with resultant deprotonation of the latter. Deprotonation occurs at neutral pH and even in slightly acidic medium. It is possible that the exocyclic NH_2 group of N9-substituted adenines may act in a similar fashion. This work reveals yet another possible way in which the anticancer drug *cis*-$(NH_3)_2PtCl_2$ may interact with DNA bases.

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Supplementary Material Available: A table of atomic parameters and temperature factors for A and listings of structure factor amplitudes for A and B (31 pages). Ordering information is given on any current masthead page.

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^{15}N NMR Spectrum of a 1,1-Diazene. *N*-(2,2,6,6-Tetramethylpiperidyl)nitrene[1]

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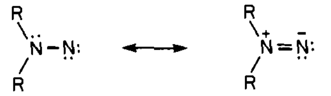
Abstract: The low-temperature ^{15}N NMR spectrum of the 1,1-diazene, *N*-(2,2,6,6-tetramethylpiperidyl)nitrene (**1**), is reported. The ^{15}N double- and mono-labeled 1,1-diazenes **1a** and **1b** were synthesized. The nitrene and amino nitrogens of **1** have resonances in dimethyl ether at −90 °C at 917.0 and 321.4 ppm, respectively, downfield from anhydrous $^{15}NH_3$, affording a chemical shift difference of 595 ppm for the directly bonded nitrogen nuclei. The chemical shift of the ring nitrogen is consistent with an amino nitrogen whose lone pair is largely delocalized. The large downfield shift of the nitrene nitrogen is consistent with a large paramagnetic term due to a low-lying n → π* transition.

Introduction

1,1-Diazenes (aminonitrenes, *N*-nitrenes) unlike their more stable 1,2-diazene isomers (azo compounds) are usually not isolated or detected by spectroscopic methods but rather are assumed intermediates on the basis of a substantial body of chemical evidence.[5] Recently, the synthesis and direct observation of



persistent[6] 1,1-diazenes, *N*-(2,2,6,6-tetramethylpiperidyl)nitrene (**1**)[7] and *N*-(2,2,5,5-tetramethylpyrrolidyl)nitrene,[8] were reported. The infrared and electronic spectra and kinetics of decomposition of these 1,1-diazenes[7,8] allowed the first comparison of experiment with theory on the nature of the bonding and the relative energies of the states of the parent 1,1-diazene (H_2N–N).[9]

^{15}N NMR spectroscopy has proven to be a sensitive probe of the electronic environment of nitrogen nuclei.[10] With the availability of persistent 1,1-diazenes, we have obtained the first ^{15}N magnetic resonance spectrum of a 1,1-diazene. The low-temperature ^{15}N NMR spectrum of *N*-(2,2,6,6-tetramethylpiperidyl)nitrene (**1**)[7] reveals the different electronic environments

Scheme I

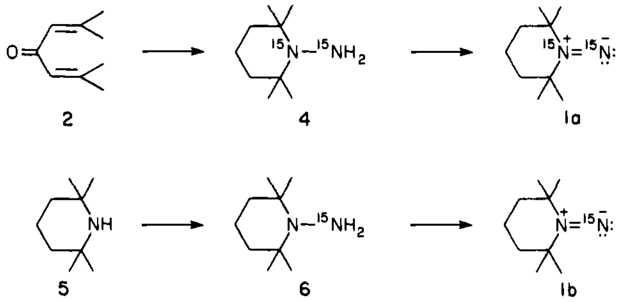
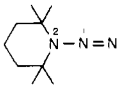
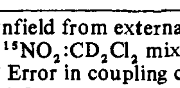


Table I

compd		$^{15}N1$	$^{15}N2$
	δ^a	917.0	321.4
	J^b	15.5	15.5
	NOE	−0.2	−5
	δ	419.5	164.6
	J	6.4	6.4
	NOE	−2	−5

[a] Downfield from external anhydrous ammonia, at 25 °C using a 1:4 $CH_3{}^{15}NO_2$:CD_2Cl_2 mixture as a secondary standard at 380.7 ppm. [b] Error in coupling constants is ±0.6 Hz. Error in chemical shift is ±0.5 ppm.

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[2] Camille and Henry Dreyfus Teacher Scholar 1978–1983.

[3] National Science Foundation Postdoctoral Fellow.

[4] National Science Foundation Predoctoral Fellow.

[5] For reviews of 1,1-diazene behavior see: (a) Lemal, D. M. In "Nitrenes"; Lwowski, W., Ed.; Interscience: New York, 1970; Chapter 10; (b) Ioffe, B. V.; Kuznetsov, M. H. *Russ. Chem. Rev. (Engl. Transl.)* **1972**, *41*, 131.

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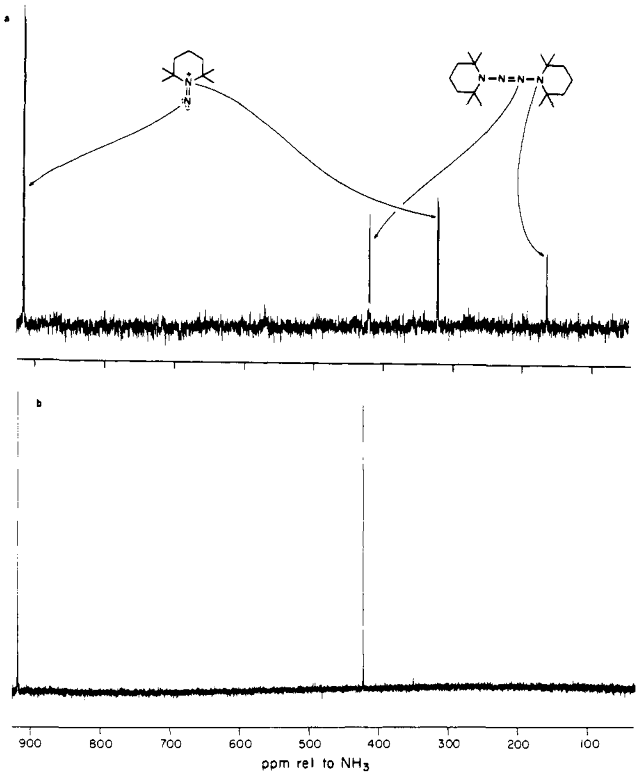

Figure 1. Fourier transform ^{15}N NMR spectra of 1,1-diazene **1** and tetrazene **7** in dimethyl ether at -90 °C (30° pulse angle, 20 s repetition time, NOE suppressed): (a) spectrum of **1a** and **7** from the nickel peroxide oxidation of 200 mg of **4** at 9.04 MHz, 250 transients; (b) spectrum of **1b** and **7** from the nickel peroxide oxidation of 100 mg of **6** at 50.7 MHz, 190 transients. The assignments of the resonances are described in the text.

of the contiguous nitrogens in the 1,1-diazene. We find the chemical shift difference for the amino and nitrene nitrogens to be 595 ppm. Their assignments were determined from the spectra of the ^{15}N double- and mono-labeled 1,1-diazene, **1a** and **1b**. The nitrene nitrogen of the 1,1-diazene has a ^{15}N resonance in dimethyl ether at -90 °C 917 ppm downfield from anhydrous $^{15}NH_3$ and represents the most highly deshielded neutral nitrogen-containing organic compound now known.

Results and Discussion

Successive treatment of phorone **2** with $^{15}NH_4Cl$/sodium hydroxide and hydrazine hydrate/potassium hydroxide afforded ^{15}N-labeled (95+%) 2,2,6,6-tetramethylpiperidine **3**.[11] Nitrosation ($Na^{15}NO_2$, 95%) and reduction with lithium aluminum hydride gave the double-labeled precursor, *N*-amino-2,2,6,6-tetramethylpiperidine (**4**).[7,12] Similarly, nitrosation ($Na^{15}NO_2$) and reduction of unlabeled 2,2,6,6-tetramethylpiperidine **5** afforded the mono-labeled precursor **6** (Scheme I).

Oxidation of **4** with nickel peroxide in dimethyl ether affords upon filtration and concentration (-78 °C) a deep purple solution of the persistent 1,1-diazene **1** whose electronic spectrum (λ_{max} = 543 nm, $(CH_3)_2O$), infrared spectrum, and thermal stability are known.[7] The ^{15}N NMR spectrum of this purple solution (~1 M) at -90 °C contains four doublets (Figure 1a). The two doublets, δ 419.5 (J = 6.4 Hz) and 164.6 (J = 6.4 Hz), can be assigned to the tetrazene **7** which has been independently synthesized and characterized.[7] The pair of doublets at δ 917.0 (J = 15.5 Hz) and 321.4 (J = 15.5 Hz) was shown by ^{15}N-^{15}N decoupling to be directly bonded nitrogen nuclei. When the mixture is warmed to 0 °C, the purple color disappears and the doublets at 917.0 and 321.4 disappear concomitant with an increase in the resonances of tetrazene **7**, the dimerization product of **1**.[7] These doublets are assigned to the 1,1-diazene **1a**. Oxidation of the mono-labeled precursor **6** in dimethyl ether at -78 °C affords singlets at δ 917.0 and 419.5 and no peaks at δ 165 and 321 (Figure 1b). This fact allows the assignment of the 917-ppm resonance to the nitrene nitrogen of the 1,1-diazene chromophore. The ^{15}N NMR parameters for the 1,1-diazene **1a** and the tetrazene **7** are presented in Table I.

The large NOE for N2 in **1a** suggests almost full nitrogen–proton dipole–dipole relaxation for this nitrogen. The nitrene nitrogen N1 was found to have a smaller NOE than N2 and, as evidenced by the response in signal intensity to changes in pulse delay, a spin–lattice relaxation time, T_1, which is insensitive to magnetic field strength and much shorter than the T_1 of N2. Thus a spin–rotation relaxation mechanism seemingly predominates for the nitrene nitrogen. This may reflect the different electron distributions between the two nitrogens since it has been shown that an electron distribution leading to large chemical shifts will lead to large spin–rotation interactions.[13]

The deshielding of the nitrene nitrogen can be attributed to the importance of the paramagnetic term as represented by mixing of the ground state with excited states which results in changes induced by the external field in the electronic wave functions.[14,15] Experimental correlations of ^{15}N chemical shift with the energy of transitions involving low-lying excited states, in particular n–π^* transitions, are well documented.[14] The magnitude of the downfield shift of the nitrene nitrogen in **1** is consistent with a very large paramagnetic term due to the low-lying n → π^* transition (λ_{max} = 543 nm in $(CH_3)_2O$).[7]

The amino nitrogen of **1a**, N2, has a ^{15}N chemical shift of 321 ppm comparable to the shifts of nitrones, nitrates, and nitro compounds, 280–380 ppm,[10] which lack nonbonding electrons on nitrogen. These molecules are formally *N*-oxides of imines, nitrites, and nitroso compounds, 330–900 ppm,[10] and are considerably more shielded, even though they are also associated with low-energy n–π^* transitions. Thus it appears that nonbonding electrons on nitrogen must be involved in the n–π^* absorption of the molecule in order for a large paramagnetic shift to be present for the nitrogen.[14c] The amino nitrogen, N2, is not deshielded, and hence its lone pair must be substantially delocalized into the empty p orbital of the nitrene nitrogen, N1. This is consistent with both experiment ($^{14}N{=}^{14}N$, stretch, 1595 cm^{-1})[7] and theory (GVB/CI),[9] both characterizing the 1,1-diazene as having an N=N π bond.

Conclusion

In summary, the low-temperature ^{15}N NMR spectrum of the 1,1-diazene, *N*-(2,2,6,6-tetramethylpiperidyl)nitrene (**1**), is reported. The nitrene and amino nitrogens of **1** have resonances in dimethyl ether at 917.0 and 321.4 ppm, respectively, downfield from anhydrous $^{15}NH_3$, affording a chemical shift difference of 595 ppm for the directly bonded nitrogen nuclei. The chemical shift of the ring nitrogen is consistent with an amino nitrogen whose lone pair is largely delocalized. The large downfield shift of the nitrene nitrogen is consistent with a large paramagnetic term due to a low-lying n → π^* transition.

Experimental Section

^{15}N Nuclear magnetic resonance (^{15}N NMR) data were recorded on a JEOL FX-90Q spectrometer at 9.04 MHz (Figure 1a) and a Brucker WM-500 spectrometer at 50.7 MHz (Figure 1b). Chemical shifts are

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(15) The paramagnetic shielding term, σ_p, of the Pople chemical shift theory[16] can be approximated as being inversely proportional to ΔE, the mean excitation energy for all excited states. Low-lying n,π^* excited states will dominate this term, affording the largest deshielding contribution to σ_p.

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given in parts per million (ppm) downfield from anhydrous $^{15}NH_3$ in δ units and coupling constants in cycles per second (Hz). ^{15}N Chemical shifts were obtained by using a 1:4 $CH_3{}^{15}NO_2$–CD_2Cl_2 solution as a secondary standard. Proton NMR data were obtained on a Varian EM-390 spectrometer. Chemical shifts are given in parts per million downfield from Me_4Si in δ units and coupling constants in cycles per second. For preparative vapor-phase chromatography (VPC), a Varian Aerograph Model 920 instrument equipped with a thermal conductivity detector and helium carrier gas was used. The VPC column was a 5 ft × 0.25 in. glass, Pennwalt 223 amine packing (Applied Sciences Laboratories, Inc.). All reactions were run under an argon atmosphere.

4-Oxa-2,2,6,6-tetramethylpiperidine-^{15}N (8). A 10.0 g (0.072 mol) sample of phorone **2** and ~100 mg of sodium hydroxide were placed in a 25-mL pyrolysis tube and then frozen under vacuum. An ammonia solution was prepared by neutralizing 5.0 g (0.092 mol) of $^{15}NH_4Cl$ (Prochemicals Limited, NJ; 95.4 atom %) with 8.0 g (0.20 mol) of sodium hydroxide in 6 mL of water. This solution was distilled under reduced pressure into the pyrolysis tube. The reactants were degassed, sealed under vacuum, and heated in a stainless-steel bomb to 135 °C for 18 h. The tube was then opened; the contents were dissolved in ether, dried (K_2CO_3), and concentrated, affording 8.2 g of a yellow oil. Recrystallization from petroleum ether at −78 °C gave 7.0 g (62%) of **8** as white needles: mp 37–38 °C (lit.[17] mp 36 °C); NMR ($CDCl_3$) δ 1.22 (d, 12, J = 2 Hz), 2.22 (s, 4).

2,2,6,6-Tetramethylpiperidine-^{15}N (9). A total of 7.0 g (0.45 mol) of **8** was stirred with 10 g of potassium hydroxide, 9.3 mL of hydrazine hydrate, and 2.0 mL of water in 67 g of triethylene glycol at reflux for 2 h. The product was distilled (bp 96–112 °C), extracted with ether, and dried (Na_2SO_4), affording 4.5 g (72%) of a clear liquid **9**: bp 145–147 °C (lit.[11] bp 151–152 °C (750mmHg)); NMR ($CDCl_3$) δ 1.12 (d, 12, J = 2 Hz), 1.3 (m, 4), 1.6 (m, 2).

1-Nitroso-2,2,6,6-tetramethylpiperidine-$^{15}N_2$ (10). A solution of 1.5 g (0.011 mol) of **9** in 13 mL of a 6.8% solution of aqueous hydrochloric acid was heated to 95 °C. To this was added 1.5 g (0.021 mol) of $Na^{15}NO_2$ (Prochemicals Limited, NJ; 95.5 atom %) in 8 mL of water. The solution was stirred at 95 °C for 48 h. The reaction mixture was allowed to cool, extracted with ether, washed with 10% aqueous hydrochloric acid, saturated aqueous sodium bicarbonate, and saturated aqueous sodium chloride, and dried (Na_2SO_4). The ethereal layer was concentrated, affording 1.2 g (64%) of a yellow oil, **10**: NMR ($CDCl_3$) δ 1.40 (d, 6, J = 2 Hz), 1.62 (d, 6, J = 2 Hz), 1.7 (m, 6).[12]

1-Amino-2,2,6,6-tetramethylpiperidine-$^{15}N_2$ (4). A solution of 1.2 g (7.0 mmol) of **10** in 4 mL of dry ether was added dropwise to 580 mg (15.3 mmol) of lithium aluminum hydride in 17 mL of 1:1 di-*n*-butyl ether–diethyl ether. The temperature was slowly raised to 95 °C with distillation of solvent; the temperature was then maintained at 95 °C for 3 h. The slurry was cooled to 0 °C, excess lithium aluminum hydride was quenched with water, and 25 mL of ether was added. The layers were separated, and the aqueous layer was washed with ether. The combined ether layers were extracted with 10% aqueous hydrochloric acid. The aqueous layer was made basic with 20% aqueous sodium hydroxide. This was extracted with ether, dried (Na_2SO_4), and concentrated, affording 1.1 g of a clear oil. This was further purified by preparative VPC (Pennwalt, 180 °C) affording a 70% yield of pure 1-amino-2,2,6,6-tetramethylpiperidine-$^{15}N_2$ (**4**). NMR ($CDCl_3$): δ 1.05 (d, J = 2 Hz, 12), 1.5 (s, 6), 2.8 (br s, 2).[12]

***N*-(2,2,6,6-Tetramethylpiperidyl)nitrene-$^{15}N_2$ (1a).** To 20 mL of anhydrous dimethyl ether, cooled to −78 °C, was added 191 mg (1.9 mmol) of triethylamine and 300 mg (1.9 mmol) of 1-amino-2,2,6,6-tetramethylpiperidine-$^{15}N_2$ (**4**) with the aid of a syringe. To this was added 3.4 g (19 mmol) of nickel peroxide[18] through a solid addition funnel with stirring over 5 min. The reaction mixture was stirred at −78 °C for 2 h, then transferred through a Teflon tube to a cooled (−78 °C) jacketed filter funnel, and filtered into a three-necked flask cooled to −78 °C. The clear purple filtrate was concentrated (~1 M) and transferred into a 10-mm NMR tube for low-temperature (−90 °C) ^{15}N NMR studies.

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(18) Nickel peroxide was prepared and the oxygen content determined by the method of Nakagawa.[19] Activation of nickel peroxide prepared in this manner with 6% sodium hypochlorite solution yielded a dark solid with an activity of (3.9–4.5) × 10^{-3} g atom of oxygen/g of nickel peroxide.

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^{13}C NMR Spectroscopic Study of the Application of the "Tool of Increasing Electron Demand" to the 7-Aryl-7-norbornenyl, 7-Aryl-7-norbornyl, 2-Aryl-2-bicyclo[2.1.1]hexyl, 1-Aryl-1-cyclobutyl, and 3-Aryl-3-nortricyclyl Cations[1]

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Abstract: The "tool of increasing electron demand", coupled with ^{13}C NMR spectroscopy as the structural probe, was used to study the nature of a series of aryl-substituted carbocations of continuing interest such as the 7-aryl-7-norbornenyl, 7-aryl-7-norbornyl, 2-aryl-2-bicyclo[2.1.1]hexyl, 1-aryl-1-cyclobutyl, and 3-aryl-3-nortricyclyl cations. This study showed structural changes in the 7-aryl-7-norbornenyl cation exclusively due to the onset of π participation even with the strongly electron-releasing *p*-methoxyphenyl substituent. It also showed the onset of increased cyclopropyl conjugation in 3-aryl-3-nortricyclyl cations with the highly electron-demanding 4-trifluoromethyl and 3,5-bis(trifluoromethyl)phenyl groups. The method is, however, not sensitive enough to detect structural changes in the 1-aryl-1-cyclobutyl and 2-aryl-2-bicyclo[2.1.1]hexyl cations whose parent systems (cyclobutyl and 2-bicyclo[2.1.1]hexyl cations) have been interpreted to involve partial or full σ bridging. The inability to detect subtle structural changes in these systems demonstrates the ineffectiveness of the tool in related solvolytic studies unless the changes are very significant.

The tool of increasing electron demand was originally applied by Gassman, Richey, and Winstein[2] to measure the electron demand of the electron-deficient carbocationic center in the 7-aryl-7-norbornenyl cations **1**. It has since become increasingly

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