NMR Studies of Picolyl-type Carbanions. IV.[1] Anions Produced by Reactions of 2-Substituted Pyridines with Butyllithium

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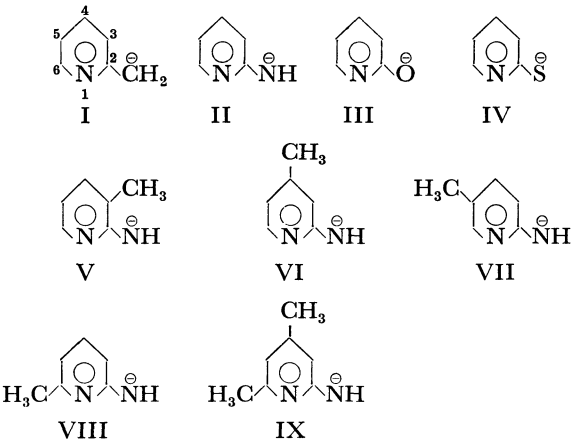
The ^{13}C and ^{1}H NMR spectra of 2-pyridylmethyl (α-picolyl), 2-pyridylamino, 2-pyridyloxy, and 2-pyridylthio anions were observed in polar solvents with lithium as a counter ion. The chemical shifts are compared with the electron densities calculated using the PPP and CNDO/2 MO methods. A linear relationship was obtained between the ^{13}C chemical shifts and π-electron densities. The charge distributions on the anions are discussed, and it is found that the 2-pyridylamino anion and its methyl derivatives can be regarded as delocalized anions with the same significance as a series of picolyl anions.

In the benzyl carbanion, a simple Hückel MO theory predicts that the excess charges are distributed at the α-, *o*-, and *p*-positions, respectively.[2] Therefore, it is reasonable to consider that carbanions which have more electronegative atoms at the *o*- or *p*-positions are more stable than the benzyl carbanion. Picolyl-type carbanions have been studied as models of these carbanions.[1,3,4] This study was extended to anions having α-atoms of nitrogen, oxygen, and sulfur. The anions prepared are numbered from II to IX as follows: (I, which was reported previously,[3,4] is presented for comparison.)



Experimental

The procedures used in this study are similar to those described in previous reports.[3,4] All the starting materials are commercially available. These materials were used after vacuum sublimation.

The ^{13}C NMR spectra were measured using a Hitachi R-20B spectrometer operating in the CW mode at 15.085 MHz. Sample concentrations were about 1.0 mol/l or more. Chemical shifts were evaluated with solvent peaks used as an internal reference. These peaks were taken to be 26.4 ppm for tetrahydrofuran (THF) and 37.0 ppm for hexamethylphosphoramide (HMPA) with respect to TMS. In the ^{1}H NMR spectra, the solvent peaks used as an internal reference were taken to be 1.79, 2.15, 2.58, and 3.28 ppm from TMS for THF, TMEDA (*N,N,N',N'*-tetramethylethylenediamine), HMPA, and DME (1,2-dimethoxyethane), respectively.

The PPP and CNDO/2 MO calculations were carried out using the Okitac-4300C and Hitachi-8450 computer systems installed at The Industrial Technology Center of Mie Prefecture and at Nagoya Institute of Technology, respectively, using modified versions of programs taken from the book of Kikuchi.[5] All the parameters used in the calculation were taken from this book and other references.[6,7] The skeletal coordinates of the anions were taken to be the same as those of pyridine.[8] The bond lengths between the 2-carbon and the α-atom used in the calculation are 1.39, 1.36, 1.31, and 1.75 Å for I, II, III, and IV, respectively.

Results and Discussion

Typical spectra of the anions are shown in Figs. 1 and 2. The ^{1}H and ^{13}C chemical shifts of both the anions and the starting materials are given in Tables 1 and 2. The results are of first order analysis.

NMR Spectra of the Anions. Typical PMR (^{1}H NMR) spectra of the anions are shown in Fig. 1. The well-separated signals permitted easy assignment. For example, the spectrum of the aromatic proton region of II, shown in Fig. 1(a), consists of four parts. The peaks appear as a doublet, a triplet, a doublet, and a triplet in passing from lower to higher field, with an integrated ratio of 1 : 1 : 1 : 1. They can, therefore, be identified as signals due to the 6-, 4-, 3-, and 5-protons. Typical CMR (^{13}C NMR) spectra are shown in Fig. 2. The signals were assigned in several ways, such as by comparison with the PMR spectra and by substitution of a methyl group for a hydrogen atom in the pyridyl ring.

From an inspection of the PMR spectra of VI, VIII, and IX shown in Fig. 1(b)—(d), the reaction sites of the starting materials having a 2-amino and 4- or 6-methyl groups with butyllithium were confirmed using chemical-shift considerations. The metal-proton exchange reaction occurred at the 2-amino group, indicating that the 2-amino group is more reactive than the 6-methyl group. The methyl protons in these anions show upfield shifts similar to the ring protons, but the shifts are about 0.1 ppm and are smaller than about 0.6 ppm in α-picolyl anions.[4] In the PMR spectra of II, V, and VII in HMPA shown in Fig. 1(a), (e)—(f), one relatively broad signal is observed in the range of 3.4—3.7 ppm. This signal may be attributed to the 2-NH.

Chemical Shift and Charge Density. In the CMR spectra of I—IV, the 5-carbon of each anion is the most shielded of the ring carbons, *i.e.*, its signal appears at a

Table 1. The proton chemical shifts of the anions and the starting materials, at 60 MHz and 31.5 °C in ppm[a)]

Compound	Solvent	Assignment				
		3-H	4-H	5-H	6-H	CH_2, CH_3
I	THF[b)]	5.64_5	6.06	4.84	6.90	$2.54(CH_2)$
	DME[b)]	5.58	6.01	4.77	6.82	$2.52(CH_2)$
	HMPA	5.16	5.68	4.33	6.81	c) (CH_2)
II	TMEDA	5.96	6.84	5.79	7.47	
	THF	5.96	6.84	5.77	7.50	
	HMPA	5.75	6.58	5.42	7.44	
III	THF[d)]	6.27	7.14	6.19	7.73	
	HMPA	6.24	7.01	5.98	7.75	
IV	HMPA	7.03	6.81	6.24	7.66	
V	HMPA		6.66	5.55	7.49	$1.89(CH_3)$
VI	DME	5.83		5.70_5	7.43_5	$1.99(CH_3)$
VII	HMPA	5.71	6.50		7.34	$1.90(CH_3)$
VIII	DME	5.89	6.84	5.77		$2.18(CH_3)$
IX	DME	5.71		5.65		1.98, $2.14(CH_3)$
2-Methylpyridine	THF[b)]	7.16	7.57	7.07	8.46	$2.48_5(CH_3)$
	DME[b)]	7.13	7.54	7.05	8.42_5	$2.48(CH_3)$
	HMPA	7.30	7.74	7.21	8.42	c) (CH_3)
2-Aminopyridine	TMEDA	6.32	7.20	6.38	7.90_5	
	THF	6.41	7.30	6.48	7.95	
	HMPA	6.60	7.29	6.38	7.86	
2-Hydroxypyridine	THF	6.46	7.43[e)]	6.19	7.43[e)]	
	HMPA	6.27	7.44[e)]	6.15	7.44[e)]	
2-Mercaptopyridine	HMPA	7.21	7.44	6.75	7.61	
2-Amino-3-methylpyridine	HMPA		7.18	6.37	7.76	$2.16(CH_3)$
2-Amino-4-methylpyridine	DME	6.26		6.31	7.79	$2.16(CH_3)$
2-Amino-5-methylpyridine	HMPA	6.51	7.12		7.69	$2.09(CH_3)$
2-Amino-6-methylpyridine	DME	6.23	7.19	6.31		$2.29(CH_3)$
2-Amino-4,6-dimethylpyridine	DME	6.06		6.17		2.10, $2.22(CH_3)$

a) Errors are estimated to be within ± 0.03 ppm. b) From Table 1 of Ref. 4, in which the measuring temperature should be 31.5 °C. c) Chemical shifts are not available because of overlapping of the large solvent peak. d) Measured at 50 °C. e) Center peak of complex multiplet.

Table 2. The carbon chemical shifts of the anions and the starting materials, in ppm[a)]

Compound	Solvent	Assignment					
		2-C	3-C	4-C	5-C	6-C	CH_2,CH_3
I	THF	164.0	115.8	131.3	97.9	148.5	$56.1(CH_2)$
	HMPA	161.5	113.7	129.9	92.5	149.2	$58.8(CH_2)$
II	THF	173.7	113.0	135.9	104.4	147.8	
	HMPA	173.0	111.7	134.0	101.3	148.2	
III	HMPA	173.3	114.0	135.8	106.3	146.6	
IV	HMPA	183.5	128.6[b)]	132.2[b)]	110.9	146.1	
V	HMPA	172.2	115.6	133.4	101.7	146.1	$18.9(CH_3)$
VII	HMPA	171.6	111.4	135.6	107.9	147.2	$17.3(CH_3)$
2-Methylpyridine	THF	159.0	123.2	136.2	120.8	149.8	$24.4(CH_3)$
	HMPA	157.9	122.9	136.0	120.5	149.0	$24.1(CH_3)$
2-Aminopyridine	THF	160.9	108.9	137.9	113.2	148.7	
	HMPA	160.5	108.5	136.8	111.7	147.8	
2-Hydroxypyridine	HMPA	162.7	120.3	136.1	104.6	140.3	
2-Mercaptopyridine	HMPA	179.9	133.6[b)]	135.8[b)]	111.3	137.3	
2-Amino-3-methylpyridine	HMPA	158.6	116.4	137.1	113.2	145.4	$16.9(CH_3)$
2-Amino-5-methylpyridine	HMPA	158.3	108.4	138.0	121.0	147.4	$17.1(CH_3)$

a) Errors are estimated to be within ± 0.3 ppm. b) Assignment uncertain.

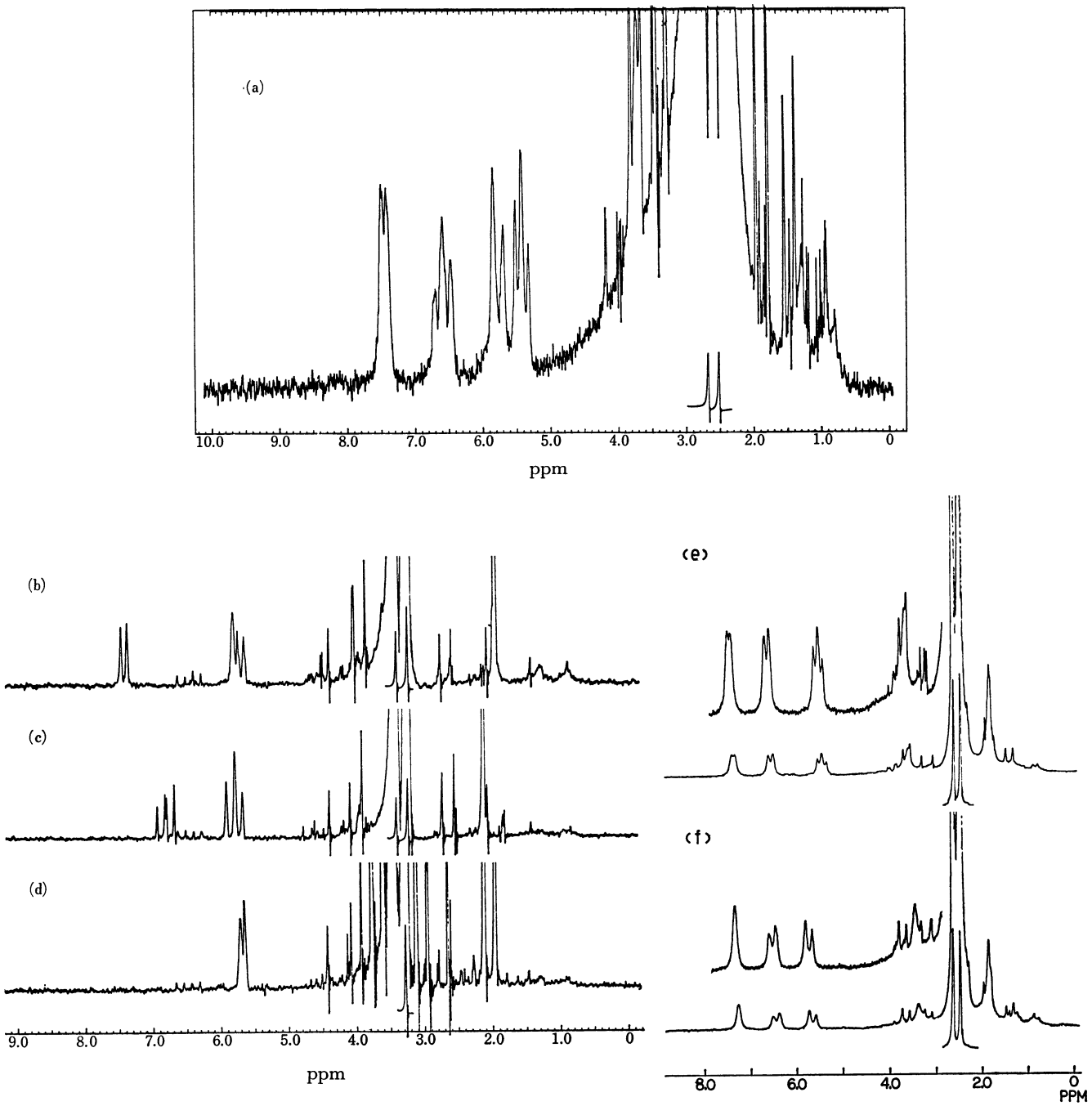


Fig. 1. PMR spectra of pyridylamino anions; (a) II in HMPA, (b) VI, (c) VIII, (d) IX in DME, and (e) V, (f) VII in HMPA.

higher field. In addition, the 5-carbon signals of I and II are shifted appreciably in the upfield direction relative to those of the starting materials. In the PMR spectra, the same tendency is observed for the 5-protons. It is apparent that the excess charges transferred from the α-atom to the pyridyl ring in I and II have the strongest influence at the 5-position, *i.e.*, the 5-carbon and proton chemical shifts are most affected by the charges. The 5-carbon and proton signals appear at higher field in the increasing order, IV, III, II, and I. Thus, it may be possible to consider that the excess charges transferred onto the ring increase in the same order.

In order to clarify the relationship between the carbon or proton chemical shifts and the π-electron densities, these densities were calculated using the PPP and CNDO/2 MO methods for I—IV and I—III, respectively. The π-electron densities calculated using the PPP method are plotted against the carbon chemical shifts in Fig. 3. The plot is linear although the 2-carbons and the methylene carbon of I deviate from linearity. One cause of this deviation may be the hybridization change in the α-atoms. On the other hand, in Fig. 4 are plotted the π-electron densities

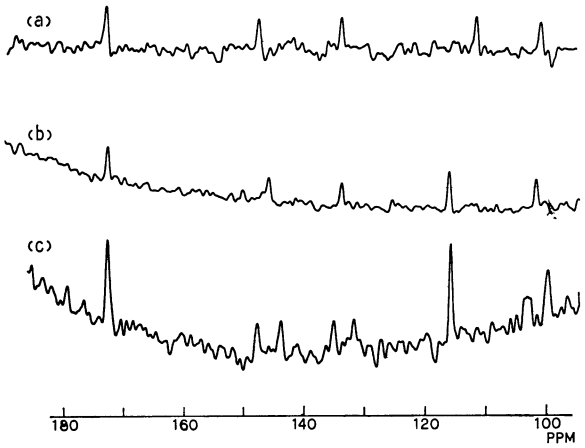


Fig. 2. CMR Spectra of the aromatic carbon region of pyridylamino anions; (a) II, (b) V in HMPA (proton noise decoupling), and (c) V in HMPA (off resonance decoupling).

calculated using the CNDO/2 method. The plot of the 4-carbons deviates considerably from linearity, as compared with the plot of the others, that is, the densities are underestimated. The cause of this is unclear at present. Next, the relation between the ring-proton chemical shifts for each anion in I—III and the π-electron densities of the adjacent carbons calculated using the PPP method is linear, and the plot of I is most distinctly linear.

The charge distributions on I—IV are discussed on the basis of the relationship shown in Fig. 3. This relationship implies that, in spite of changes in the α-atoms, the π-electron densities of the ring carbons in these anions can be evaluated from the carbon chemical shifts using an identical scale. The δ-values of the ring-carbon chemical shifts of each anion increase in the order 5-, 3-, 4-, 6-, and 2-carbons, indicating that the π-electron densities decrease in the same order. Of these anions, the 6-carbon chemical shifts are almost the same, the shift range is about 3 ppm, and, of course, is smaller than about 18 ppm for the 5-carbons. This may be due to the strong induction effect caused by the neighboring nitrogen atom. Here, from an assignment of both the 3- and 4-carbon signals of IV, the calculated charge densities distinguish the 3- from the 4-carbon. In this sense, this assignment may be uncertain. Therefore, at least in I—III, the π-electron distribution patterns are clearly analogous, *i.e.*, I—III are anions of the same type. The ring nitrogens in I—III are expected to follow the same tendency as the 5-carbons, over which the charges transferred from the α-atoms are largely distributed and the π-electron densities increase in the order III, II, and I. The π-electron densities of the ring nitrogen calculated using both the PPP and CNDO/2 methods also increase in the order III, II, and I.

The PMR spectra of I in THF were temperature dependent; chemical shifts of the ring protons at −25 °C were 0.10—0.15 ppm upfield from the 31.5 °C values. This variation is larger than those for benzyllithium and 1- and 2-naphthylmethyllithium.[9] This relatively large temperature dependence shows that solvent separation in I occurs to an appreciable extent. In addition to this fact, the ring proton and carbon signals in HMPA move to higher field in comparison with those in THF, *i.e.*, the excess charges on the α-atom are transferred more into the ring for HMPA than for

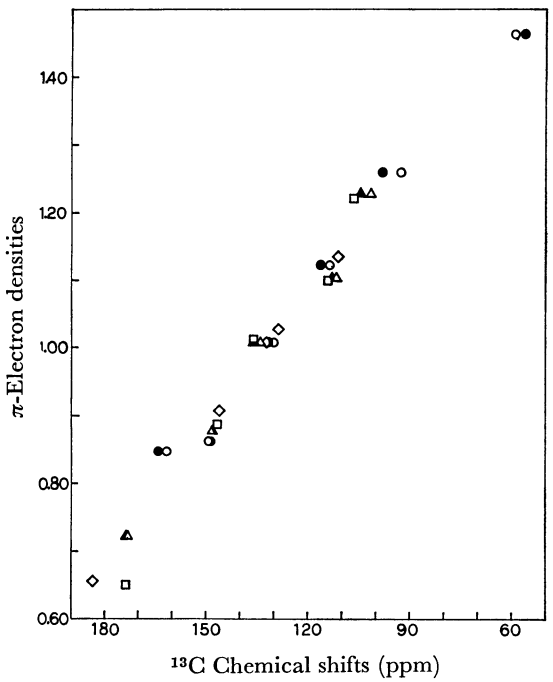


Fig. 3. π-Electron densities (PPP method) *vs.* ^{13}C chemical shifts.
○ I in HMPA, ● I in THF, △ II in HMPA, ▲ II in THF, □ III in HMPA, ◇ IV in HMPA.

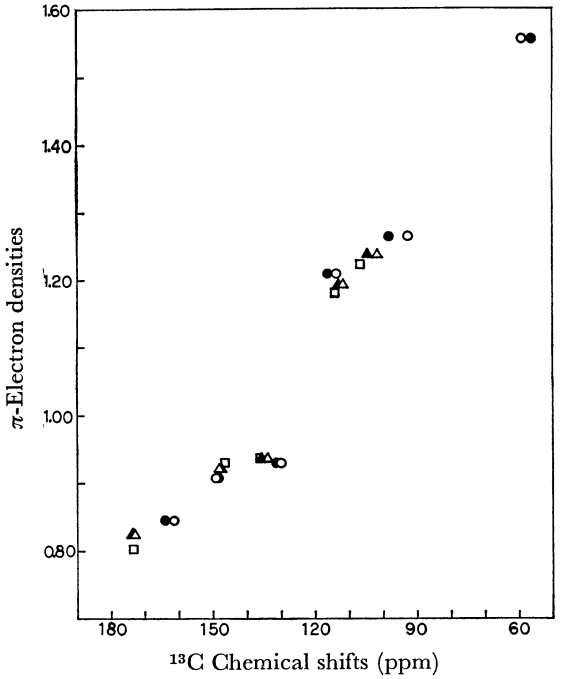


Fig. 4. π-Electron densities (CNDO/2 method) *vs.* ^{13}C chemical shifts.
○ I in HMPA, ● I in THF, △ II in HMPA, ▲ II in THF, □ III in HMPA.

Table 3. Comparison of charge densities calculated using the PPP and CNDO/2 MO methods for the 2-pyridylmethyl, -amino, -oxy, and -thio anions

Compd	I			II			III			IV
Atom	PPP	CNDO/2		PPP	CNDO/2		PPP	CNDO/2		PPP
		$\pi(P_z)$	Total		$\pi(P_z)$	Total		$\pi(P_z)$	Total	
1-N	1.437	1.292	5.305	1.391	1.247	5.296	1.380	1.229	5.300	1.269
2-C	0.847	0.846	3.802	0.722	0.822	3.753	0.650	0.802	3.712	0.655
3-C	1.122	1.209	4.153	1.103	1.193	4.157	1.099	1.180	4.166	1.027
4-C	1.008	0.928	3.941	1.008	0.934	3.944	1.012	0.936	3.946	1.008
5-C	1.260	1.265	4.171	1.227	1.237	4.156	1.221	1.222	4.149	1.135
6-C	0.863	0.907	3.871	0.878	0.920	3.880	0.887	0.928	3.882	0.907
α-X	1.462	1.554	4.366	1.672	1.647	5.520	1.751	1.702	6.592	2.000
3-H			1.046			1.042			1.039	
4-H			1.070			1.069			1.070	
5-H			1.060			1.058			1.057	
6-H			1.090			1.090			1.089	
α-H			{1.064 1.061			1.035				

THF. In this sense, I is more stable in HMPA than in THF. Consequently, I exists as either solvent separated ion pairs or free ions in HMPA. The ring protons of II—III and the ring carbons of II in HMPA are also more shielded than those in THF. The 5-proton chemical shift of each anion in I—III shows the largest variation with a change in solvents from THF to HMPA, and the magnitudes are 0.21, 0.35, and 0.51 ppm for III, II, and I, respectively. For the 5-carbon chemical shifts of both I and II, the same tendency is observed, and the magnitudes are 5.4 and 3.1 ppm. With a change in solvents, the densities at the 5-position vary greatly. In HMPA, the PMR spectral patterns of II and III are similar to that of I. From these results for II and III in polar solvents and the relationship among I—III as shown in Fig. 3, it is possible to consider that II and III also exist as analogous ions in HMPA, as does I, and, furthermore, so may IV.

The 5-carbons in V and VII show upfield shifts of about 10 ppm similar to that in II. This magnitude is smaller than about 25 ppm in I, but much larger than about 0 ppm in III and IV. This suggests that the excess charges on the α-nitrogen atoms are appreciably transferred onto the pyridyl rings with a change in starting materials to lithium salts in polar solvents. Therefore, anions II and V—IX, whose α-atoms are nitrogens, can be regarded as delocalized anions with the same significance as a series of picolyl anions.

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