On periodate oxidation, this sample consumed 3.88 molar equivalents of the reagent and the phosphate compound found in the oxidation product was identified on paper chromatogram with authentic glycolaldehyde phosphate.

(b) **D-Mannitol 1,6-Diphosphate**—Among fractions obtained from cellulose column fractionation in above (a) the phosphate fractions giving a spot of $Rf_1$ 0.04～0.05 were collected and evaporated to a small volume (20 cc.). The concentrate was passed through a column of Amberlite IR-120 ($H^+$) and the acid effluent was neutralized with cyclohexylamine. The mixture was evaporated to dryness *in vacuo* below 35° and 30 cc. of acetone was added to the syrupy residue dissolved in 10 cc. of dehyd. MeOH. The separated crystals were recrystallized from 50 cc. of dehyd. EtOH containing 0.5 cc. of water; needles (240 mg.), m.p. 206～207°(decomp.). The sample for analysis was dried over $P_2O_5$ *in vacuo* for 4 hr. *Anal.* Calcd. for $C_{24}H_{55}O_{12}N_3P_2$ (Tricyclohexylammonium D-mannitol 1,6-diphosphate): C, 45.04; H, 8.65; N, 6.56; P. 9.69. Found: C, 45.30; H, 8.91; N, 6.43; P, 9.96. $Rf_1$ 0.05, $Rf_2$ 0.17.

On periodate oxidation, the sample consumed 2.85 molar equivalents of the reagent and the phosphate found in the oxidation product was identified on paper chromatogram with authentic glycolaldehyde phosphate.

## Summary

The alcoholysis of catechol cyclic phosphate (I) with several polyols was investigated. Ethylene glycol and 1,2-propanediol gave the corresponding hydroxyalkyl 1,2-cyclic phosphates (III) via intermediate hydroxyalkyl *o*-hydroxyphenyl phosphates (II). (III) were hydrolyzed by acid to the corresponding hydroxyalkyl phosphates (IV). In the case of the polyols containing more than three vicinal hydroxyl groups such as, glycerol, erythritol, and mannitol, the intermediates (II) were too labile to be detected on paper chromatogram of the reaction products, but converted into the corresponding cyclic phosphates (III) which were further hydrolyzed to (IV). Thus glycerol 1,2-cyclic phosphate, DL-erythritol 1-phosphate, and D-mannitol 1-phosphate were isolated and identified.

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# 77. **Hideyo Shindo**: Studies on the Infrared Spectra of Heterocyclic Compounds. VI.[1] Infrared Spectra of Substituted α-Pyridones and α-Quinolones. (1). The Region from 2000 to 4000 cm$^{-1}$.

(*Takamine Research Laboratory, Sankyo Co., Ltd.**)

It is well known that α- and γ-hydroxypyridines and -quinolines are tautomeric with respect to the keto and the enol forms. Thus 2-hydroxypyridine (I) is tautomeric with 2-pyridone (II). Much study has been devoted to the structure of these compounds, and it has been established by infrared[2~5] and ultraviolet[6~8] spectroscopy, ionization constants,[9,10] dipole moment,[9] and X-ray analysis[11] that these compounds exist pre-

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* Nishi-shinagawa, Shinagawa-ku, Tokyo (進藤英世).

[1] Part V. H. Shindo: This Bulletin, **6**, 117(1958).

[2] P. Sensi, G.G. Gallo: Ann. Chim. (Italy), **44**, 232(1954).

[3] J.A. Gibson, W. Kynaston, A.S. Lindsey: J. Chem. Soc., **1955**, 4340.

[4] R.H. Wiley, S.C. Slaymaker: J. Am. Chem. Soc., **78**, 2393(1956).

[5] S.F. Mason: J. Chem. Soc., **1957**, 4874.

[6] G.W. Ewing, E.A. Steck: J. Am. Chem. Soc., **68**, 2181(1946).

[7] H. Ley, H. Specker: Ber., **72**, 197(1939), H. Specker, H. Gawrasch: *Ibid.*, **75**, 1338(1942).

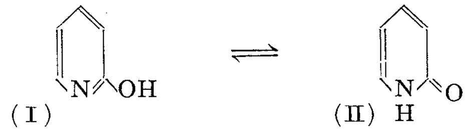
[8] S.F. Mason: J. Chem. Soc., **1957**, 5010.

[9] A. Albert, J.N. Philips: *Ibid.*, **1956**, 1294 (Approximate ratio of amide to enol tautomer was calculated as 340 and 3000 for 2-hydroxy-pyridine and -quinoline, respectively, in neutral aqueous solution).

[10] S.F. Mason: J. Chem. Soc., **1958**, 674.

[11] B.R. Penfold: Acta Cryst., **6**, 591(1953).

dominantly as amide form (such as II) both in the solid and in the solution state in other than alkaline media.



Infrared spectral studies on the tautomerism of various N-heteroaromatic hydroxyl compounds have been made recently by Mason[5] and infrared spectra of the compounds with a hydroxyl group $\alpha$ to ring nitrogen have been characterized by the appearance of a strong carbonyl absorption near 1650 $cm^{-1}$, both in solid and solution state, and of NH stretching absorption in the range of 3360 and 3420 $cm^{-1}$ in dilute solution, providing definite proofs for the presence of an amide group in these compounds.

However, the 3 $\mu$ region of their spectra has not yet been clearly interpreted, especially in the case of solid spectra, because of its broad and complex nature, hence the difficulty in distinguishing between NH and OH absorptions, and the hydrogen bonding in these compounds has also not been investigated in any detail. Furthermore, other characteristic absorptions for pyridone structure which are expected to appear in the frequency region below 1500 $cm^{-1}$ have not been established as yet.

In the present work, infrared spectra of a number of variously substituted $\alpha$-pyridones and $\alpha$-quinolones were measured, and the characteristic absorption bands for $\alpha$-pyridone structure were established by comparing these spectra with those of the corresponding N-deuterated compounds.

In this paper, the region from 2000 to 4000 $cm^{-1}$ in such a spectrum was examined in various states with sodium chloride or lithium fluoride prism and the characteristic behavior of NH stretching abosorption in $\alpha$-pyridone structure was pointed out and discussed in terms of the mode of molecular association.

## Result and Discussion

In the solid state, majority of $\alpha$-pyridones and $\alpha$-quinolones examined did not show any absorption in the region of 3200~3400 $cm^{-1}$ where NH stretching absorption of secondary amide was expected,[12] but showed a strong and very broad absorption with several maxima extending from 3200 $cm^{-1}$ down to 2400 $cm^{-1}$. This broad nature of NH absorption is very characteristic for usual $\alpha$-pyridone structure, and this band disappears on deuteration and the complementary ND absorption appears as a narrower band with a strong peak in the region of 2100~2300 $cm^{-1}$, as shown in Fig. 1-A. The observed maxima are listed in Table I. The ratio of $\nu_{NH}/\nu_{ND}$ for the strongest maxima gave a constant value of 1.27~1.30, which is somewhat smaller than the theoretical value of 1.37,[13] but is characteristic for these structures. The last five compounds in the table (Nos. 18~22) did not show such broad nature in their NH absorptions and the $\nu_{NH}/\nu_{ND}$ ratio gave a value of 1.34~1.36, which is in good agreement with the theoretical value. The characteristic of this group of compounds will be discussed later.

Under higher resolution of LiF prism, it was found that these broad absorptions were extremely complex absorptions consisting of a large number of fine peaks, as shown in Fig. 1-B and in Table II. Mason[5] did not notice this complex nature, but assigned two weak bands at the highest frequency side, peaks at 3198 and 3165 $cm^{-1}$ of 2-pyridone, and those at 3280 and 3252 $cm^{-1}$ of carbostyril, to their NH stretching frequency, neglecting much stronger peaks in a lower frequency region. However, that these complex

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[12] L. J. Bellamy: "The Infra-red Spectra of Complex Molecules," 175(1954), Methuen and Co., London.

[13] T. Miyazawa, T. Shimanouchi, S. Mizushima: J. Chem. Phys., **24**, 408(1956).

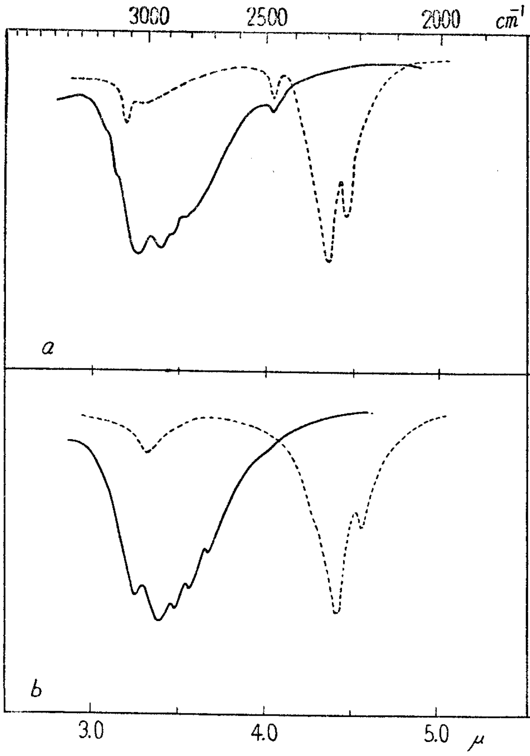

Fig. 1-A.

NH and ND Stretching Absorption of 2-Pyridone (a) and Carbostyril (b) (Perfluorocarbon mull, NaCl prism)

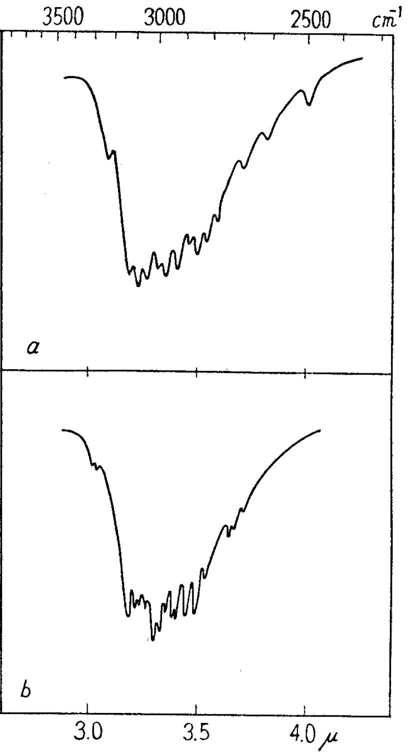

Fig. 1-B.

Fine structures in NH Stretching Absorption of 2-Pyridone (a) and Carbostyril (b) (Perfluorocarbon mull, LiF prism)

Table I. NH and ND Stretching Frequencies of Substituted α-Pyridones and α-Quinolones (Perfluorocarbon mull, NaCl prism)

| No. | Compd. | $\nu_{NH}$ (cm$^{-1}$)[a] | | | | $\nu_{ND}$ (cm$^{-1}$) | | | | Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2-Pyridones | | | | | | | | | |
| 1 | 2-Pyridone | 3065 s[b] | **2960** s | 2840 m | | 2469 w | 2285 s | 2235 m | | 1.29 |
| 2 | 6-Methyl- | 3090 m | 2928 m | 2870 s | **2795** s | 2237 s | 2203 s | 2174 sh | | 1.27 |
| 3 | 5-Nitro- | 3003 m | 2820 s | | | 2230 s | 2110 m | | | 1.27 |
| 4 | 4-Chloro- | 3060 m | 2930 sh | **2765** s | 2665 s | | | [c] | | |
| 5 | 3-Cyano-4,6-dimethyl- | 3115 w | 2985 m | 2850 s | | 2304 w | 2190 s | 2105 w | | 1.30 |
| 6 | 3-Cyano-4,5,6-trimethyl- | 3058 m | 2833 s | **2755** s | | 2160 m | 2132 s | | | 1.29 |
| 7 | 3,6-Dimethyl-5-ethoxycarbonyl- | 2865 s | **2795** s | | | 2245 m | 2188 s | 2105 w | | 1.28 |
| 8 | 3-Cyano-5-ethoxycarbonyl-6-methyl- | 2920 m | **2865** s | 2793 s | | 2203 s | 2198 m | | | 1.30 |
| | Carbostyrils | | | | | | | | | |
| 9 | Carbostyril | 3115 m | 2985 s | 2850 m | | 2283 s | 2179 m | | | 1.31 |
| 10 | Isocarbostyril | 3155 w | 2995 s | **2857** s | | 2240 s | 2123 m | | | 1.28 |
| 11 | 4-Methyl- | 3067 w | 2945 m | 2830 s | | 2245 m | 2174 s | 2037 w | | 1.30 |
| 12 | 6-Nitro- | 3030 m | 2985 m | **2830** s | 2790 s | 2268 m | 2242 m | 2188 s | | 1.29 |
| 13 | 3-Nitro- | 3067 m | 3003 m | **2865** s | 2750 w | 2247 s | 2208 s | 2155 m | | 1.28 |
| 14 | 4-Acetoxy- | 3125 w | 2960 m | **2840** s | | 2247 m | 2190 s | | | 1.30 |
| 15 | 4-Methyl-6-methoxy- | 2967 m | 2907 m | 2786 s | | 2268 m | 2242 m | 2151 s | 2045 w | 1.29 |
| 16 | 3-Ethyl-4-methoxy- | 3145 m | 3095 m | 3010 s | 2960 s | | | [c] | | |
| 17 | 3-Bromo-5-nitro- | 3110 w | 2975 m | 2840 s | | | | [c] | | |
| 18 | 7,8-Dimethoxy- | **3120** s | 2960 s | 2850 w | | 2315 s | 2283 sh | 2237 w | | 1.35 |
| 19 | 3-Ethyl-4,7,8-trimethoxy- | **3120** s | 2950 s | 2855 w | | | | [c] | | |
| 20 | 3,5,6,8-Tetrabromo- | **3160** s | 3050 s | | | 2305 s | | | | 1.36 |
| 21 | 3-Bromo-8-nitro- | 3330 s, sp | | | | 2488 s, sp | | | | 1.34 |
| 22 | 3,6,8-Trinitro- | 3280 s, sp | | | | 2437 s, sp | | | | 1.36 |

a) Strongest maxima are in bold-face type. c) Not measured.

b) s : strong, m : medium, w : weak, sh : shoulder, sp : sharp.

Table II.

Absorption Peaks of Some $\alpha$-Pyridones and $\alpha$-Quinolones in the Region of 2500～3500 cm$^{-1}$ (Perfluorocarbon mull, LiF prism)

| Compound | Observed maxima[a] (cm$^{-1}$) |
|---|---|
| 2-Pyridone | 3197, **3090**, **3055**, 2980, **2978**, 2912, 2868, 2843, 2811, 2672 |
| 6-Methyl-2-pyridone | 3242, 3091, 3001, 2950, **2915**, 2863, **2845**, **2786**, 2745, 2577 |
| Carbostyril | 3282, 3254, 3117, 3086, 3061, 3040, **3012**, **2991**, 2955, 2930, **2912**, **2882**, 2841, 2812, 2722 |
| 4-Methylcarbostyril | 3269, 3143, 3104, 3068, 2994, 2948, **2917**, 2888, **2844**, 2815, 2716, 2736, 2697 |
| Isocarbostyril | 3297, 3164, 3140, 3073, **2993**, 2986, 2958, **2930**, 2915, 2889, 2856, 2718, 2701 |

*a*) Strongest maxima are in bold-face type.

peaks are all attributable to NH stretching mode was confirmed by the facts that (i) all these peaks, except a weak CH absorption near 3010 cm$^{-1}$, disappear on deuteration; (ii) the corresponding N-methyl derivatives do not show any of these absorptions except CH absorption (Fig. 2-B), and (iii) by the behavior of these peaks on dilution in solution spectra, as will be described below.

This broad and complex nature of NH absorption persists also in solution spectra, and at a concentration above 0.025*M* in $CCl_4$, 2-pyridone and carbostyril show only a broad and complex absorption similar to their solid spectra in the region of 2400 and 3300 cm$^{-1}$, as shown in Fig. 2. On dilution to below 0.025*M*, however, in addition to the broad band a weak but sharp band appears near 3400 cm$^{-1}$, which increases in its intensity slightly with further dilution and markedly with rise in its temperature from

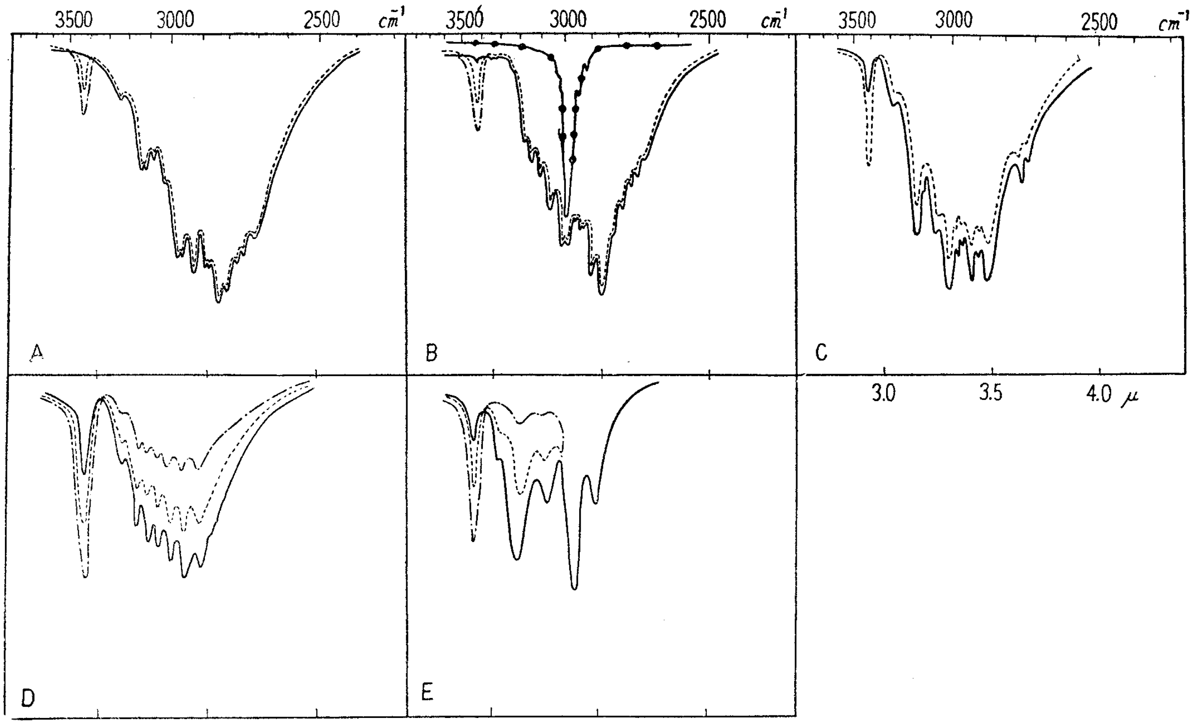

Fig. 2. NH Stretching Absorptions of $\alpha$-Pyridone Structures in Solution Spectra ($CCl_4$ solution, LiF prism)

A : 2-Pyridone ——— 0.025 *M*, ·········· 0.001 *M* (20°), —·—·— 0.001 *M* (65°)
B : Carbostyril ——— 0.025 *M*, ·········· 0.001 *M* (20°), —·—·— 0.001 *M* (65°)
1-Methylcarbostyril -•-•-•- 0.025 *M*
C : Isocabostyril ——— 0.025 *M*, ·········· 0.001 *M*
D : 3-Pyridazone ——— 0.025 *M*, ·········· 0.0025 *M*, —·—·— 0.001 *M*
E : δ-Valerolactam ——— 0.05 *M*, ·········· 0.005 *M*, —·—·— 0.001 *M*
(Cell thickness : 0.5～20.0 mm)

20° to 65° at the concentration of 0.001*M*, as shown in Fig. 2. These observations indicate that there is involved intermolecular hydrogen bonding and a sharp band near 3400 $\mathrm{cm}^{-1}$ is due to free NH stretching absorption, while the broad band is due to associated NH stretching absorption, contradicting the presence of intramolecular hydrogen bonding suggested by Wiley, *et al.*[4] and also the possibility that the broad band is due to acid $\overset{+}{\mathrm{N}}\mathrm{H}$ group.[14] This behavior is most pronounced in 3-pyridazone, as shown in Fig. 2-D, in which all of the complex peaks markedly decrease in their intensities on dilution, in quite parallel way, accompanied with a marked increase in intensity of the free NH absorption at 3400 $\mathrm{cm}^{-1}$. This fact indicates that all of the complex peaks are attributable to the associated NH absorption. The fact that any evidence of free OH absorption was not observed near 3600 $\mathrm{cm}^{-1}$ during these examinations indicates that these compounds exist almost completely in amide form.

Furthermore, an important feature common to these compounds is that over a concentration range from 0.02*M* to 0.0005*M* in $CCl_4$ and with the change of its temperature from 20° to 65°, precise positions and relative intensities of associated NH peaks do not change to any extent, as can be seen from Fig. 2. This fact indicates that there can be only one kind of associated molecules, excluding the presence of a polymeric association, and the mode of association is considered to be a ring dimer (V), two molecules being combined through the double NH····O bonding, just as in carboxylic acid dimer (IV). In secondary amide, it has been shown by Tsuboi[15] that a shift of the absorption maxima of associated NH in N-methylacetamide takes place with lowering concentration or with the rise of temperature in $CCl_4$, while no such shift occurs in δ-valerolactam. It was thereby concluded that the former, in which NH and C=O are *trans* to each other, associates through a polymer (VI), while the latter, in which NH and C=O are *cis* to each other, associates through a cyclic dimer (VII). This behavior in δ-valerolactam is compared in Fig. 2-E. X-Ray analysis[11] of 2-pyridone also indicates the presence of a dimeric unit in crystal.

This configuration explains the broad nature of associated NH absorption and abnormal stability of the associated molecules. Such a broad and complex absorption down to 2400 $\mathrm{cm}^{-1}$ region is very similar to those observed in OH stretching absorption in carboxylic acid dimer[16] or intramolecularly chelated hydroxyl compounds[17] such as acetylacetone in which the hydrogen bond can be greatly strengthened by resonance stabilization. It is well recognized that the contribution of ionic structure such as (III′) is very large to the resonance of amide (III), and the contribution of analogous ionic structure like (II′) is expected to be much more important in the resonance of 2-pyridone because of aromatic stabilization. On the other hand, the exceptional strength of the hydrogen bond in carboxylic acid dimer has been attributed[18] to contribution from ionic resonance structure like (IV′). Quite analogous resonance stabilization by contribution from ionic structure like (V′) is also possible for 2-pyridone dimer and extreme strength of the hydrogen bond can be expected.

As can be seen from Fig. 2, 2-pyridone and carbostyril molecules are almost com-

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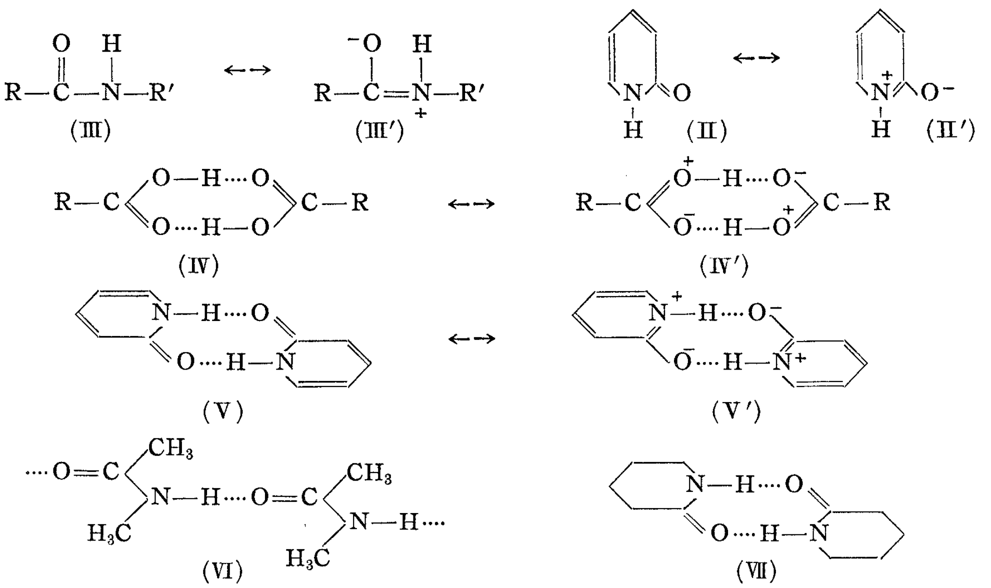
[14] For example, acidic NH bond at 9-position in purine derivatives exhibits a broad band in the region of 2400 and 2800 $\mathrm{cm}^{-1}$ (cf. J.A. Montgomery, L.B. Holum: J. Am. Chem. Soc., **80**, 404 (1958)).

[15] M. Tsuboi: Bull. Chem. Soc. Japan, **22**, 215(1949); **24**, 75(1951); cf. also W. Klemperer, M.W. Cronyn, A.H. Maki, G.C. Pimental: J. Am. Chem. Soc., **76**, 5846(1954).

[16] a) M. St. Flett: J. Chem. Soc., **1951**, 962. b) S. Bratoz, D. Hadozi, N. Sheppard: Spectrochim. Acta, 8, 249(1956).

[17] a) A.E. Martin: Nature, **166**, 474(1950). b) S. Bratoz, D. Hadzi, G. Rossmy: Trans. Faraday Soc., **52**, 464(1956); M. St. Flett: Spectrochim. Acta, **10**, 21(1957).

[18] L. Pauling: "Nature of Chemical Bond," 2nd ed., 306(1945).



pletely in associated state, at a concentration above 0.025$M$ in $CCl_4$, and even at such a low concentration as 0.0005$M$ these are for a major part in associated state. On the other hand, at a concentration above 0.02$M$ in $CCl_4$, most carboxylic acids are almost completely associated[17a)] and at a concentration below 0.01$M$ they exhibit a monomeric hydroxyl band near 3500 cm$^{-1}$. Therefore, it is concluded that the hydrogen bond involved in pyridone dimer is extremely strong, being almost equal to that involved in carboxylic acid dimer. The abnormal strength of hydrogen bond in 2-pyridone is also shown by comparison with the hydrogen bond in $\delta$-valerolactam, in which free NH absorption clearly appears at 3428 cm$^{-1}$ even at a high concentration of 0.25$M$ and associated NH bands at 3213 and 3094 cm$^{-1}$ almost disappear at a concentration of 0.001$M$.

This tendency of molecular association is very sensitive to structural changes. As can be seen from Fig. 2, isocarbostyril exhibits its free NH absorption more strongly than 2-pyridone and carbostyril at the concentration of 0.001$M$ and 3-pyridazone much more strongly, these indicating that the strength of hydrogen bond involved decreases in the order of $\alpha$-pyridone$\sim$carbostyril$>$isocarbostyril$\gg$3-pyridazone. This is considered to be due to the fact that the inductive effect of phenyl ring and of ring nitrogen inhibits contribution of the resonance structure like (V′) which stabilizes the dimer, resulting in weakness of hydrogen bonds. The degree of such contribution should be measured as the basicity of carbonyl oxygen as a basic center, and the approximate extinction coefficient of free NH absorption of these compounds at a constant concentration increased with decreasing pKa′ values,[9)] as shown in Table IV. It is expected that the substituent on the ring also exhibits a similar effect, and 4-chloro- and 5-nitro-2-pyridone showed a reasonable order in increasing the intensity as compared to that of 6-methyl-2-pyridone.

As can be seen from Table III, substituted $\alpha$-pyridones generally exhibit their free NH absorption as only a very weak band under these conditions, while substituted carbostyrils exhibit it more distinctly as a medium or weak band. Substituted pyridazones show it always much more strongly.[19)]

All compounds in Table III did not show any evidence of free OH absorption in the region of 3600 cm$^{-1}$, indicating that they are all in amide form and that the tautomerism in these compounds may not be influenced by the electronic effect of different substituent groups. For example, the appearance of free NH absorption of 3-nitro-

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19) H. Shindo : Unpublished data.

Table III. NH Stretching Frequencies of Substituted α-Pyridones and α-Quinolones ($CHCl_3$ and $CCl_4$ solution, LiF prism)

| Compound | $CHCl_3$ soln.[a] | $CCl_4$ soln.[b] | |
|---|---|---|---|
| | free NH | free NH | associated NH[c] |
| 2-Pyridones | | | |
| 2-Pyridone | 3403 vw[d] | 3405 vw | 3265, 3242, 3136, 3082, 2959, **2921**, 2886, 2854, **2822**, 2741, 2697 |
| 6-Methyl- | 3383 vvw | 3395 vvw | 3289, 3123, 3032, **2950**, **2930**, 2835, **2791**, 2752 |
| 4-Chloro- | (3398 w)[e] | 3414 vvw | 3312, 3283, 3144, 3069, 2977, 2950, **2918**, 2874, **2815**, 2754, 2704 |
| 5-Nitro- | (3373 m) | | [f] |
| 3,6-Dimethyl-5-ethoxycarbonyl- | 3381 vw | 3390 vvw | 3144, 3010, **2981**, **2900**, 2801, 2677 |
| 3-Cyano-5-ethoxycarbonyl-6-methyl- | (3359 vw) | 3375 vvw | 3167, 3069, 3021, **2983**, 2924, **2896**, 2874, 2805, 2675 |
| 3-Pyridazone | 3395 m | 3401 s | 3153, 3096, 3052, 3015, **2990**, **2955**, **2882** |
| Carbostyrils | | | |
| Carbostyril | 3400 vw | 3405 w | 3318, 3272, 3165, 3145, 3102, 3064, **3010**, 2961, 2939, **2890**, **2853**, 2776 |
| Isocarbostyril | 3413 m | 3427 m | 3300, 3169, 3069, **3018**, 2960, **2928**, 2899, **2869**, 2726 |
| 4-Methyl- | 3393 vw | 3408 w | 3265, 3143, 3102, 3071, **3000**, 2960, 2921, **2888**, **2853**, 2736, 2694 |
| 3-Ethyl-4-methoxy- | 3398 m | 3416 m | 3167, 3106, **2961**, **2941**, 2895, 2877, **2766**, 2749 |
| 4-Acetoxy- | [g] | 3408 w | 3147, 3100, 3067, **3008**, 2961, **2890**, **2851**, 2758, 2740, 2694 |
| 4-Methyl-6-methoxy- | (3399 w) | | [f] |
| 4-Methyl-6-nitro- | (3389 m)[h] | | [f] |
| 3-Nitro- | (3370 m)[h] | | [f] |
| 7,8-Dimethoxy- | 3388 s | 3412 s | —— |
| 3-Ethyl-4,7,8-trimethoxy- | 3390 s | [g] | |
| 3,5,7,8-Tetrabromo- | 3360 s | 3369 s | —— |
| 3-Bromo-8-nitro- | 3330 s | 3335 s | —— |
| 3,6,8-Trinitro- | (3310 s)[h] | 3311 s | —— |

*a*) 0.2*M* in $CHCl_3$; cell thickness, 0.1 mm. Associated NH peaks are quite similar to those observed in $CCl_4$ solution.
*b*) 0.001*M* in $CCl_4$; cell thickness, 20.0 mm.
*c*) Strongest maxima are in bold-face type.
*d*) vvw : very very weak, vw : very weak, w : weak, m : medium, s : strong.
*e*) 0.01*M* in $CHCl_3$; cell thickness, 2.0 mm.
*f*) Insoluble.
*g*) Not measured.
*h*) 0.002*M* in $CHCl_3$; cell thickness, 10.0 mm.

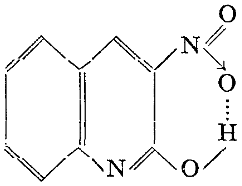
Table IV. Comparison of Intensities of Free NH Absorption

| Compound | approx. ε in $CHCl_3$[a] | approx. ε in $CCl_4$[b] | pKa′ |
|---|---|---|---|
| 2-Pyridone | 0.08 | 0.04 | 0.75 |
| Carbostyril | 0.14 | 0.065 | −0.31 |
| Isocarbostyril | 0.29 | 0.17 | −1.20 |
| 3-Pyridazone | 0.41 | 0.32 | −1.80 |
| 6-Methyl-2-pyridone | vvw | vvw | |
| 4-Chloro-2-pyridone | 0.04 | —— | |
| 5-Nitro-2-pyridone | 0.10 | —— | |

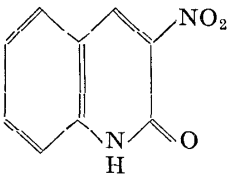
*a*) 0.01*M* in $CHCl_3$; cell thickness, 2.0 mm.
*b*) 0.001*M* in $CCl_4$; cell thickness, 20.0 mm.

carbostyril at 3370 cm$^{-1}$ in dilute $CHCl_3$ solution, as well as the appearance of carbonyl absorption at 1678 cm$^{-1}$ in the solid indicates that this compound exists not as intramolecularly chelated enol form (Ⅷ) but as the form (Ⅸ).

Carbostyrils with a substituent at 8-position, the last five compounds in Tables I and Ⅲ, showed entirely different behavior from other compounds in their NH absorptions.



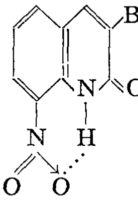
(Ⅷ)



(IX) (dimeric)

8-Methoxy and 8-bromo derivatives (Nos. 18~20) showed a strong peak in the region of 3120~3160 cm$^{-1}$, and in the region of 2305~2315 cm$^{-1}$ on deuteration, in the solid state due to ordinary hydrogen-bonded NH(ND) absorption, and did not show any fine structure with LiF prism. In solution state, they showed only a strong and sharp band due to free NH absorption in the region of 3360~3420 cm$^{-1}$, even in a concentration of 0.025$M$ in $CCl_4$, indicating that in the solid state there is involved intermolecular hydrogen bonding with only ordinary strength. This is considered to be due to the steric inhibition of a bulky substituent at 8-position from the sufficient proximity of NH group to the carbonyl group of another molecule to form a stable dimer.

8-Nitro derivatives (Nos. 21 and 22) showed only a single sharp band in the region of 3280~3330 cm$^{-1}$ both in the solid and in solution state. On deuteration a sharp ND band appeared in the region of 2435~2490 cm$^{-1}$, which is considerably higher than that of other compounds. The fact that the position of the band in solution state does not differ to any appreciable extent from that in solid state indicates the absence of intermolecular hydrogen bonding in the solid state, and it is considered that the intramolecular hydrogen bonding as (X) does not permit the formation of any intermolecular bonding even in solid state. Considerably lower value of these frequencies as compared to that of free NH absorption in other nitro derivatives also supports this view.



(X)

The $\nu_{NH}/\nu_{ND}$ ratio of these five compounds gave a value of 1.34 to 1.36, which is characteristic for the monomeric $\alpha$-pyridone structure and is comparable to the lower value of 1.27 to 1.30 for dimeric structure. The characteristic behaviors of these compounds are compared in Fig. 3.

The appearance of complex NH absorption peaks in dimeric $\alpha$-pyridones is difficult to interpret at present, but it is a phenomenon of general occurrence in the spectra of hydroxyl compounds with extremely strong hydrogen bond and several attempts have previously been made for their interpretation but no generally acceptable explanation has as yet been proposed. The fine structure observed in the broad OH band in carboxylic acid dimer has been analysed and interpreted[17b)] as due to overtones and combination frequencies of COOH fundamentals, four peaks in acetic acid and benzoic acid were satisfactorily explained in this way.

It is important to note that an entirely different pattern was observed for the fine structure of ND band as compared to the more complex structure of NH band and the overall width of the former (half-band width, 200~250 cm$^{-1}$) is markedly less than that of the latter (half-band width, 450~600 cm$^{-1}$). This situation is just the same as that found in OH and OD bands in carboxylic acid, and most likely these peaks are considered to be related to the combination and overtones of the lower frequency fundamentals, and these normally very weak bands are enhanced in intensity by Fermi resonance with a broad structureless NH(ND) band.

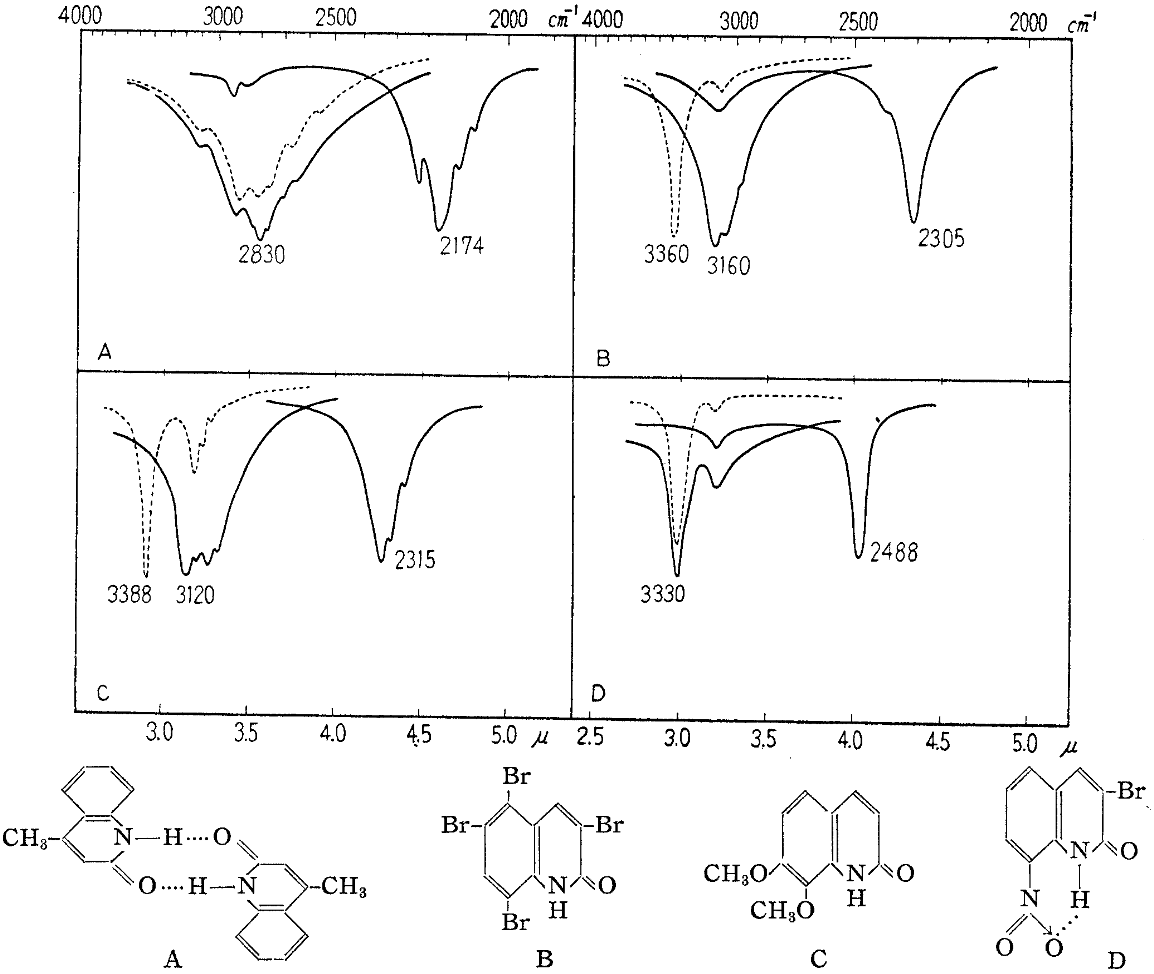


Fig. 3. Characteristic Behavior in NH and ND Stretching Absorptions of 8-Substituted Carbostyrils (NaCl prism)

———— : NH and ND absorptions in the solid state.

·················· : NH absorption in $CHCl_3$ solution.

It is difficult to say which peak in these complex peaks is attributable to the true NH absorption peak. The known NH····O distance of 2.77 Å[11] in crystalline $\alpha$-pyridone gives the value of $3159\,\mathrm{cm}^{-1}$ for bonded NH frequency from the empirical equation,[20] $\Delta\nu=0.548\times10^3(3.21-R)$, and the frequency of ND absorption peak of $2285\,\mathrm{cm}^{-1}$ also gives $3131\,\mathrm{cm}^{-1}$ on multiplying it by 1.37. In the region of 3130 and $3160\,\mathrm{cm}^{-1}$, however, there can be found only very weak peaks, which are not considered to be true NH absorption from the above discussion.

In any way, considering from the absence of the complex NH band in δ-valerolactam and in 8-bromo and 8-methoxy derivatives of carbostyril, the abnormal strength of hydrogen bonding resulting from resonance stabilization seems to be a requisite condition for the appearance of complex broad NH band.

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20) G.C. Pimentel, C.H. Sederholm : J. Chem. Phys., **24**, 639(1956).

## Experimental

**Material**—2-Pyridone was prepared by the rearrangement reaction of pyridine 1-oxide with $Ac_2O$,[21] and carbostyril by the rearrangement reaction of quinoline 1-oxide with tosyl chloride.[22] All substituted 2-pyridones were supplied from the Faculty of Pharmaceutical Sciences, University of Tokyo. 3-Ethyl-4-methoxy-, 7,8-dimethoxy-, and 3-ethyl-4,7,8-trimethoxycarbostyrils were supplied by Prof. T. Ohta of the Tokyo College of Pharmacy. Other substituted carbostyrils and isocarbostyril were supplied from the Faculty of Pharmaceutical Sciences, University of Tokyo.

The preparation of deuterated compounds was carried out with 99.5% $D_2O$ of the Stuart Oxygen Co. Most of the samples were deuterated by dissolving the sample in a hot mixture of dioxane and considerable excess of $D_2O$, and evaporating the solvents under reduced pressure. If necessary, this procedure was repeated. No further purification was made of the substance prepared in this way. Some of the substituted carbostyrils were deuterated by recrystallization from deuterium oxide-dioxane mixture.

**Method**—Infrared spectra were measured with a Perkin-Elmer model 21 double-beam spectrophotometer provided with NaCl or LiF prism. Solid spectra were obtained as perfluorocarbon or Nujol mull, and KBr-disk method was not adopted because, (i) a weak band near 3450 $cm^{-1}$ due to water cannot be completely removed, and (ii) deuterated sample is readily reversed to hydrogen compound during the preparation of a pellet.

Samples of low solubility were dissolved in hot $CCl_4$ and measured after cooling to the room temperature. Detailed conditions of measurement are described under Table III and Fig. 2. Sealed cells of various thickness with NaCl windows were used.

## Summary

The infrared spectra of a number of substituted $\alpha$-pyridones and $\alpha$-quinolones were investigated in the region of 2000 to 4000 $cm^{-1}$, and the characteristic behavior of NH absorption in $\alpha$-pyridone structure was pointed out and discussed in terms of the mode of molecular association.

Extremely complex and broad nature extending from 3300 down to 2400 $cm^{-1}$ of the bonded NH absorption was interpreted as being due to the extreme strength of intermolecular hydrogen bond associated through a cyclic dimer. Abnormal stability of the dimer, being approximately equal to that of carboxylic acid dimer, was pointed out and discussed in terms of resonance stabilization.

Ratio of $\nu_{NH}/\nu_{ND}$ for strongest maxima was found to be 1.27 to 1.30 and 1.34 to 1.36, respectively, for dimeric and non-dimeric $\alpha$-pyridone structure. Characteristic behavior in 8-substituted carbostyrils was also pointed out.

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21) M. Katada : Yakugaku Zasshi, **67**, 51(1947).
22) E. Ochiai, T. Yokokawa : *Ibid.*, **75**, 213(1955).