Formation of 1,2-Bis(1-methyl-1,4-dihydro-4-pyridinylidene)cyclobutane by Dehydrogenated Intermolecular Cyclization of 4-Vinyl-1-methylpyridinyl Radical

Takashi Muramatsu,*[1] Azumao Toyota,[2] and Yusuke Satou[1]
[1]*Environmental Education Center, Miyagi University of Education, Sendai 980-0845*
[2]*Department of Chemistry, Faculty of Education, Art and Science, Yamagata University, Yamagata 990-8560*

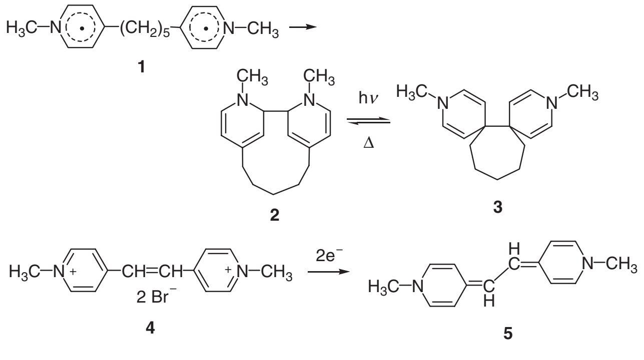
(Received June 22, 2009; CL-090586; E-mail: t-mura@staff.miyakyo-u.ac.jp)

The one-electron reduction of 4-vinyl-1-methylpyridinium bromide with sodium amalgam in degassed acetonitrile at 0 °C leads to the formation of 1,2-bis(1-methyl-1,4-dihydro-4-pyridinylidene)cyclobutane, which is characterized by means of ^{1}H NMR, ^{13}C NMR, and UV–vis absorption spectroscopy.

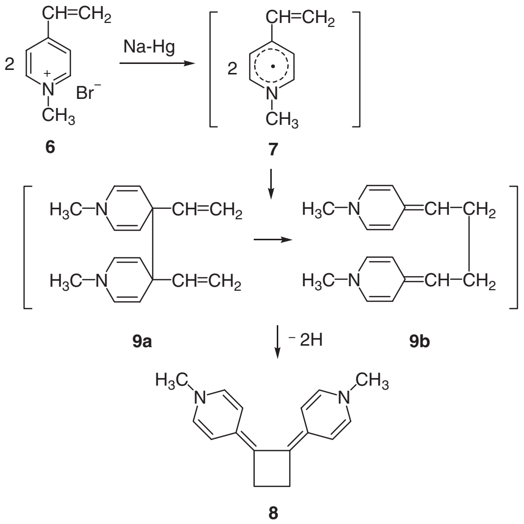
It has been established that 1-methylpyridinyl radicals with an alkyl group at the 4-position of the pyridine ring are in equilibrium with covalently bonded dimers.[1] Through photochemical bond cleavage of dimers, the physicochemical properties of the dimers were elucidated by kinetic EPR and CIDEP studies. In recent years, we have studied the properties of pyridinyl diradicals generated by the reduction of bispyridiniums of the type $Py^{+}–(CH_2)_n–Py^{+}$ ($n = 3–5$, Py^{+} = 1-methylpyridinium).[2] In the $n = 5$ bispyridinium, the resulting diradical **1** undergoes an intramolecular cyclization reaction to yield the corresponding cyclomer **2**, which is converted photochemically into the dispiro compound **3** (Scheme 1). In this connection, the two-electron reduction of 1,2-bis(1-methyl-4-pyridyl)ethylene dibromide (**4**) leads to the formation of 1,2-bis(1-methyl-1,4-dihydro-4-pyridinylidene)ethane (**5**).[3] In contrast, no chemical behavior of 4-vinyl-1-methylpyridinyl radical (**7**) and its derivatives have so far been studied because of the presence of a highly reactive vinyl group.[4–6] As part of a study on the chemical reactivities of such radical species, we carried out the one-electron reduction of 4-vinyl-1-methylpyridinium bromide (**6**) with sodium amalgam under vacuum. We will report herein that the reduction of **6** leads to the formation of a novel diamagnetic compound, 1,2-bis(1-methyl-1,4-dihydro-4-pyridinylidene)cyclobutane (**8**) in solution.

The starting material **6** was prepared by reaction of methyl bromide with 4-vinylpyridine.[7] It should be remarked that **6** is stable for a period of several days at 0 °C but polymerizes slowly on standing at room temperature to a whitish substance, poly(4-vinyl-1-methylpyridinium bromide).[8] To control polymerization, reduction of **6** was carefully carried out at 0 °C with sodium amalgam in degassed acetonitrile (Scheme 2). Reduction was followed by UV–vis absorption spectroscopy. Figure 1 shows the spectral change during the course of reduction, where spectral line (a) corresponds to the spectrum of **6**. As the reduction proceeds, the acetonitrile solution changed gradually from colorless to orange. After 0.5 h of reduction, the absorption maximum at about 260 nm decreased in intensity and the spectrum changed into spectral line (b) with the longest wavelength absorption band at 450 nm.

After 4 h of reduction, the spectrum changed into spectral line (d) and, at this stage, no spectral change was observed upon



Scheme 1.



Scheme 2.

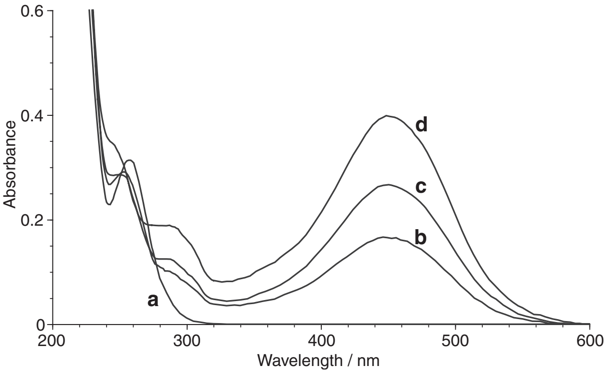


Figure 1. Absorption spectral change during the course of reduction of **6** (1.0×10^{-2} mmol) with 3% sodium amalgam (2.2×10^{-2} mmol) in degassed acetonitrile (5 mL) at 0 °C: (a) before reduction, (b) after 0.5 h, (c) after 1 h, and (d) after 4 h.

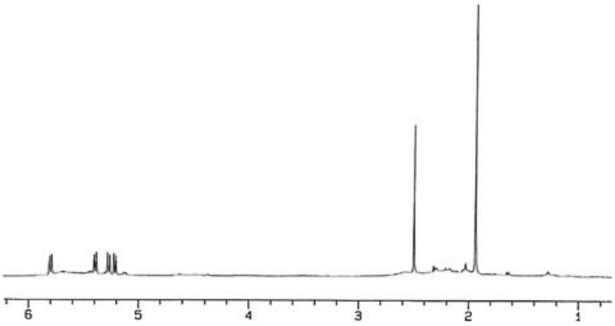


Figure 2. 400 MHz ^{1}H NMR spectrum of **8** in C_6D_6.

further reduction. Accordingly, the reduction products dissolved in a solution of acetonitrile were extracted with benzene and filtrated through a glass filter under degassed conditions.

The reduction products in the orange benzene solution are unstable to ambient oxygen, and after replacement of the C_6H_6 solvent with C_6D_6, ^{1}H NMR, ^{13}C NMR (BCM,OFR), and HC-COSY measurements for characterization were carried out in a sealed tube under vacuum. Figure 2 shows the ^{1}H NMR spectrum, suggesting that the chief reduction product should have a symmetric structure because of the spectral features being quite simple.[9] The spin-decoupling techniques reveal that the four types of ^{1}H NMR signals observed at 5.21, 5.26, 5.38, and 5.79 ppm and the respective ^{13}C NMR signals at 129.95, 130.01, 110.99, and 112.47 ppm exhibit a clear-cut correlation with a molecular structure possessing two 1,4-dihydropyridinylidene skeletons. The ^{13}C signal observed at 119.37 ppm is assigned to the C atom at the 4-position in the 1,4-dihydropyridine skeleton. Further, the ^{1}H NMR signals observed at 2.48 and 1.93 ppm, together with the respective ^{13}C signals observed at 26.26 and 39.85 ppm, are readily assigned to the protons attached to the methylene and methyl groups, respectively. It should be noted that in tetrakis(1-ethoxycarbonyl-1,4-dihydro-4-pyridinylidene)cyclobutane,[10] the ^{13}C signal observed at 113.8 ppm is assigned to the C(sp^{2}) atom of the four-membered ring. In 1,2-dimethylenecyclobutane, the ^{13}C signal of the C(sp^{3}) atom is observed at 28.1 ppm.[11] Hence, the ^{13}C NMR signals observed at 118.66 and 26.26 ppm for the reduction product are reasonably assigned to the C(sp^{2}) and C(sp^{3}) atoms of the four-membered ring in the 1,2-dimethylenecyclobutane skeleton, respectively. By reference to the ^{1}H NMR spectrum of **5**,[3] the structural assignment can be made unambiguously such that the reduction product should possess the novel structure of 1,2-bis(1-methyl-1,4-dihydro-4-pyridinylidene)cyclobutane (**8**).[12,16] From the UV–vis absorption spectroscopy, it is also added that the spectral features of **8** resemble quite well the spectrum of **5**, especially with the longest wavelength absorption band at about 450 nm.[3] This is ascribed to the fact that **5** and **8** contain two 1-methyl-1,4-dihydro-4-pyridinylidene groups which are directly conjugated together, the two chromophores being in the trans and cis configurations, respectively.

The formation of **8** from **6** can be rationalized as follows (Scheme 2). At 0 °C, the intermediate radical **7** undergoes predominantly an intermolecular radical reaction preferentially at the 4-position to give the 4,4′-dimer **9a**. This is based on AM1 calculations, showing that the spin density of **7** is largest at the 4-position.[13] Successively, **9a** is in equilibrium with its isomeric dimer **9b** formed by the Cope rearrangement,[4] where the equilibrium is largely shifted to the latter side. At the end of the reaction, **9b** is converted to **8** through an elimination of two hydrogen atoms and a successive cyclization reaction. It is added finally that contrary to our expectation, the reduction of **6** gives no trace amounts of poly(4-vinylpyridine), which is clearly confirmed by the ^{1}H NMR spectral analysis.[14]

In short, the reduction of **6** is shown clearly to result in the formation of **8** quantitatively through a dehydrogenated intermolecular cyclization of **7** in degassed acetonitrile at 0 °C. We are currently extending our studies to analogous pyridinium salts to see whether the corresponding radicals generated by reduction undergo generally intermolecular cyclization reactions to yield diamagnetic species with a four-membered ring.[15]

References and Notes

1 Y. Ikegami, *Rev. Chem. Intermed.* **1986**, *7*, 91.

2 T. Muramatsu, A. Toyota, M. Suzuki, *J. Am. Chem. Soc.* **2005**, *127*, 4572, and references therein.

3 T. Muramatsu, A. Toyota, Y. Ikegami, *J. Org. Chem.* **1995**, *60*, 4925.

4 F. H. Quina, D. G. Whitten, *J. Am. Chem. Soc.* **1977**, *99*, 877.

5 T. Nakamura, K. Takagi, Y. Sawaki, *Bull. Chem. Soc. Jpn.* **1998**, *71*, 419.

6 B. J. Coe, J. A. Harris, B. S. Brunschwig, J. Garin, J. Orduna, *J. Am. Chem. Soc.* **2005**, *127*, 3284, and references therein.

7 Bromide **6** was synthesized by reaction of methyl bromide with 4-vinylpyridine in methanol at 0 °C. **6**: 400 MHz ^{1}H NMR (DMSO-d_6): δ 8.69 (d, $J = 5.86$ Hz, 2H), 8.01 (d, $J = 5.86$ Hz, 2H), 6.96 (dd, $J = 17.60$, 10.82 Hz, 1H), 6.46 (d, $J = 17.60$ Hz, 1H), 5.97 (d, $J = 10.82$ Hz, 1H), 4.31 (s, 3H).

8 Formation of poly(4-vinyl-1-methylpyridinium bromide) is readily confirmed by the ^{1}H NMR spectral analysis. For the NMR data, see: B. L. Rivas, M. del Carmen Aguirre, E. Pereira, *J. Appl. Polym. Sci.* **2007**, *106*, 89.

9 In Figure 2, the weak proton signals observed over the ranges from 1.2–2.4 and 5.1–5.7 ppm will probably be assigned as arising from slight amounts of the intermediate **9a** and a by-product with a five-membered ring, where the latter is considered to be formed by an intramolecular hydrogen transfer and a successive cyclization reaction from **9b**.[15] Detailed analyses of such minor products are now in progress.

10 For the ^{13}C NMR data, see: M. Horner, S. Hünig, H.-U. Reißig, *Liebigs Ann. Chem.* **1983**, 658.

11 For the ^{13}C NMR data, see: H. U. Pfeffer, M. Klessinger, *Org. Magn. Res.* **1977**, *9*, 121.

12 Under degassed conditions, **8** is stable for a long period of time at room temperature. As analogous compounds to **8**, see: M. Horner, S. Hünig, *Liebigs Ann. Chem.* **1983**, 642.

13 J. J. P. Stewart, *J. Comput. Chem.* **1989**, *10*, 221. AM1 calculations of **7** show that the spin density at the 4-position (0.32) is twice larger than those at the 2(6)-positions (0.15) of the ring and the β-position (0.13) of the vinyl group.

14 Z. Chen, J. Cai, X. Jiang, C. Yang, *J. Appl. Polym. Sci.* **2002**, *86*, 2687.

15 In contrast to **6**, our preliminary study shows that the one-electron reduction of 4-styryl-1-methylpyridinium bromide results in the formation of a dimeric compound with a five-membered ring.[9]

16 Supporting Information is available electronically on the CSJ-Journal Web site, http://www.csj.jp/journals/chem-lett/index.html.