Ultraviolet Absorption Spectra of Three Isomeric Pyridine Monocarboxylic Acids and Their N-Oxides

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In a previous paper[1], the author has reported the effect of hydroxymethyl group on the absorption spectra of pyridine and pyridine *N*-oxide. In order to obtain the knowledge on the effect of an electron-attracting substituent, the present author measured the ultraviolet absorption spectra of three isomeric pyridine monocarboxylic acids and their *N*-oxides in various solvents, and discussed the solvent effects on their spectra and also the effect of a carboxyl group on the absorption spectra of pyridine and pyridine *N*-oxide. The results of these spectral measurements were shown to be interpreted under the assumption of the intramolecular hydrogen bond formation or the steric interaction in picolinic acid and its *N*-oxide.

Experimental

Commercial picolinic, nicotinic, and isonicotinic acid were purified by recrystallization from ethanol several times.

Picolinic acid: m. p., 135°~7°C; nicotinic acid: m. p., 232°C; isonicotinic acid: m. p., 315°C.

Picolinic[2] and isonicotinic acid *N*-oxide[3] were synthesized by the method given in all kinds of literature, and nicotinic acid *N*-oxide was synthesized by treating the nicotinic acid with aqueous hydrogen peroxide in glacial acetic acid in a similar way as for isonicotinic acid *N*-oxide, all of which were purified by recrystallisation from ethanol or methanol several times.

Picolinic acid *N*-oxide: m. p., 160°C, (from ethanol); nicotinic acid *N*-oxide: m. p., 247°~8°C, decomp., (from methanol); isonicotinic acid *N*-oxide: m. p., 260°C, (from methanol).

Solvents used in the spectral measurements were dioxane, ethanol and water which were purified according to the directions described in "Organic Solvents"[4]. The ultraviolet absorption spectra were measured with a Shimadzu Quartz Spectrophotometer Type QB-50, using a fused quartz cell of 1 cm. thickness.

Results and Discussion

Figs. 1 to 6 show the absorption curves of three isomeric pyridine monocarboxylic acids and their *N*-oxides in various solvents, and the schematic spectra of these compounds are given in Fig. 7. The observed values of maximum wavelength, wave number, and molar extinction coefficient are listed in Table I.

(1) Pyridine monocarboxylic acids:— From the spectral measurements of these compounds, the following results were obtained for the absorption appearing in the region between 35000 cm^{-1} and 40000 cm^{-1}.

a) The absorption maximum of picolinic acid does not essentially shift in solvents such as dioxane, ethanol and water, but that of nicotinic or isonicotinic acid shifts to the shorter wavelength in the above order of solvents.

b) The absorption maxima of all these compounds occur in the shorter wavelength than that of benzoic acid[5].

c) The absorption at about 38900 cm^{-1} (257 mμ) of pyridine in ethanol shifts to longer wavelength by the introduction of a carboxyl group to the pyridine nucleus[8].

The 38500 cm^{-1} (260 mμ) absorption of benzene shifts to the longer wavelength by substituting a carboxyl group into the benzene nucleus. This shift is regarded as mainly due to the electron migration effect from the benzene ring to the carboxyl group[9]. Moreover, it may be

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[1] N. Hata. This Bulletin, in press.

[2] R. Adams and S. Miyano, *J. Am. Chem. Soc.*, **76**, 3168 (1954).

[3] E. Chigi, *Ber.*, **75**, 1318 (1942).

[4] A. Weissberger and E. S. Proskauer, "Organic Solvents" 2nd. Ed., (1955).

[5] The absorption maximum of benzoic acid occurs in 36750 cm^{-1} (272 mμ) in dioxane or ethanol[6] and 36890 cm^{-1} (271 mμ) in water[7], where the value of absorption maximum in various solvents shows that of the greatest intensity in the fine structures of this band.

[6] H. E. Ungnade and R. W. Lamb, *J. Am. Chem. Soc.*, **74**, 3789 (1952).

[7] C. Moser and A. I. Kohlenberg, *J. Chem. Soc.*, **1950**, 804.

[8] In this paper, the effects of a carboxyl group on the absorption spectra of pyridine and pyridine *N*-oxide are discussed in relation to the spectra of ethanol solution, since the compounds used in this experiment are insoluble in non-polar solvents.

[9] About the effect of the substituent on the electronic absorption spectrum of benzene, see, for example, W. West, "Chemical Applications of Spectroscopy", Chapter V, New York, (1956).

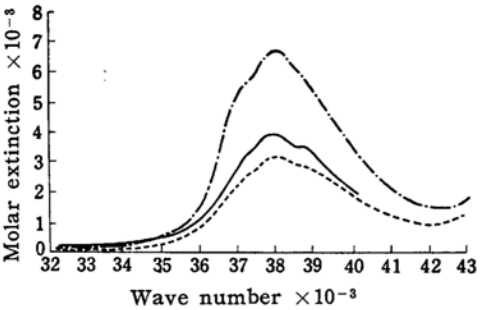


Fig. 1. Absorption curve of picolinic acid.
—— Dioxane. - - - Ethanol. -·-·- Water.

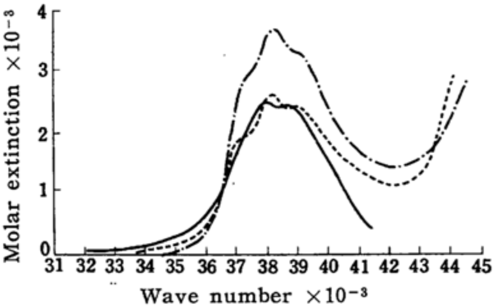


Fig. 2. Absorption curve of nicotinic acid.
—— Dioxane. - - - Ethanol. -·-·- Water.

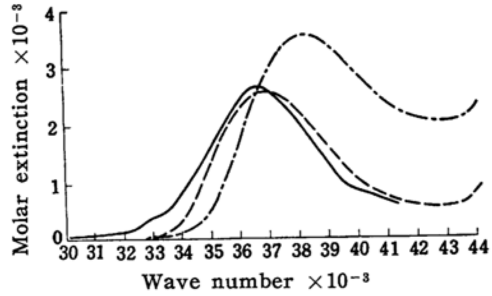
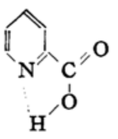


Fig. 3. Absorption curve of isonicotinic acid.
—— Dioxane. - - - Ethanol. -·-·- Water.

expected that there exists a qualitatively parallel relationship between the wavelength shift and the magnitude of the electron migration. If one of the C—H groups of benzene is replaced by a nitrogen atom, the electron migration possibly decreases to some extent compared with the case of benzoic acid, since the electron attracting power of the nitrogen atom of pyridine nucleus competes with that of the carboxyl group. Thus, pyridine monocarboxylic acid absorbs the shorter wavelength light than benzoic acid does. Here, since the competetive resonance interaction between the nitrogen atom and the carboxyl group is the greatest in nicotinic acid, its absorption spectrum appears in the region of the shorter wavelength than that of the other two acids.

It is of interest to know that the absorption maximum of pyridine shifts to longer wavelength by the introduction of a carboxyl group upon the pyridine nucleus. Particularly in the case of 2-carboxyl substitution, the absorption maximum locates at the shorter wavelength than that of 4-carboxyl substitution. These facts are remarkably different from the effect of substitution of an electron-repelling group (e.g., methyl, amino, halogen etc.). In this case, the absorption maximum of 2-substituted derivatives occurs in the longer wavelength than that of 4-substituted ones[1,10]. To explain such a displacement toward shorter wavelength of the absorption band of picolinic acid (when compared with the absorption band of isonicotinic acid), we assumed the formation of the intramolecular hydrogen bond as shown in (A) for picolinic acid. This assumption leads to the conclusion that the electron migration from the pyridine ring to the carboxyl group in picolinic acid should be somewhat prevented by the increase in the electronegativity of the nitrogen atom caused by the formation of such an intramolecular hydrogen bond, from which the hindrance of resonance of this molecule may result. Consequently, the absorption spectrum of picolinic acid appears in the shorter wavelength than that of isonicotinic acid in which the intramolecular hydrogen bond does not occur.



(A)

Moreover, it seems to be accepted as an additional evidence for such an intramolecular hydrogen bond formation that the absorption maximum in dioxane solution of picolinic acid does not shift in solvents such as ethanol and water acting as a proton donor to the nitrogen atom of pyridine nucleus.

(2) Pyridine monocarboxylic acid *N*-oxides:—From the spectral measurements of these compounds, the following results are obtained for the absorption appearing in the region between 30000 and 41000 cm^{-1}.

a) The absorption maxima of these

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[10] H. Tsubomura, *J. Chem. Soc. Japan, Pure Chem. Sec.*, (*Nippon Kagaku Zassi*), **78**, 293 (1957).

compounds show a greater blue shift with the change of the solvents from dioxane to ethanol and water[11]. However, the extent of the shift in picolinic acid *N*-oxide is smaller than that in nicotinic or isonicotinic acid *N*-oxide.

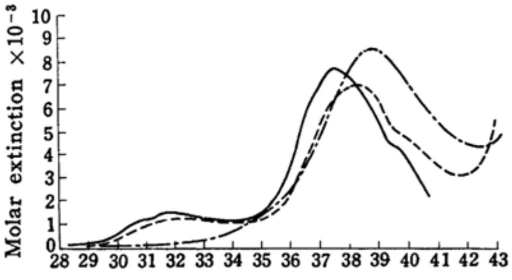


Fig. 4. Absorption curve of picolinic acid *N*-oxide.
—— Dioxane. - - - Ethanol. -·-·- Water.

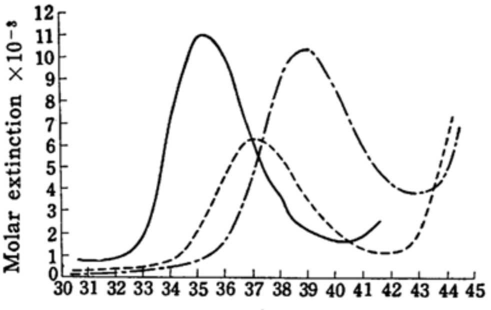


Fig. 5. Absorption curve of nicotinic acid *N*-oxide.
—— Dioxane. - - - Ethanol. -·-·- Water.

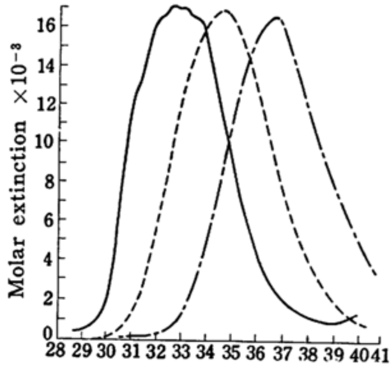


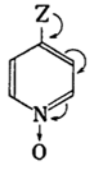
Fig. 6. Absorption curve of isonicotinic acid *N*-oxide.
—— Dioxane. - - - Ethanol. -·-·- Water.

b) The absorption spectrum of picolinic acid *N*-oxide shows considerable similarity to that of picolinic acid in the value of maximum wavelength. On the other hand, for nicotinic or isonicotinic acid *N*-oxide, the maximum wavelength is noticeably different from that of the corresponding acid.

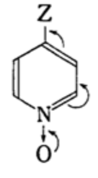
c) The maximum wavelength of isonicotinic acid *N*-oxide in water is nearly the same value with that of isonicotinic acid in dioxane, while the maximum wavelength of picolinic acid *N*-oxide in water locates at the shorter wavelength than that of the corresponding acid in dioxane.

d) The absorption at about 37700 cm^{-1} (265 mμ) of pyridine *N*-oxide in ethanol shifts to the longer wavelength by the substitution of a carboxyl group at 3- or 4-position and to the shorter wavelength by that at 2-position.

It is infarred from the value of dipole moment[13] and the chemical reactivity[14] of pyridine *N*-oxide that the electron migration both into the pyridine ring from the N—O group, and in the opposite direction, is possible. From the studies of dipole moments of 4-substituted pyridine *N*-oxides by Katritzky et al.[15], however, it was shown that the N—O group behaves as an electron-attracting group whën 4-substituent (Z) is an electron-repelling group as shown in (B). On the other hand, the N—O group shows a character acting as an electron repelling group when 4-substituent (Z) is an electron attracting group as shown in (C). Therefore, if one assumes the N—O group as an electron-repelling group in pyridine monocarboxylic acid *N*-oxides, the following qualitative discussions are made for their spectra.



(B)
(Z=CH_3, Cl, $N(CH_3)_2$, etc.)



(C)
(Z=NO_2, $COOC_2H_5$ etc.)

The absorption spectrum of pyridine monocarboxylic acid *N*-oxide is expected

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[11] Such a greater blue shift is probably due to the hydrogen bonding effect between the oxygen atom of N-O group and R-OH of solvent like other pyridine *N*-oxides[1,12].

[12] T. Kubota, *J. Pharm. Soc. Japan* (*Yakugaku Zassi*), **74**, 831 (1954). M. Ito and N. Hata, This Bulletin, **28**, 260 (1955). N. Hata, ibid., **29**, 82 (1956).

[13] E. P. Linton, *J. Am. Chem. Soc.*, **62**, 1945 (1940).

[14] E. Ochiai, *J. Org. Chem.*, **18**, 534 (1953).

[15] A. R. Katritzky et al., *J. Chem. Soc.*, **1957**, 1769.

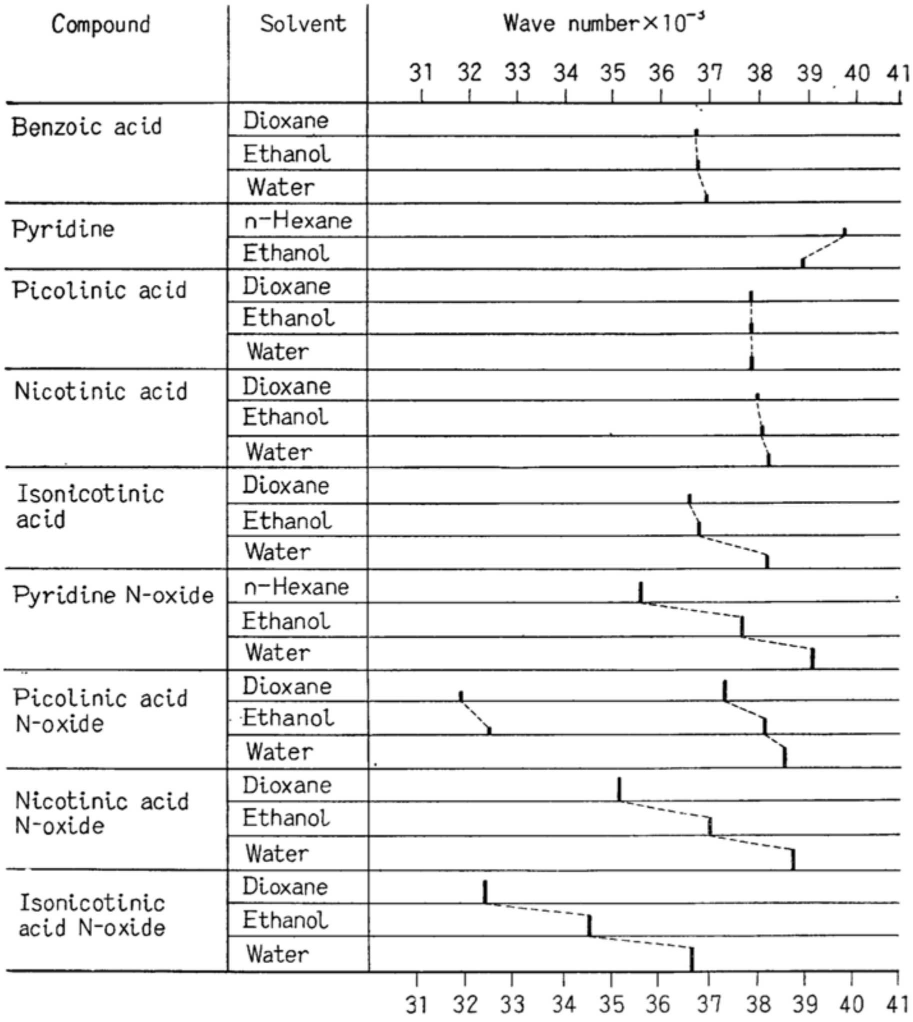
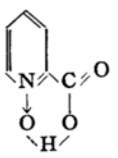


Fig. 7. Schematic spectra of three isomeric pyridine monocarboxylic acids and their *N*-oxides.

to occur in the region of the longer wavelength than that of pyridine *N*-oxide or benzoic acid, because the electron migration from the ring to the carboxyl group is facilitated by the N—O group acting as an electron-repelling group. Here, since the resonance interaction between N—O and carboxyl group is the greatest in picolinic and isonicotinic acid *N*-oxides, it is presumed that the absorption spectra of these two *N*-oxides occur in the longer wavelength than that of nicotinic acid *N*-oxide. Although nicotinic or isonicotinic acid *N*-oxide shows an effect expected above, picolinic acid *N*-oxide shows a blue-shift with a decreased intensity like other 2-substituted pyridine *N*-oxides[1,16]. To explain these facts, the author attributed the formation of the intramolecular hydrogen bond and the steric interaction in picolinic acid *N*-oxide, both of which prevented the resonance of this molecule.

Firstly, if one assumes the intramolecular hydrogen bond as shown in (D) for picolinic acid *N*-oxide, the electron migration from the oxygen atom of N—O group to the pyridine ring may be somewhat pre-



(D)

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[16] N. Ikekawa and Y. Sato, *Pharm. Bull.*, 2, 400 (1954).

TABLE I

WAVE LENGTHS, WAVE NUMBERS, AND MOLAR EXTINCTION COEFFICIENTS OF THREE ISOMERIC PYRIDINE MONOCARBOXYLIC ACIDS AND THEIR *N*-OXIDES

Compound	Solvent	Wave length (mμ)	Wave Number (cm^{-1})	Molar extinction coefficient
Picolinic acid	Dioxane	264	37900	3980
	Ethanol	264	37900	3240
	Water	264	37900	6750
Nicotinic acid	Dioxane	263	38000	2500
		259	38600	2460
	Ethanol	262	38100	2640
		257	38900	2430
	Water	261.5	38200	3660
Isonicotinic acid	Dioxane	273	36600	2670
	Ethanol	271.5	36800	2580
	Water	261.5	38200	3520
Picolinic acid *N*-oxide	Dioxane	313	31900	1500
		268	37350	7700
	Ethanol	307.5	32500	1250
		261.5	38200	7000
	Water	259	38600	8600
Nicotinic acid *N*-oxide	Dioxane	284	35200	11000
	Ethanol	269.5	37100	6300
	Water	258	38800	10300
Isonicotinic acid *N*-oxide	Dioxane	308.5	32400	17000
	Ethanol	289	34600	16500
	Water	272	36700	16300

vented owing to the increase in its electronegativity caused by this intramolecular hydrogen bond. Therefore, the maximum wavelength of picolinic acid *N*-oxide may be close to that of picolinic acid. Such an intramolecular hydrogen bond will also decrease the effect of the solvent acting as a proton donor to the oxygen atom of N—O group on the absorption spectrum of picolinic acid *N*-oxide. The above expectations are in good agreement with the experimental results a) and b).

Secondly, it is also necessary to consider the steric or the electrostatic interaction between the N—O group and the carboxyl group. As is seen from Table I, the maximum wavelength lies in the order of 4->3->2-isomer and the intensity decreases remarkably in the same order. These facts are partly regarded to be due to the obstruction of the coplanarity of this molecule caused by the steric or the electrostatic interaction between N—O group and carboxyl group, just as in the spectra of ortho-substituted benzoic acids7), by which the conjugation between the ring and the carboxyl group becomes weakened17). Such interactions are the greatest in picolinic acid *N*-oxide and the small electrostatic interaction may also arise from the polarities of N—O group and carboxyl group in nicotinic acid *N*-oxide. This consideration is in agreement with the spectral behavior of these compounds.

It seems probable that the experimental results c) are accounted for by the weakening of the conjugation between the ring and the carboxyl group in picolinic acid *N*-oxide, (when compared with that of corresponding acid) resulting from the steric or the electrostatic effect mentioned above. If the conjugation between the ring and the carboxyl group of pyridine monocarboxylic acid *N*-oxide were nearly identical with that of the corresponding acid, an increase in the electronegativity of the oxygen atom caused by the hydrogen bond formation between the

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17) About the steric effect in the electronic absorption spectra see, for example, E. A. Braude and E. S. Waight, "Progress in Spectrochemistry. I." (edited by W. Klyne), London, p. 136, (1954).

oxygen atom of N—O group and the hydrogen atom of water should result in the fact that the wevelength of the absorption maximum observed with the *N*-oxide molecule might be similar to that of the corresponding acid.

In the case of picolinic acid *N*-oxide, in addition to the strong absorption band near 37350 cm^{-1} (268 $\mathrm{m}\mu$), a small one at about 31900 cm^{-1} (313 $\mathrm{m}\mu$) is observed in dioxane, which shows a blue shift in ethanol and apparently disappears in water. This disappearance is possibly due to the overlap with the strong absorption band at the shorter wavelength. This absorption may be regarded as due to an n–π^* transition like other pyridine *N*-oxides.

Summary

The ultraviolet absorption spectra of 2-, 3- and 4-pyridine monocarboxylic acid and their *N*-oxides were measured in various solvents. The absorption spectra of these compounds with the exception of picolinic acid show the blue shift with the change of the solvent from dioxane to ethanol and water.

The absorption band of picolinic acid occurs in the region of the shorter wavelength than that of isonicotinic acid; this fact may be caused by the formation of the intramolecular hydrogen bond, which prevents the resonance of this molecule. The absorption band of picolinic acid *N*-oxide occurs in the region of the shorter wevelength than that of nicotinic or isonicotinic acid *N*-oxide, for which the present author attributed the formation of the intramolecular hydrogen bond and the steric interaction in picolinic acid *N*-oxide.

We also observed the n–π^* absorption in picolinic acid *N*-oxide.

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