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A Convenient Phase-Transfer Method for Preparation of Pure *cis*-Dimethyldiazene (*cis*-Azomethane) in Aqueous Solution. Proton and Carbon NMR Studies of *trans*- and *cis*-Dimethyldiazene

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The preparation and chemistry of *cis*-dimethyldiazene (*cis*-azomethane) is of interest for several reasons, including its structural relationship to *cis*-diazene, a possible intermediate in nitrogen fixation.[1] *trans*-Azomethane (**1**) can be prepared by several methods[2−4] and is stable in pure form at room temperature. The *cis* isomer **2**, however, rapidly isomerizes to formaldehyde methylhydrazone at room temperature and must be manipulated in organic solutions at temperatures below −50 °C using vacuum line techniques to avoid decomposition.[5−7] Vibrational and photoelectronic spectroscopy of both **1** and **2** have been reported,[3,8−13] but the ^{13}C NMR of **2** has not been studied. Seeking a simple, direct route to aqueous solutions of pure **2**, we have investigated the photoisomerization of **1** in a mixed-phase solvent system. Photoconversion of **1** to **2** was previously reported to proceed at room temperature in D_2O with an equilibrium constant $K_{eq} = [\mathbf{2}]/[\mathbf{1}]$ of 0.09,[5] and **2** was noted to be stable in aqueous solution;[5,6] however, solutions of *pure* **2** were prepared by photoirradiation of **1** as a glass at −196 °C, followed by trap-to-trap distillation and co-condensation into a vessel with D_2O. We report here a phase-transfer photoisomerization procedure for direct preparation of concentrated aqueous solutions of **2** at room temperature. A complete set of ^1H and ^{13}C NMR data was obtained for both azomethane isomers in D_2O.

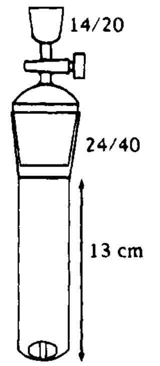
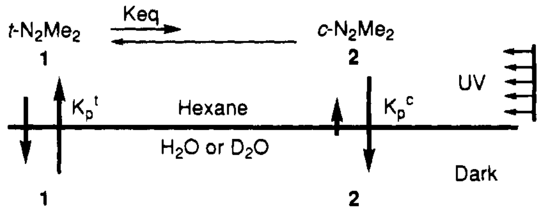


Figure 1. Apparatus for preparation of aqueous solutions of **2**. The lower portion was made from a quartz tube to which a standard taper 24/40 joint was annealed. The top portion consisted of a 24/40 joint, glass stopcock, and 14/20 joint annealed together.

Scheme 1



trans-Azomethane (**1**) was prepared by the method of Renaud and Leitch[2] from 1,2-dimethylhydrazine and purified from traces of water and chloromethane (byproduct) by standard vacuum line techniques. This isomer is moderately soluble in water (Henry's law constant of 1.50 M/atm at 30 °C),[14] permitting its aqueous (H_2O or D_2O) solutions to be prepared up to ~0.5 M. Irradiation of the above solutions in a photochemical reactor (Experimental Section) yielded an equilibrium mixture of **1** and **2** in the ratio of 10:1 as previously reported.[5] Extraction of the equilibrium mixture with degassed hexane resulted in complete removal of **1** (<0.5%, NMR) from the aqueous phase. Proton NMR of the hexane layer ($CDCl_3$) showed **2** to be virtually absent (<1% of **1**) in the organic phase, consistent with the polar nature of the *cis* isomer.

The much greater solubility of **2** in water compared to hexane prompted us to consider photoisomerization of **1** in a two-phase system, in which only the organic layer is irradiated. Under these conditions, newly formed **2** was expected to transfer to the aqueous phase and accumulate there as the irradiation proceeded, thereby enriching the dark phase and correspondingly depleting the irradiated phase in **2**, allowing its net formation to continue (Scheme 1).

To test this idea, the apparatus shown in Figure 1 was constructed. The lower two-thirds of the irradiation vessel portion was made of quartz. The standard taper joint and stopcock in the upper, removable portion permits attachment to a gas manifold or a vacuum line, if necessary. Details of charging the vessel and masking the aqueous phase zone are given in the Experimental Section. Figure 2 shows the result of a typical irradiation experiment. For dilute (<0.05 M) starting solutions of **1**, the concentration of **2** reached constant values after ca. 12 h of irradiation (data not shown). When concentrated solutions of **1** were used, longer irradiation times were necessary in order to achieve the maximum yield of **2**. In our unthermostated photoreactor, however, despite operation in a 4 °C cold room, long *continuous* irradiations caused excessive warming of the mixture and formation of byproducts. This complication was eliminated by applying the UV radiation *discontinuously* in ca. 1 h intervals followed by 30 min of radiationless

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(1) McKenna, C. E. In *Molybdenum and Molybdenum-Containing Enzymes*; Coughlan, M. P., Ed.; Pergamon Press, New York, 1980, pp 439−62.

(2) Renaud, R.; Leitch, L. C. *Can. J. Chem.* **1954**, *32*, 545−9.

(3) Craig, N. C.; Ackermann, M. N.; MacPhail, R. A. *J. Chem. Phys.* **1978**, *68*, 236−46.

(4) Thiele, J. *Chem. Ber.* **1909**, *42*, 2575−80.

(5) Hutton, R. F.; Steel, C. *J. Am. Chem. Soc.* **1964**, *86*, 745−6.

(6) Ackermann, M. N.; Craig, N. C.; Isberg, R. R.; Lauter, D. M.; MacPhail, R. A.; Young, W. G. *J. Am. Chem. Soc.* **1977**, *99*, 1661−3.

(7) Ackermann, M. N.; Dobmeyer, D. J.; Hardy, L. C. *J. Organomet. Chem.* **1979**, *182*, 561−79.

(8) West, W.; Killingsworth, R. B. *J. Chem. Phys.* **1938**, *6*, 1−8.

(9) Stevens, J. F., Jr.; Curl, R. F., Jr.; Engel, P. S. *J. Phys. Chem.* **1979**, *83*, 1432−8.

(10) Stevens, J. F., Jr. *Diss. Abstr. Int. B* **1977**, *38*, 1238.

(11) Mosher, O. A.; Foster, M. S.; Flicker, W. M.; Beauchamp, J. L.; Kuppermann, A. *J. Chem. Phys.* **1975**, *62*, 3424−30.

(12) Haselbach, E.; Schmelzer, A. *Helv. Chim. Acta* **1971**, *54*, 1575−80.

(13) Ackermann, M. N.; Craig, N. C.; Isberg, R. R.; Lauter, D. M.; Tacy, E. P. *J. Phys. Chem.* **1979**, *83*, 1190−200.

(14) Simeonov, A. M.; McKenna, C. E. Unpublished data.

0022-3263/95/1960-1897$09.00/0

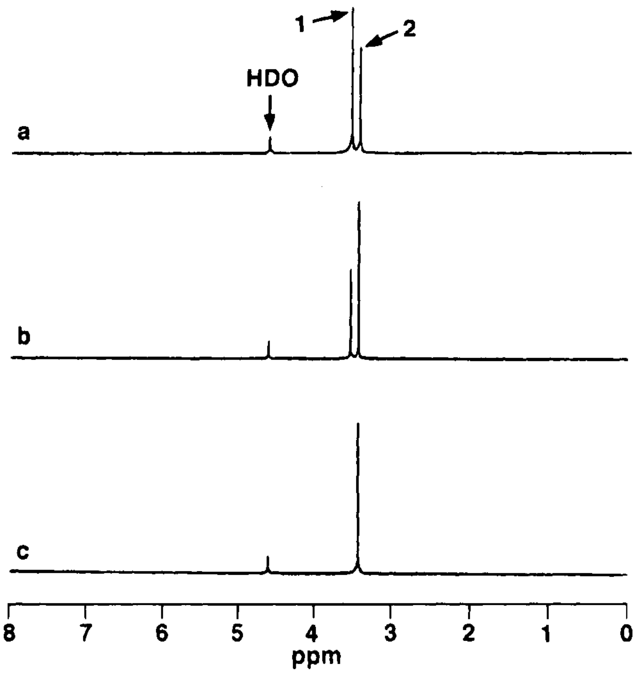

Figure 2. Results from a typical irradiation process performed in the designed apparatus. The apparatus in Figure 1 was charged with 5 mL of D_2O and 25 mL of 0.5 M hexane solution of **1**. (a) ^1H NMR spectrum of the aqueous layer after 3 h; **1**:**2** ratio = 1.3:1. (b) Same, after 5 h; **1**:**2** ratio = 1:2.0. (c) The aqueous layer from b after extraction with five 10 mL portions of hexane. Note: the resonances due to the hydrazone rearrangement product from decomposition of **2**, if present, would have been observed near 2.5 and 6.5 ppm.[5,16]

stirring.[15] It was possible to prepare highly concentrated (up to 1 M) solutions of **1** by condensing it into degassed hexane at −80 °C. By charging the apparatus with these solutions at 4 °C and performing the irradiation, it was possible to obtain **2** in concentrations of up to 0.30 M. At the end of the process, residual **1** was quantitatively removed from the aqueous layer by extraction with degassed hexane. Aqueous solutions of purified **2** were stable for at least 4 months (NMR, UV) at −20 °C. Storage at room temperature for more than 2 weeks resulted in tautomerization of **2** as evidenced by the appearance of ^1H NMR peaks corresponding to the formaldehyde methylhydrazone.[5,16] A fact worth noting is that the conversion of **1** into **2**, although about three times higher than obtained with monoaqueous irradiation, is still less than predicted by K_{eq} and our estimates of the respective partition coefficients (defined as molarity in aqueous phase/molarity in organic phase): K_p^t (0.3) and K_p^c (100) (data not shown). There are two possible explanations for this result. Firstly, in our simple apparatus, stray UV light may enter the aqueous phase, depleting the *cis* isomer by conversion to the *trans* isomer. Secondly, some photodecomposition occurs, as evidenced by a moderate pressure buildup over the course of the reaction. It is clear, however, that the remaining hexane solution of **1** can be reused by simply withdrawing the aqueous layer and recharging the apparatus with a new portion of degassed water, and, if necessary, with an additional amount of concentrated hexane solution of **1**.

Table 1. *trans*- and *cis*-Dimethyldiazene: ^1H and ^{13}C NMR Spectral Data

	dimethyldiazene isomer	
NMR parameter	trans (**1**)	cis (**2**)
^1H δ (ppm)	3.70 ($CDCl_3$)[a]	
	3.54 (D_2O)[b]	3.44 (D_2O)[b]
^1H $^5J_{HH}$ (Hz)	1.59 ($CDCl_3$)	
	1.56 (D_2O)	
^{13}C δ (ppm)	56.70 ($CDCl_3$)[c]	
	55.12 (D_2O)	46.89 (D_2O)
^{13}C $^1J_{CH}$ (Hz)	136.3 ($CDCl_3$)	
	137.7 (D_2O)	143.6 (D_2O)

[a] A value of 3.67 ppm was reported in ref 5. [b] Hutton and Steel (ref 5) reported **1** and **2** as having resonances at 0.984 and 1.08 ppm upfield from HDO. [c] Van Baar et al. (ref 19) report 55.65 ppm.

With concentrated D_2O solutions of **1** and **2** at hand, we decided to obtain a set of ^1H and ^{13}C NMR data for both compounds using relatively high-field (250, 360 MHz) spectrometers, as the literature data were obtained on early NMR instruments, the ^1H NMR data for **2** in D_2O used HDO as the reference, and the ^{13}C NMR of **2** was not reported. The results of our studies are summarized in Table 1. The proton chemical shifts for both isomers are in good agreement with the published values obtained at 100 MHz or below.[5,17] The ^{13}C satellites in the proton spectrum of **1** appear as *quartets* ($^5J_{HH}$ = 1.59 Hz), which we attribute to long-range five-bond proton−proton coupling in naturally abundant *trans*-$H_3{}^{13}CN{=}N^{12}CH_3$. $^5J_{HH}$ coupling has been reported for **1** only in a complex formed with $W(CO)_5$.[7] In this case, the methyl groups were chemically nonequivalent (only one N coordinated to the metal). The isomer **1** thus demonstrates a homoallylic coupling system, wherein the *trans* configuration of the double bond particularly favors the distal spin−spin coupling interaction.[18] The corresponding *J* value in **2**, expected to be <1 Hz,[7,18] was not discernable from our spectra.

A ^{13}C NMR chemical shift of 55.65 ppm was previously reported for **1** in $CDCl_3$[19] whereas we obtain 56.70 ppm. The ^{13}C chemical shifts of both **1** and **2** have been predicted on the basis of IGLO calculations.[20] Our ^{13}C chemical shift values (D_2O) are comparable in magnitude to the calculated chemical shifts, but occur in reverse order (**1** > **2**). This disagreement with the predicted ^{13}C chemical shift order is also seen for the ^1H chemical shifts (ref 6; Table 1) and points to an anomalous behavior for **1** and **2** relative to larger homologues.[21]

In summary, we have developed a simple room temperature method for preparation of concentrated aqueous solutions of pure *cis*-azomethane, obviating vacuum line manipulation of this compound. The structures and stereocompactness of **1** and **2** have made them interesting candidates as metal ligands,[7,19] and their photo- and thermal lability make them valuable sources for methyl radicals.[22−24] The procedure presented here will facilitate the use of **2** in these or other[14] applications.

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(15) A reaction vessel equipped with a cooling water jacket would doubtless permit uninterrupted irradiation; however, the method described works satisfactorily and minimizes cost of vessel construction.

(16) Lemal, D. M.; Menger, F.; Coats, E. *J. Am. Chem. Soc.* **1964**, *86*, 2395−401.

(17) Freeman, J. P. *J. Org. Chem.* **1963**, *28*, 2508−11.

(18) Jackman, L. M.; Sternhell, S. *Applications of NMR Spectroscopy in Organic Chemistry*; Pergamon: Oxford, 1969.

(19) Van Baar, J. F.; Vrieze, K.; Stufkens, D. J. *J. Organomet. Chem.* **1974**, *81*, 247−59.

(20) Schindler, M. *J. Am. Chem. Soc.* **1987**, *109*, 5950−5.

(21) Engel, P. S.; Bishop, D. J. *J. Am. Chem. Soc.* **1975**, *97*, 6754.

(22) Weldon, M. K.; Friend, C. M. *Surf. Sci.* **1994**, *310*, 95−102.

(23) North, S. W.; Longfellow, C. A.; Lee, Y. T. *J. Chem. Phys.* **1993**, *99*, 4423−9.

Experimental Section

All NMR samples were prepared in $CDCl_3$ or D_2O as noted. ^1H NMR spectra were recorded at 250.13 or 360.13 MHz and ^{13}C NMR spectra at 62.89 MHz on Bruker AC-250 or Bruker AM-360 spectrometers. Chemical shifts were recorded in ppm relative to internal $CDCl_3$ ($\delta = 7.24$, ^1H; $\delta = 77.0$, ^{13}C), internal D_2O ($\delta = 4.63$, ^1H), and internal acetone ($\delta = 2.04$, ^1H; $\delta = 29.8$, ^{13}C). Coupling constants (J) are reported in Hz. Hexane (Mallinckrodt) was analytical grade, D_2O (Cambridge Isotope Laboratories) was 99.9% D, and H_2O (Aldrich) was HPLC grade. Ultraviolet and IR spectra were recorded on a Shimadzu UV-260 spectrophotometer and a Perkin-Elmer 281 spectrophotometer, respectively. The extinction coefficients for **1** ($\epsilon_{343} = 25$) and **2** ($\epsilon_{353} = 240$)[5] in water were used to measure the concentrations in aqueous solutions. The literature values were verified by ^1H NMR spectra of samples to which known amounts of a standardized methylamine solution were added, followed by peak integration (data not shown). Photoisomerization was performed in a Rayonet photochemical reactor equipped with eight GE G8T5 germicidal lamps.

***Trans*-Azomethane (1).** *sym*-Dimethylhydrazine dihydrochloride (10 g, 75 mmol) (Aldrich) was oxidized by HgO in water and purified by passage in a N_2 stream through −80 and −196 °C traps.[2] Yields were 55−67%, and purity was satisfactory (IR,[25] NMR,[17] UV[5]). The product was either stored at −196 °C or else used immediately for preparation of its solutions in hexane or water by condensation into a flask filled with the degassed solvent and cooled to −80 °C (dry ice/*i*-PrOH). The same approach was adopted for preparation of NMR samples of newly synthesized **1**. For IR spectroscopy, **1** was expanded into a preevacuated gas cell with NaCl windows (74 mm path length, 30 mL capacity) at partial pressures of 0.066−0.4 atm.

Irradiation of 1 in D_2O Solution and Extractive Purification of 2. In a Beckman quartz cuvette (Ar) was placed 3.5 mL of 0.5 M **1** in D_2O. The mixture was irradiated in the photochemical reactor for 5 h, after which a 0.5 mL sample was removed for NMR analysis (Hamilton gas-tight syringe). The spectrum showed that photochemical equilibrium (**1**:**2** = 10:1) had been established. To the sample in an NMR tube (5 mm, capped with rubber septum) was added an equal volume of degassed hexane, the tube was inverted repeatedly, the settled hexane layer was removed, and the spectrum was recorded. The process was repeated until the proton signal for **1** was no longer detectable. Loss of **2** was negligible.

Preparation of Aqueous Solutions of 2 in the Designed Apparatus. The apparatus described in Figure 1, containing 5 mL of D_2O, was assembled and secured by a clamp. A rubber septum stopper was emplaced and the apparatus connected to an Ar manifold via a 18G needle. Three cycles of pumping and argonation were performed, after which a 20−30 mL hexane solution of **1** (0.1−1 M) was injected. The lower portion of the apparatus was wrapped with Al foil to a height 5 mm above the top of the aqueous layer. The apparatus was then removed from the manifold and fitted above a small magnetic stirrer inside the photochemical reactor placed in a cold room (4 °C). Stirring was continuous (ca. 120 rpm), and irradiation was done either continuously or discontinuously (see main body of the text). The progress of the reaction was monitored by removal of the apparatus from the reactor and withdrawal of NMR samples from the selected layer by the use of a 20G 25 cm stainless steel needle (Aldrich). When the proton signal of the *cis* isomer in D_2O samples ceased to grow, irradiation was stopped, the hexane layer was removed, and residual **1** was removed from the aqueous layer by repeated extraction with degassed hexane in the same apparatus. The resulting colorless aqueous solution of **2** was free of detectable impurities (NMR, UV). When **2** was prepared in H_2O, the progress of the reaction was monitored by removal of an aqueous sample, extraction with hexane, and recording the UV spectrum.

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[24] Squillacote, M.; De Felippis, J. *J. Org. Chem.* **1994**, *59*, 3564−71.

[25] Durig, J. R.; Pate, C. B.; Harris, W. C. *J. Chem. Phys.* **1972**, *56*, 5652−62.