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29. Yutaka Kawazoe, Mitsuhiro Tsuda, and Masako Ohnishi : Stereochemistry in Solution. II.[*1] Factors influencing the Relaxation Time T_1 of ^{14}N-Nucleus in Quaternary Amine Cations.[*2]

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It was shown that the relaxation time of ^{14}N nucleus was strongly dependent on the nature of solvent, temperature and stereochemical structure of N,N-dimethylpiperidinium derivatives.

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With regard to ^{14}N nucleus, which has a spin number of an unity, spin lattice relaxation can be performed through interaction of the nuclear quadrupole moment with fluctuating electric field gradients in addition to the usual spin lattice relaxation which is attributed to energy transfer through magnetic dipolar interactions. This additional relaxation process in ^{14}N nucleus results in a remarkable decrease in the spin lattice relaxation time, T_1, so that the spin-spin coupling of ^{14}N nucleus with neighboring protons is usually unobservable because of the uncertainty of each spin state of ^{14}N nucleus.[1,2] However, since this relaxation is caused by the quadrupolar coupling with electric field gradient at ^{14}N nucleus, no consideration needs to be paid to the quadrupolar relaxation when highly symmetrical electric field gradient is achieved around the ^{14}N nucleus. It is of interest in organic chemistry to determine which chemical structure of nitrogens satisfies the condition of symmetric highly enough for giving the spin splitting to the signal. It is known that quaternary amines and isonitrils[3] are of this case and that, however, not all the quaternary nitrogens take part in splitting signals of the neighboring protons even in the cases where the substituents of the nitrogen are all alkyl groups of $N(alkyl)_4^+$.[4~8] This paper concerns the structure-dependence of the decoupling of the indirect N-H spin coupling, $J_{NH(\beta)}$, in quaternary methylpiperidinium ions. The purpose for this study is to obtain a new insight into the fine stereochemistry of quaternary amine salts in solution, as one of our serial studies on "stereochemistry in solution". Some experimental results were recently reported on the quadrupolar relaxation of this nucleus but detailed informations have not yet been obtained so far.

Results and Discussion

It seems to be concluded from the experimental results[4~8] that the spin-spin coupling of the ^{14}N nucleus is larger in the magnitude with the protons on the β-carbons

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[*2] This paper also constitutes Part XII of a series entitled "Nuclear Magnetic Resonance Studies" by T. Okamoto and Y. Kawazoe.

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1) J.A. Pople, W.G. Schneider, H.J. Bernstain: "High Resolution Nuclear Magnetic Resonance," p. 214, 227 (1959). McGraw-Hill Co. (New York).
2) J.A. Pople: Mol. Phys., **1**, 168 (1958).
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8) Unpublished data of Dr. Tori's group of Shionogi Co., Osaka.

than those on the α-carbons. This is true for the spin coupling constants of ^{117}Sn,[9] ^{119}Sn,[9] ^{199}Hg,[10,11] ^{207}Pb,[12] and ^{13}C[13] with protons and also ^{15}N with proton.[14,15] For instance, β-proton signal of tetraethylammonium bromide in wateris split by 1.7 c.p.s., whereas α-proton signal is just broadened. Our attention will be focussed in this paper on the nitrogen and β-proton coupling, $J_{NH(\beta)}$, and discussions will be made on the factors which are expected to influence the quadrupolar relaxation of the ^{14}N nucleus, namely, to be effective in decoupling of these couplings. The results will be described under the following four factors.

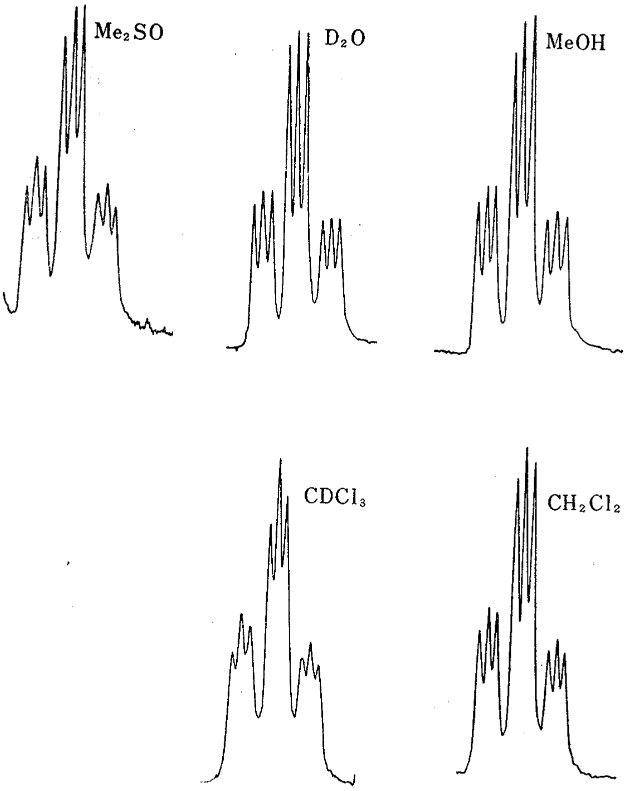

Fig. 1. Solvent Effect on the Signal Shape of Methyl Protons of Tetraethylammonium Bromide

Dependence on the Solvent Nature

The proton magnetic spectra of tetraethylammonium bromide were measured at 23° in several kinds of solvents, that is, in heavy water, methanol, dimethylsulfoxide, methylene chloride and chloroform. The spectra, reproduced in Fig. 1, clearly show the solvent-dependence of the fine structures on the triplet of methyl protons. The most deeply notched triplet was observed in heavy water or methanol and it became broadened most in chloroform into a hazy triplet. This tendency was maintained for all the quaternary amines examined in the present study. Thus, no further splitting nor remarkable line-broadening was observed on the doublet for 2-methyl protons of any N,N-dimethylpiperidinium salts in chloroform, whereas triple splitting or considerable line-broadening was found in the heavy water or methanol solutions. The spectra of 2,N,N-tri- and *cis*-2,6,N,N-tetramethylpiperidinium iodides were reproduced in Figs. 2(a) and 2(b), respectively. Similar solvent-dependence was observed at elevated temperatures (Fig. 3). It can, therefore, be concluded that the relaxation time of ^{14}N nucleus in these cations is considerablly dependent upon the nature of the solvent. Now, let us consider the mechanisms of the change in the relaxation time. One possibility is the formation of more intimate ion-pair with the counter anion in less polar solvent, which may be attributed mainly to the dielectric nature of the solvent. In this mechanism, electronic symmetry of ^{14}N atom is distorted by an approach of the anion from most favorable site depending on its stereochemical structure. An alternative mechanism is the unfavorable increase in the correlation time caused mainly by increase in viscosity of the solution. Dielectric constants and viscosities of

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[10] *Idem* : J. Am. Chem. Soc., **82**, 34 (1960).
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[12] E. B. Baker : *Ibid.*, **26**, 960 (1957).
[13] G. J. Karabatos, J. D. Graham, F. Vane : J. Am. Chem. Soc., **83**, 2778 (1961).
[14] G. O. Dudek, E. P. Dudek : *Ibid.*, **86**, 4283 (1964).
[15] Y. Kawazoe, K. Tori, M. Ohnishi, K. Aono : To be published.

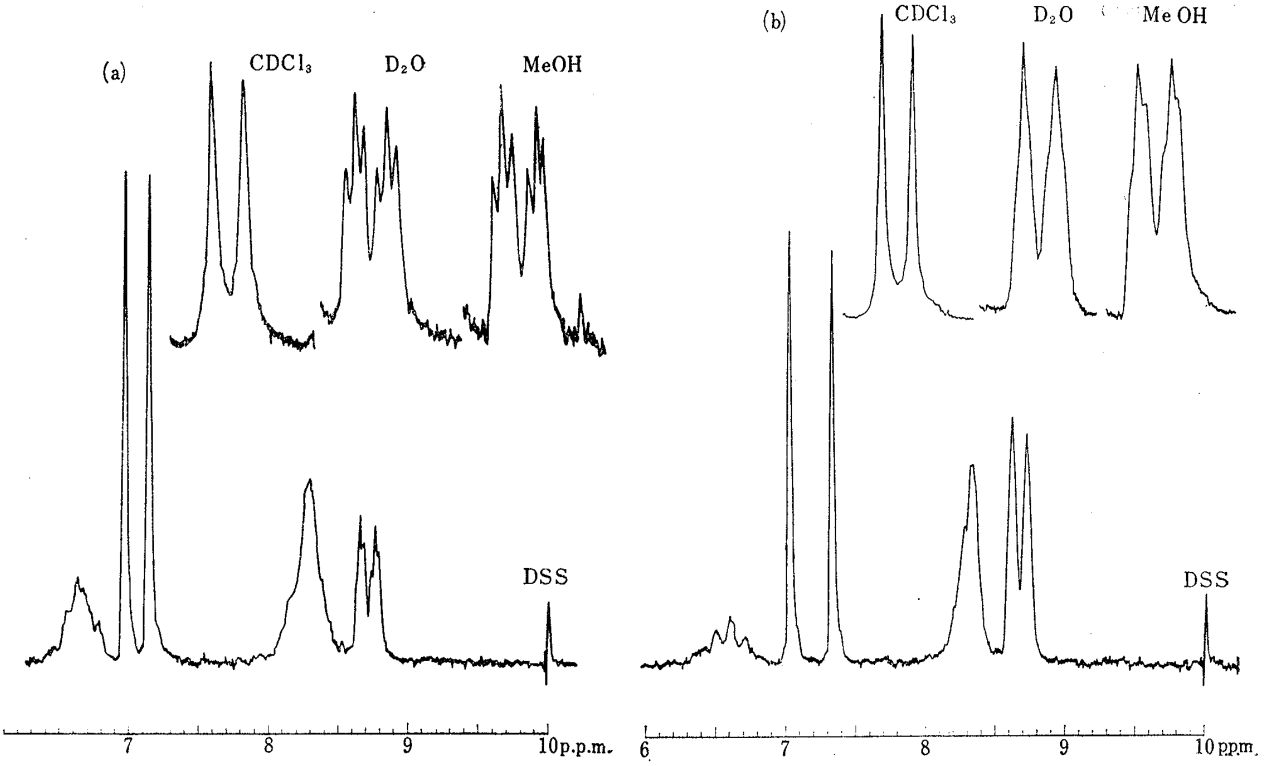

Fig. 2. Solvent Effect on the Signal Shape of α-Methyl Protons of 2,N,N-Trimethylpiperidinium Iodide (a) and *cis*-2,6,N,N-Tetramethylpiperidinium Iodide (b)

the solvents used are tabulated in Table I. It seems to be conclusive that the solvent-dependence of T_1 is based on the solvent-dependence of the stereochemical structure of the molecule.

Table I. Dielectric Constants and Viscosity of the Solvents Used

Solvent	Dielectric constant (ε)	Viscosity (centipoise)
H_2O	80 (20°)	1.01(20°), 0.55(50°)
Me_2SO	48.9	1.1 (27°)
CH_3OH	32.4(20°)	0.62(20°), 0.39(50°)
CH_2Cl_2	10.5(20°)	0.44(20°), 0.36(40°)
$CHCl_3$	5.0(20°)	0.57(20°), 0.43(50°)

Dependence on Temperature

In Fig. 3 and 4 are shown spectra of tetraethylammonium bromide and *cis*-2,6,N,N-tetramethylpiperidinium iodide at various temperatures. At higher temperature, more deeply notched spectrum was obtained in either solvent. But some of the cations examined caused only line-broadening even at about 100°. It is, indeed, a reasonable explanation that higher temperature enables easier rotational and translational motion of/in the molecule in solution, resulting in smaller correlation time. But an alternative mechanism that a better symmetry in the electronic structure of the nitrogen might be attained by raising temperature is also probable.[7,16,17]

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16) J.D. Roberts: J. Am. Chem. Soc., **78**, 4495 (1956).
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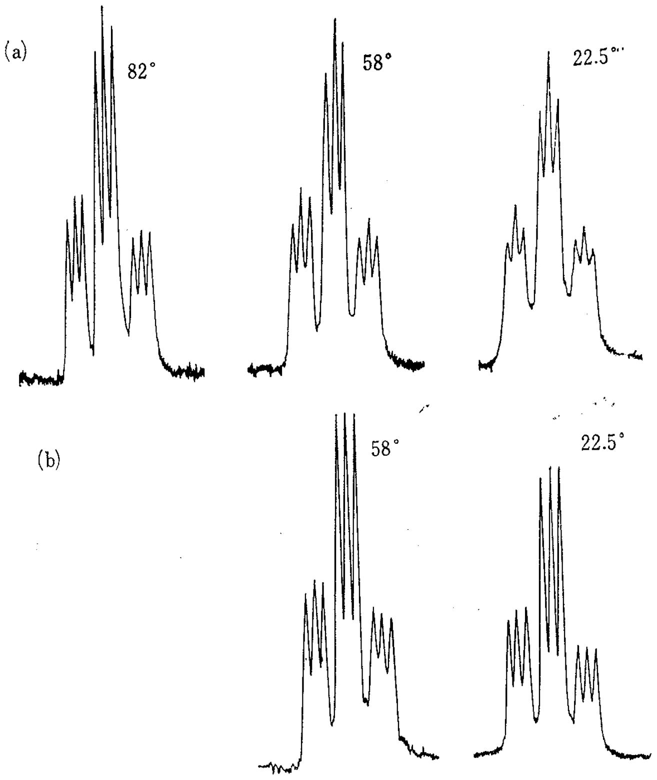


Fig. 3. Temperature-dependence of the Signal Shape of Methyl Protons of Tetraethylammonium Bromide in Chloroform (a) and in Water (b)

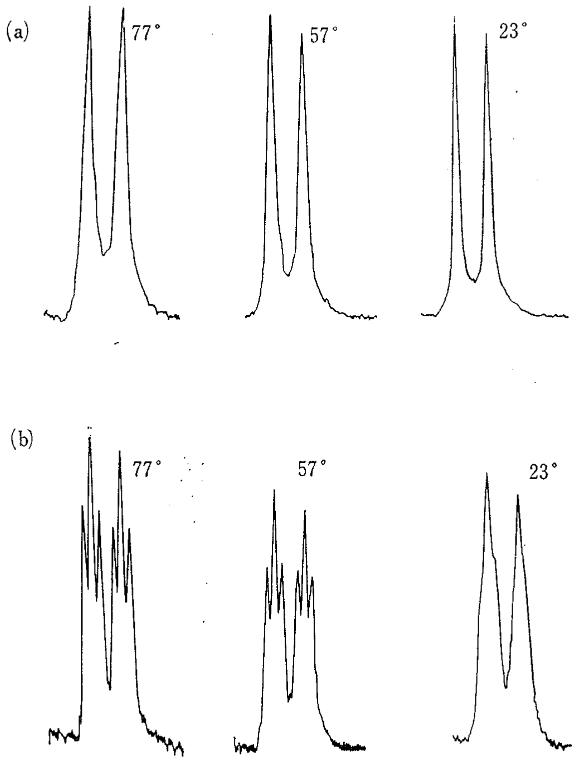


Fig. 4. Temperature-dependence of the Signal Shape of Methyl Protons of *cis*-2,6,N,N-Tetramethylpiperidinium Iodide in Chloroform (a) and in Water (b)

Dependence on Stereochemistry of Piperidinium Cations

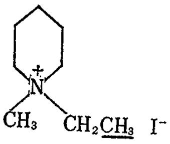
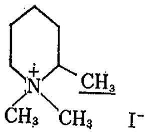
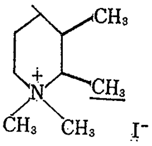
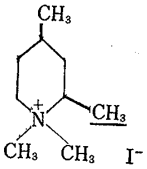
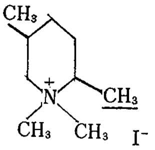
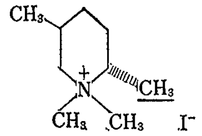
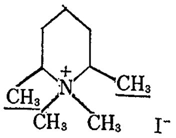
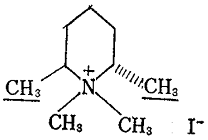
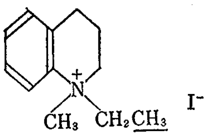
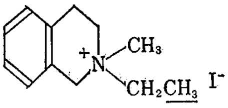
Our compounds listed in Table II are constituted of only sp^3 carbons except for the nitrogen concerned, including no strongly strained alicyclic ring either. Therefore, the results shown in Table II can be considered as caused by steric distortion of four substituents bonded to the nitrogen concerned. It can be considered that one can qualitatively evaluate the relaxation times of ^{14}N nucleus by comparing the notching depth of the methyl proton signals,[2] provided that the coupling constants, $J_{NH(\beta)}$, of these cations are almost equal to each other.[4,6] In chloroform solutions of piperidinium cations, no clear splitting was observed, line broadening being found in some cases. Qualitative comparisons were made of the 2-methyl signals of these compounds, as shown in Table II, ⧻, ⧺, and + representing those having clearer triply splitting structures in this order and − representing just broadened lines, and − − meaning almost sharp lines. Rough estimation of T_1 can be carried out from an equation due to Pople,[2] $\eta=10\pi T_1 J$, where η is a dimentionless parameter reflecting the degree of resolution of a proton multiplet. Thus, T_1 of ⧻ compounds (estimated roughly to be $\eta^2 \geqq 10^3$) may be longer than 0.56 sec. and that of − − compounds ($\eta^2 \leqq 1$) may be shorter than 0.02 sec.

No definite correlation seems, however, to be derived only from these data between T_1 and chemical structure nor rapid ring-conversibility.

Dependence on the Kind of the Counter Anion

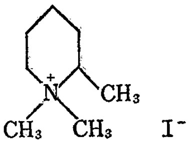
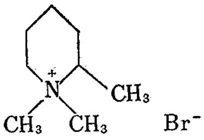
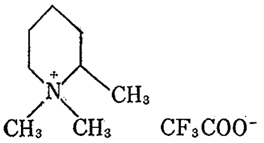
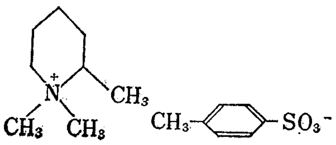
The spectra of various kinds of salts of 2,N,N-trimethylpiperidinium cation were measured, that is, the bromide, iodide, trifluoroacetate and *p*-toluene sulfonate. Table

Table II. Structure-dependence of Quadrupolar Relaxation effect of ^{14}N Nucleus on the Signal Shape of the Methyl Protons Underlined

Solvents / Compound	D_2O	$CDCl_3$
$(\underline{CH_3}CH_2)_4N^+Br^-$	⧻	+
	⧺	−
	⧺	−
	+	−
	±	− −
	±	− −
	±	− −
	±	− −
	±	− −
	−	insoluble
	−	〃

Cis-trans assignment of the ring methyls were tentatively done by NMR data, details being reported in a forthcoming paper.

Table III. Effect of the Counter Anion on the Signal Shape of α-Methyl Protons of 2,N,N-trimethylpiperidinium Salts

	In D_2O		In $CHCl_3$
	$J_{NH(\beta)}$	half width	half width
	1.75(c.p.s.)	5.00	3.47
	1.77	5.10	3.35
	1.76	4.95	3.55
	1.80	5.37	3.05

III shows the splitting constants and half-width of the triplet of these salts in water and in chloroform. No remarkable difference was observed in the signal width between these salts.

Conclusion

It can be concluded that the relaxation time of ^{14}N nucleus is strongly dependent upon the nature of solvent, temperature and electronic structure of the nitrogen but hardly upon the sort of counter anions. Two reasons for this difference are conceivable: the distortion of the symmetry of the electronic structure of the nitrogen and the change in the ease of molecular reorientation or, more exactly, the change in the correlation time. The former case is closely related to the fine stereochemistry of quaternary amines in solution and further investigations from this point of view might yield useful informations on the stereochemistry.

Experimental

Compounds

The quaternary amines examined in this study were synthesized by the authentic preparative methods.[18]

NMR measurements

Spectra were obtained by an JNM-3H-60 spectrometer of Japan Electron Optics Lab. Co. operating at 60 Mcps. Degassing effect on resolution of signal splitting seemed to be very small in most cases. Sample concentrations were 50 to 100 mg. in 0.5 ml. of the solvent.

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[18] Y. Kawazoe, M. Tsuda, M. Ohnishi: This Bulletin, **15**, 51 (1967).