier Orbitals and Organic Chemical Reactions,' Wiley, New York, 1980.
- J. P. Snyder, R. J. Boyd, and M. A. Whitehead, *Tetrahedron Lett.*, 1972, 4347.
- B. Bigot, R. Ponec, A. Sevin, and A. Devaquet, *J. Am. Chem. Soc.*, 1978, **100**, 6576.
- E. Schmitz, C. Hörig, and C. Grundemann, *Chem. Ber.*, 1967, **100**, 2093.
- (a) R. A. Shepard and S. E. Wentworth, *J. Org. Chem.*, 1967, **32**, 3197; (b) G. Diderich, *Helv. Chim. Acta*, 1972, **55**, 2103.

Received 1st March 1985; Paper 5/348