CHEMICAL
&
PHARMACEUTICAL BULLETIN

Vol. 6 No. 2 **April 1958**

UDC 544.621 : 547.823

20. **Hideyo Shindo :** Studies on the Infrared Spectra of Heterocyclic Compounds. V.⁽¹⁾ Infrared Spectra of Substituted Pyridine 1-Oxides.

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

Previously,⁽²⁾ the strong absorption in the region of 1200 and 1300 $\mathrm{cm^{-1}}$ in the infrared spectra of pyridine 1-oxide and its alkyl derivatives was assigned to their characteristic N-O stretching frequency, despite the previous assignment of a band near 830 $\mathrm{cm^{-1}}$ for this absorption by Ito, *et al.*⁽³⁾ More recently, Wiley, *et al.*⁽⁴⁾ made the same assignment for the spectra of picoline and some methylpyrimidine 1-oxides. A further confirmatory evidence to this assignment has now been obtained by observing the change in the spectra of these compounds following hydrogen-bond formation with methanol in nonpolar solvent, the details of which will be reported in a subsequent paper.

In the present study, the infrared spectra of substituted pyridine 1-oxides containing various kinds of substituent mainly at 3- or 4-position were determined, and their N-O stretching frequencies were found to be clearly correlated with the electronic nature of the substituent. Other spectral changes on passing from pyridines to their N-oxides were discussed in terms of electronic effect of ring N-O group.

The infrared spectra of following pyridine 1-oxides have been studied by Costa, *et al.* : 4-Nitro-, 4-chloro-, and 4-methoxy derivatives,⁽⁵⁾ 4-amino- and 4-hydroxy derivatives,⁽⁶⁾ and carboxylic acid derivatives.⁽⁷⁾

The chemistry of aromatic heterocyclic N-oxides was reviewed by Ochiai⁽⁸⁾ and, recently, by Katritzky,⁽⁹⁾ and it was shown that the structures (Ⅳ) and (Ⅴ) were also important contributors to the resonance system of pyridine 1-oxide, as well as the mesomeric structures (Ⅱ) and (Ⅲ), which were first proposed by Linton⁽¹⁰⁾ in 1940. The ability of the N-oxide group both to accept and to donate electrons was clearly shown by Katritzky, *et al.*⁽¹¹⁾ by a comparison of the electronic dipole moments of 4-substituted pyridines and their N-oxides. This fact accounts for the facile substitution of both electrophilic and nucleophilic reagents at the 4-position in pyridine 1-oxide.

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* Nishi-Shinagawa, Shinagawa-ku, Tokyo (進藤英世).
1) Part Ⅳ. H. Shindo : This Bulletin, **5**, 472(1957).
2) H. Shindo : *Ibid.*, **4**, 460(1956).
3) M. Ito, N. Hata : Bull. Chem. Soc. Japan, **28**, 260(1955).
4) R.H. Wiley, S.C. Slaymaker : J. Am. Chem. Soc., **79**, 2233(1957).
5) G. Costa, P. Blasina : Z. Phys. Chem. (Frankfurt), **4**, 24(1955).
6) G. Costa, P. Blasina, G. Sartori : *Ibid.*, **7**, 123(1956).
7) G. Costa, E. Pauluzzi : Univ. Trieste, Fac. sci. Inst. chim., No. **12**, 15(1956)(C. A., **49**, 4823(1957)).
8) E. Ochiai : J. Org. Chem., **18**, 534(1953).
9) A.R. Katritzky : Quart. Revs., **10**, 395(1956).
10) E.P. Linton : J. Am. Chem. Soc., **62**, 1945(1940).
11) A.R. Katritzky, E.W. Randall, L.E. Sutton : J. Chem. Soc., **1957**, 1769.

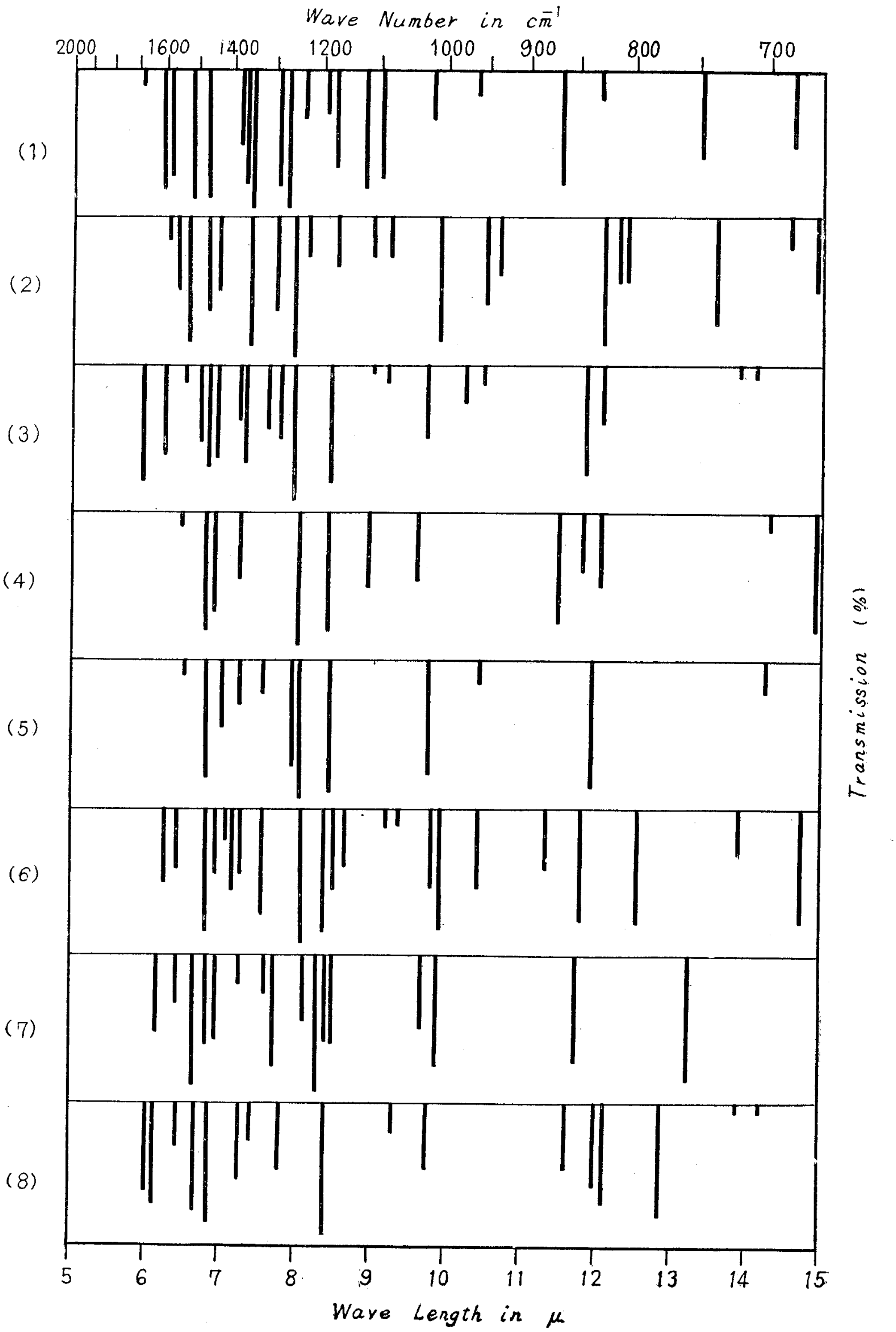
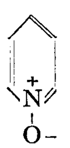
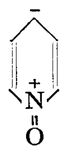
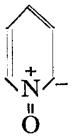
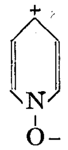


Fig. 1. Infrared Spectra
(1) 4-Nitro-, (2) 3-nitro-, (3) 4-acetyl-, (4) (7) 4-methoxy-, and (8) 4-amino-pyridine 1-oxides, and (5) 4,4′-bipyridine and (6) 3,3′-bipyridine 1,1′-dioxides
(Mull in Nujol)


(I)


(II)


(III)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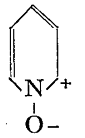
(V)

The infrared spectra of these compounds can also be interpreted on the basis of the contribution of these resonance structures and the principal absorptions will be discussed below. Some of the spectra obtained are shown in Fig. 1.

I. N-O Stretching Frequencies

All N-oxide compounds examined showed a very strong absorption in the region of 1200 and 1300 cm^{-1}, which could be clearly attributed to the N-O stretching vibration. The observed frequencies in dilute carbon disulfide solution and in solid state are listed in Table I. These frequencies should be determined principally by the bond-order of N-O link, which in turn should depend on the degree of contributions of the resonance structures (II) to (V) to the molecule. Therefore, it is expected that the N-O frequency should be directly affected by the electronic effect of the substituent. For example, an electron-attracting substituent such as 4-nitro group would be expected to increase

TABLE I. N-O Stretching Frequencies of Substituted Pyridine 1-Oxides

No.	Substituent	σ-Value	CS_2 dil. soln. (cm^{-1})		Nujol mull (cm^{-1})	
			N-O Stretching frequency[a]	Inflexion or satellite band	N-O Stretching frequency[a]	Inflexion or satellite band
1	4-NO_2	0.778	1303	1285 w sh[b]	1269	1284 s sh
2	3-NO_2*	0.710	1298	1265 s	1258	1300 s
3	3-CH_3, 4-NO_2	0.709	1311	1258 m	1256	1304 s
4	3-CN*	0.678	1307	1289 s	1275	1287 sh
5	4-CN*	0.628	1301		1279	
6	4-$COOC_2H_5$	0.522	1267 ?	1297 m	1258	1297 m
7	4-$COCH_3$	0.516	1258	1292, 1299 m	1258	1287 w sh
8	3-$COOC_2H_5$	0.398	1302 ?	1284 m sh	1294	1316 s
9	3-Br	0.391	1294	1263 v s 1309 w sh	—	
10	3-Cl	0.373	1293	1265 v s 1250 w sh 1309 w sh	—	
11	3-$COCH_3$*	0.306	1302	1287 sh	1294	
12	3-$CONH_2$	0.280	—		1234	
13	4-Br	0.232	1271		1245	
14	4-Cl	0.227	1269		1243	
15	H	0.000	1265	1271 s sh	1250	
16	3-C_2H_5	−0.043	1276		—	
17	3-CH_3	−0.069	1285	1272 sh 1309 m	—	
18	3,5-di CH_3	−0.138	1319		1316	
19	4-C_2H_5	−0.151	1260		1238	
20	3-NH_2	−0.161	—		1161	1256 m
21	4-CH_3	−0.170	1260	1236 m	1250	1225, 1229 s
22	4-OCH_3	−0.268	1240	1225 w sh	1206	1233 sh
23	4-$OCH_2C_6H_5$*	−0.416	1238		1225	1274 s
24	4-NH_2	−0.660	—		1192	
25	3-CH_3, 4-NH_2	−0.729	—		1147	1242 s
	4-$CONH_2$		—		1242	1227 sh
	4,4′-bipyridine-		—		1239	1258 sh
	3,3′-bipyridine-		—		1235, 1247	
	2,2′-bipyridine-		—		1253, 1259	
	2-CH_3		1260		—	
	2-CH_3, 4-NO_2		1298	1261 m	1269	1285 s
	2,6 di CH_3, 4-NO_2		1292		1280	
	2-NH_2		—		1192	

* Saturated solution in CS_2, cell thickness : 5.0 mm. Others : Saturated or 0.2% solution in CS_2, cell thickness : 1.0 mm.

a) Intensity is all very strong.

b) s : strong m : medium w : weak sh : shoulder the contribution of the structures (II) and (III), resulting in an increase of a double bond character of N–O bond and a consequent higher frequency shift of the N–O frequency, while an electron-donating substituent such as 4-methoxyl group would be expected to prevent the contribution of the structures (II) and (III), and might favor the structures (IV) and (V), resulting in an increase of ionic nature of N–O bond and a consequent lower frequency shift of the frequency. In fact, the results in Table I agree well with these expectations.

It is well known that the Hammett substituent constants[12] represent a measure of the resultant effect of both inductive and mesomeric effects of a substituent in aromatic molecules, and in many cases they form a linear relation with the characteristic vibration frequencies of those molecules. The applicability of the Hammett equation to the prediction of the effect of substituents on the reactivity of heterocyclic aromatic compounds was discussed by Jaffe, *et al.*[13] and it was shown that the basicity of a series of substituted pyridines and pyridine 1-oxides had a linear relationship with σ-values of the substituents.

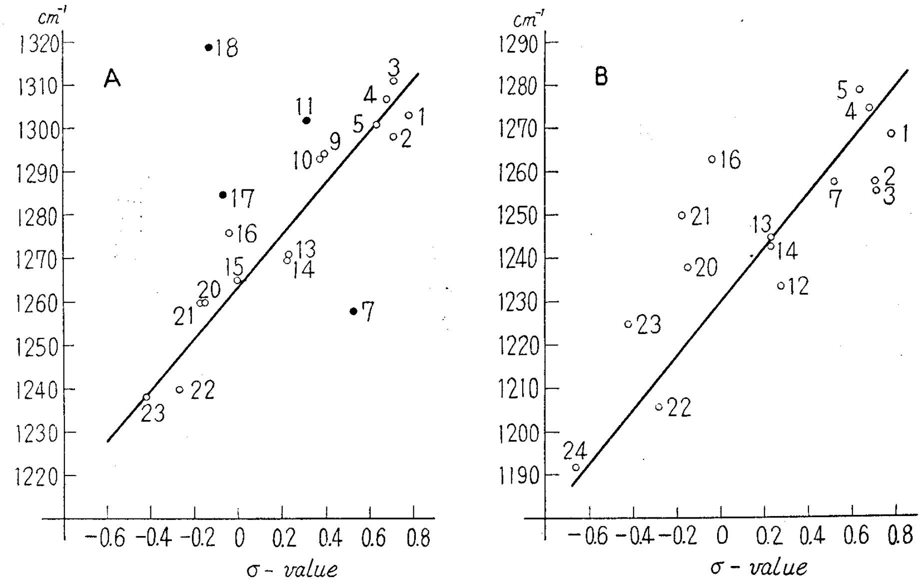

Fig. 2. N–O Stretching Frequency vs. Hammett's Substituent Constant for Substituted Pyridine 1-Oxides
A : Dilute CS_2 solution B : Mull in Nujol

Thus, the N–O stretching frequencies in dilute carbon disulfide solution were plotted against the σ-values of the substituents and shown in Fig. 2–A. It can be seen that with some exceptions the points lie approximately close to a straight line, in which the frequency showed a significant increase with increasing σ-value of the substituent.

The compounds which showed deviation of more than 15 cm^{-1} from the straight line are 3-methyl, 3- and 4-acetyl, and 3- and 4-ethoxycarbonyl derivatives. The abnormally higher frequencies of 3-alkyl derivatives have been already pointed out,[2] and Wiley, *et al.*[4] also described this phenomenon and noted that 5-methylpyrimidine 1-oxide, where methyl group is not attached to an electron-deficient carbon, absorbed at a considerably higher frequency (1300 cm^{-1} in CCl_4) than other methyl derivatives. Therefore, this may be a characteristic phenomenon for the methyl derivatives (and, presumably, to a lesser extent for other alkyl derivatives) where methyl group is attached to β-position with respect to the N-oxide group. The 3- and 4-acetyl deri-

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[12] a) L. P. Hammett : "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, Chap. VII (1940). b) H. H. Jaffe : Chem. Revs., **53**, 191(1953).
[13] H. H. Jaffe, G. O. Doak : J. Am. Chem. Soc., **77**, 4441(1955).

vatives show a strong absorption at 1302 and 1258 cm^{-1}, respectively, but the corresponding pyridines also have a strong band at 1269 and 1261 cm^{-1}, respectively. Therefore, from the comparison of these spectra, any new band attributable to N–O stretching vibration cannot be found. Ethoxycarbonylpyridines show a strong absorption near 1250 cm^{-1} originating in the ester C–O, and their N-oxides do not show any new absorption elsewhere in this region. In these spectra, it is assumed that some vibrational interaction between these two vibrational modes is present, causing a disturbance of a linearity of their frequencies.

This view was confirmed by a comparison of the magnitude of the shift caused by the solvation effect(2) of methanol. All compounds which gave a linear plot showed a shift of 30∼35 cm^{-1} to lower frequencies by the addition of methanol to 10% in carbon tetrachloride, while, in contrast to these large shifts, above six compounds, which showed a considerable deviation, showed a shift of only 7∼15 cm^{-1}. This fact indicates that in latter cases some vibration mode other than N–O stretching mode also considerably contributes to these absorptions.

The above observation seems to suggest that this linear relation cannot be applied to the N-oxides with a carbonyl group attached to the ring, or at least a great care must be taken in considering their spectra.

3-Halogen derivatives showed two strong absorptions with approximately the same intensity in this region, but the band at higher frequency side gave a better linear plot. Pyridine 1-oxide showed a strong shoulder at 1271 cm^{-1} other than a strong peak at 1265 cm^{-1}, in carbon disulfide.

Jaffe(13) used σ^* value(12b) for the *p*-nitro group in correlating with the pK value, but the N–O frequency gave a better linear plot against σ_p-value rather than σ_p^* value.

It is finally concluded that, except in the cases where any vibrational interaction is involved, the result of both inductive and mesomeric effects of a substituent is the principal factor determining the N–O stretching frequency, and this relation can be used for the prediction of the frequency. The fact which makes this relation more useful is that the magnitude of a shift following change in the nature of a substituent is very large. This correlation line obeys the equation $\nu=1263.5+58.6\,\sigma$, where the correlation constant is much larger than that in the case, for example, of the carbonyl frequencies of substituted acetophenones and of the nitro asymmetric stretching frequencies of substituted nitrobenzenes, whose correlation lines are represented by the equations $\nu=1689.5+14.0\,\sigma$ and $\nu=1521.5+20.3\,\sigma$, respectively. This may be due to the fact that the N-oxide function is strongly polarizable in both directions, giving rise to a great change in the bond order of N–O links. Katritzky, *et al.*(11) pointed out this fact by a comparison of dipole moments of some 4-substituted pyridines and their N-oxides, in which the N–O group moment decreased with increasing electronegativity of the substituent.

Although the effect of substituent at α-position is not clear because of the lack of samples, α-picoline 1-oxide absorbed at the same frequency as that of γ-picoline 1-oxide, both showing a lower frequency shift of 5 cm^{-1} from pyridine 1-oxide. On the other hand, 2-methyl-4-nitro and 2,6-dimethyl-4-nitro derivatives showed the absorption at 1298 and 1292 cm^{-1}, respectively, showing a progressive shift of 5 and 6 cm^{-1} to a lower frequency with increasing number of methyl group at α-position as compared to 4-nitropyridine 1-oxide (1303 cm^{-1}). These facts seem to indicate that the effect of a substituent at α-position also gives a constant influence upon the N–O frequency.(14)

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14) A constant influence of *ortho*-substituent upon the frequency in aromatic compound was pointed out recently by Kellie, *et al.* (A. E. Kellie, D. G. O'Sullivan, P. W. Sadler: J. Org. Chem., **22**, 29(1957). See also, O'Sullivan, P. W. Sadler: J. Chem. Soc., **1957**, 2839).

In a solid state, the absorption always appeared at about 20~30 cm^{-1} lower in frequency than that in dilute carbon disulfide solution, with anticipated exception of acetyl derivatives which did not show any appreciable shift, and these shifts are assumed to be due to intermolecular dipolar association between N–O dipoles. These frequencies showed a wide scattering against the σ-value, as plotted in Fig. 2–B, but the approximate linear trend is also apparent.

The N–O frequency has, in many cases, a satellite band or an inflexion around the main peak, and in some cases (for example, the first four compounds in Table I) the intensities of these bands seem to be reversed following change in the state of measurement, from solution state to solid state, as pointed out by Costa, *et al.*,5) but the intensities did not change to any appreciable extent by further dilution in carbon disulfide, indicating that these bands are not caused by intermolecular interactions.15)

II. Ring C-H Out-of-plane Bending Frequencies

In the region of 650 and 950 cm^{-1}, the strong absorptions originating in ring C–H out-of-plane bending vibrations are expected. Assigned band frequencies are listed in Table II with other prominent absorptions in this region. In the case of N-oxide compounds, this region is a little complicated by the occurrence of another moderate

TABLE II. Absorption Frequencies in the Region of 650 and 900 cm^{-1}

Substituent	δ C–H (out-of-plane)	$\Delta\nu$ a)	Other prominent bands		
I. 4-Substituted Pyridine 1-Oxides					
NO_2	867 s (846) b)	+20 (+2) b)	874 s	749 m	681 m
CN	854 s (837)	+25 (+20)	840 w	713 s	
$COCH_3$	845 s (838)	(+26)	828 w		
SO_3Na	846 s	+23			705 s
$CONH_2$	855 s	+9	870 s	779 m	
$COOC_2H_5$	877 s (848) ?	(0)	867 m	770 s	687 s
Br	866 s (827)		840 m	824 m	
Cl	868 s (829)	(+21)	848 m	829 m	670 s
bipyridine	838 s	+31			
CH_3*	823 s	+30	855 m	761 s	
C_2H_5*	833 s	+15	849 m	743 s	
OCH_3	850 s (830)	(+16)		756 s	
NH_2	826 s	+4	862 m	778 s	
II. 3-Substituted Pyridine 1-Oxides					
NO_2	812, 808 m (789)	−25 (−30)	824 s	735 s	668 m
CN	809 s (783)	−1 (−20)		732 m	675 s
$COCH_3$	805 s (790)	(−17)		721 s	679 s
$CONH_2$	743 s	−35	817 m		672 m
$COOC_2H_5$	817 m ?		870 m	757 s	683 m
Br*	770 s	−18	844 m		662 s
Cl*	769 s	−23	843 m		662 s
bipyridine	796 s		847 s	724 m	679 s
CH_3*	778 s	−4	847 m	749 m	674 s
C_2H_5*	785 s	−20	863 m	740 m	675 s
NH_2	763 s	−36	852 m	870 m	676 s
$NHCOCH_3$	800 s		850 m	781 s	670 s
III. 2-Substituted Pyridine 1-Oxides					
bipyridine	767 s	+12	838, 853 s		723 m
CH_3*	757 vs	+8	854 s		695 m
NH_2	784 s	+15	846, 870 m		739 s

* In CS_2 solution, others in Nujol mull.

a) Frequency differences as compared to those of the parent pyridines in the same state.

b) Values in parentheses are frequencies and their differences observed in CS_2 solution.

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15) Examination of the solvation effect indicated that these inflexion or satellite bands are also related to the N–O stretching mode.

or strong band in the region of 720~780 cm^{-1} and 840~880 cm^{-1}, respectively. The latter bands are those assigned to N–O stretching frequencies by Ito, *et al.*,[3] and as can be seen from Table II, most of the N-oxides examined showed a band in the region of 840 and 870 cm^{-1} and they are considered to be a characteristic absorption of N-oxide compounds, presumably originating in N–O bending mode (compare the N–O bending frequency of aromatic nitroso compounds : 850~810 cm^{-1} for monomer, 855 cm^{-1} for dimer[16]). However, these bands are very variable in both frequency and intensity, and do not show any correlation with the structure.

C–H Out-of-plane bending frequencies can be interpreted in terms of the number of adjacent free hydrogen atoms on the ring in a similar way to substituted benzenes or pyridines.[1] The overall ranges are as follows : A characteristic strong absorption[1] shown by β-substituted pyridines in the region of 690 and 730 cm^{-1} appeared at a considerably lower frequency region of 660 and 680 cm^{-1} in their N-oxides with decreased intensity.

4-Substituted pyridine 1-oxides	820~870 cm^{-1}	s
3-Substituted pyridine 1-oxides	760~820 cm^{-1}	s-m
and always	660~680 cm^{-1}	s-m
2-Substituted pyridine 1-oxides	750~790 cm^{-1}	vs

These frequencies did not show so distinct a relation with the nature of substituent as in the case of substituted pyridines,[1] but they showed a regular shift from those of the corresponding pyridines depending upon the type of substitution. It was shown previously[2] that these bands in alkylpyridine 1-oxides did not show any shift in a definite direction as compared to those of the parent pyridines, but β-alkyl derivatives tend to shift to a lower frequency. From a comparison in mono-substituted derivatives, it was found that 4- and 2-substituted pyridine 1-oxides showed this absorption always at a higher frequency than the corresponding pyridines, regardless of the nature of a substituent, while 3-substituted derivatives showed this absorption always at a lower frequency than the corresponding pyridines, as shown in Table II.

The reason for this behavior is difficult to understand, but these frequency differences are thought to correspond to those in the nature of ring C–H bonds between pyridines and their N-oxides. According to the view of Kross, *et al.*,[18] the above results indicate that the ring π-electron density decreases in 4- and 2-substituted pyridine 1-oxides and increases in 3-substituted derivatives as compared to that of the corresponding substituted pyridines, and a possible explanation on this basis will be given later in connection with the σ-values for the N-oxide group.

In these compounds, C–H out-of-plane bending frequencies largely depend on the state of measurement, and in solid state they showed a considerable shift of usually 20~40 cm^{-1} to a higher frequency than those in solution state (cf. Table II). This may be due to the fact that the dipolar interaction between N–O dipoles in solid state also appreciably affects the ring hydrogen vibration.[17]

III. Absorptions in the Region of 900 and 1200 cm^{-1}

It was shown[1] that a series of weak absorptions in this region shown by substituted pyridines were very characteristic for the type of substitution, assigning them to a ring C–H in-plane bending mode involving a considerable ring vibration. Their

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[16] K. Nakamoto, R. E. Rundle : J. Am. Chem. Soc., **78**, 1113(1956). Lüttke, however, assigned these bands to coupled C–N stretching frequencies (W. Lüttke : Z. Elektrochem., **61**, 302(1957)).

[17] According to the author's experience, these frequencies in substituted benzenes usually show only a minor shift of 2~7 cm^{-1} to a higher frequency on passing from solution to solid spectra, while those in substituted pyridines show somewhat larger shift of, in many cases, 10~15 cm^{-1}, and this may be also due to the influence of dipolar interaction between ring nitrogens.

[18] R. D. Kross, V. A. Fassel, M. Margoshes : J. Am. Chem. Soc., **78**, 1332(1956).

N-oxides also showed two or three absorptions in this region which were relatively constant depending upon the type of substitution, but their intensities are much increased and their frequencies did not show such a similarity with those of the parent pyridines as would be expected. Prominent absorptions in this region are listed in Table III.

TABLE III. Absorption Bands in the Region of 900 and 1200 cm^{-1}

Substituent	Observed frequencies (cm^{-1})					
	I. 4-Substituted Pyridine 1-Oxides					
NO_2	1168 1174 ms	(1166)	1096 1122 s	1019 m	(1019)	
CN	1174 s	(1163)		1034 ms	(1028)	
$COCH_3$	1179 s	(1163)	1089 w	1028 m	(1027)	
$CONH_2$	1198 s 1152 s		1105 m 1125 ms	1034 w		
$COOC_2H_5$	1167 s	(1156)	1101 m 1133 ms	1022 s	(1019)	
Br	1189 s	(1164)	1095 m	1041 m	(1029)	
Cl	1189 s	(1163)	1116 m	1042 m	(1030)	
Bipyridine	1183 vs			1024 s		
CH_3*	1170 ms			1037 m		
C_2H_5*	1172 s			1036 m		
OCH_3	1179 1188 ms	(1163)		1013 s 1033 m	(1022) (1033)	
NH_2				1027 m		
	II. 3-Substituted Pyridine 1-Oxides					
NO_2	1170 m		1080 1116 w	1014 s	(1012)	952 ms 939 m
CN	1166 s	(1153)	1151 1101 m	1018 s	(1013)	958 909 ms
$COCH_3$	1167 m	(1156)		1011 s	(1011)	977 m 926 ms
$CONH_2$	1166 m		1120 m	1022 s		936 s
$COOC_2H_5$		(1153 w)	1112 1125 s	1026 m 1009 s	(1011)	958 m
Br*	1155 m		1082 m	1009 s		897 s
Cl*	1153 m		1093 ms	1010 s		918 s
Bipyridine	1191 s		1157 1178 m	1008 s 1018 m		958 m
CH_3*	1170 1159 s			1018 s		948 m
C_2H_5*	1167 1159 s			1017 s		926 ms
NH_2				1019 m		973 s
	III. 2-Substituted Pyridine 1-Oxides					
Bipyridine	1148 ms		1119 w	1023 ms		960 m
CH_3*	1217 s		1111 m	1049 m		990 m
NH_2	1153 1134 ms			1033 w		977 917 w

* In CS_2 solution, others in Nujol mull.
vs : very strong s : strong ms : medium strong m : medium w : weak
Values in parentheses are frequencies observed in CS_2 solution.

Most of the N-oxide compounds examined showed a strong absorption in the range of 1150 and 1190 cm^{-1}, which may be useful in recognition of the N-oxides as well as a stronger absorption due to N-O stretching vibration at a higher frequency side. These bands are considered to be due to ring C-H in-plane bending mode, but they showed a regular shift to a higher frequency on passing from solution in carbon disulfide to solid state, in contrast to a shift to a lower frequency observed for N-O stretching frequencies, suggesting that the oxygen bending mode also contributes appreciably to these absorptions (cf. Table III).

The 4- and 3-derivatives showed a moderate strength band in the ranges of 1020～

1050 cm^{-1} and 1005～1030 cm^{-1}, respectively, which may correspond to a similar band in the region of 990 and 1030 cm^{-1} in substituted pyridines and attributed to a ring vibration. These bands do not permit so clear a differenciation between these two types of substitution, but 3-derivatives showed one or two bands in the region of 890 and 950 cm^{-1}, while 4-derivatives usually did not show any absorption in this region.

IV. Ring Double-Bond Stretching Vibrations

Substituted pyridine 1-oxides usually showed three or four absorptions in the region of 1450 and 1630 cm^{-1} in a similar way to that of the substituted pyridines,[1] due to their ring double-bond stretching vibrations, but their exact frequencies and intensities are very variable as shown in Table IV. However, just as in the case of substituted pyridines,[1] absorption patterns of the two bands between 1560 and 1630 cm^{-1} showed a distinct relation with the structure, a normal absorption patterns where a band on a higher frequency side is stronger was shown by compounds with a strongly electron-attracting substituent at 4-position and those with a halogen or an electron-donating substituent at 3-position, and other compounds showed an abnormal pattern where the relative intensity was reversed (3-nitro or 3-acetyl derivatives), any appreciable absorption was not shown (4-halo or 4-alkyl derivatives), or an abnormally higher frequency shift was observed (4-amino or 4-methoxy derivatives). It follows that γ- and β-derivatives show entirely a reverse behavior following change in the nature of the substituent, and furthermore, these behaviors are entirely reverse of those[1] observed in parent pyridines (compare, for example, nitro derivatives).

TABLE IV. Absorption Bands in the Region of 1450 and 1650 cm^{-1}

Substituent	Observed maxima (cm^{-1})[a] [b]					
	4-Substituted derivs.			3-Substituted derivs.		
NO_2	1605 s	1590 ms	1464 s	1592 vw	1559 m	1441 m
CN	1616 m		1484 s 1449 m	1604 m	1559 vw	1486 s 1439 s
$COCH_3$	1608 s	1541 w	1490 m	1604 w	1560 m	1490 m
$COOC_2H_5$	1617 ms			1610 m	1567 w	1488 m 1477 s
$CONH_2$		1550 ms	1502 m 1451 s		1572 m	1443 s
Br[c]			1471 s	1596 ms	1538 w	1471 s 1427 s
Cl[c]		1550 vw		1596 ms	1546 m	1471 s 1427 s
Bipyridine		1543 vw	1477 s	1608 m	1558 m	1471 s
CH_3[d]	1634 vw		1488 s	1608 ms	1565 w	1488 1429 m
C_2H_5[d]	1629 vw		1490 s	1608 s	1563 m	1481 m 1439 s
OCH_3	1628 m	1565 w	1499 s			
NH_2	1638 s	1558 w	1466 s	1587 s	1573 s	1499 s 1456 s

a) NO_2 asym.-stretching and NH_2 deformation frequencies were omitted.
b) s : strong ms : medium strong m : medium w : weak vw : very weak
c) For 3-derivatives, in $CHCl_3$
d) In CCl_4, others in Nujol mull

Considering the electron distribution in the ring, this seems to be related to the fact that the mesomeric structures (II) and (III) are important contributors in pyridine 1-oxide ring, contrary to the well known fact that the contributions of the comparable structures (VI) and (VII) are negligible in a pyridine ring, giving a further confirmation to the view[1,19] that the intensities of these two bands have a direct relation to the

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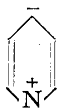
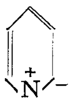
[19] Bomstein has pointed out that the intensities of these bands in disubstituted benzenes could be correlated with the orientation and position of the substituents (J. Bomstein : Anal. Chem., **25**, 512(1953)).

type of π-electron distribution on the ring.


(VI)


(VII)

V. Effect of Ring N-O Group on the Absorption Frequency of a Substituent

In the preceding paper,[1] it was pointed out and discussed that the electronic effect of ring nitrogen toward each position of the ring appeared regularly as a frequency shift in a characteristic vibration of ring substituent, deriving the σ-values of 0.93, 0.62, and 1.02, respectively, for 4-, 3-, and 2-position of pyridine. The same consideration should also hold for pyridine 1-oxide ring, where it should be possible to detect the electronic effect of ring N-O group towards each position of the ring through the frequency shift of a characteristic vibration.

Thus, the characteristic frequencies of some 4- and 3-substituted pyridine 1-oxides were compared carefully with those of the substituted pyridines under the same conditions, and it was found, as can be seen from Table V, that the 4-substituted pyridine 1-oxides always showed an absorption at the lowest frequency among these five compounds, while 3-substituted derivatives showed it always at the highest frequency. These results indicate that the electron-withdrawing power of the N-oxide group is very weak toward 4-position of the ring, while extremely strong towards the 3-position.

Table V. Absorption Frequencies of Some Derivatives of Pyridine 1-Oxide and Pyridine

A. Acetyl derivatives

Compound	C=O Stretching frequency (cm^{-1} in CS_2)
4-Acetylpyridine 1-oxide[a]	1693
3-Acetylpyridine 1-oxide[b]	1706
4-Acetylpyridine	1703
3-Acetylpyridine	1697
2-Acetylpyridine	1704

B. Ethoxycarbonyl derivatives

Compound	C=O Stretching frequency (cm^{-1} in CS_2)
Ethyl isonicotinate 1-oxide[a]	1727
Ethyl nicotinate 1-oxide[a]	1737
Ethyl isonicotinate	1734
Ethyl nicotinate	1730
Ethyl picolinate	1722, 1750

C. Nitro derivatives

Compound	NO_2 Stretching frequency (cm^{-1} in $CHCl_3$)	
	Asymmetric	Symmetric
4-Nitropyridine 1-oxide[c]	1531	1342
3-Nitropyridine 1-oxide[c]	1539	1360
4-Nitropyridine	1539	1355
3-Nitropyridine	1533	1355
2-Nitropyridine	1548	1355

D. Cyano derivatives

Compound	C$\equiv$N Stretching frequency (cm^{-1} in CCl_4)
4-Cyanopyridine 1-oxide[b]	2240
3-Cyanopyridine 1-oxide[b]	2247
4-Cyanopyridine	2243
3-Cyanopyridine	2240
2-Cyanopyridine	2245

a) Approx. 0.3% solution; cell thickness, 1.0 mm.
b) Saturated solution in CS_2 or CCl_4; cell thickness, 5.0 mm.
c) Approx. 3% solution; cell thickness, 0.1 mm.

On the basis of the well established correlation,[20] $\nu = 1689.5 + 14.0\,\sigma$, between carbonyl frequencies and σ-values of the substituents in substituted acetophenones involving acetylpyridines, the σ-values of N-oxide group can be calculated as 0.25 and 1.18, respectively, for 4- and 3-positions of pyridine 1-oxide, from the observed carbonyl frequencies of 4- and 3-acetylpyridine 1-oxides. The C=O frequencies of ethoxycarbonyl derivatives and C$\equiv$N frequencies of cyano derivatives confirmed the validity of these σ-values as plotted in Fig. 3-B and D. Observed discrepancy of NO_2 asymmetric stretching frequencies is assumed to be caused by the hydrogen bond formation between N-oxide and chloroform (Fig. 3-C).

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20) This equation was calculated by the author on the basis of the data in Part IV of this series. Cf. also R. N. Jones, W. F. Foroes, W. A. Mueller: Can. J. Chem., **35**, 504(1957).

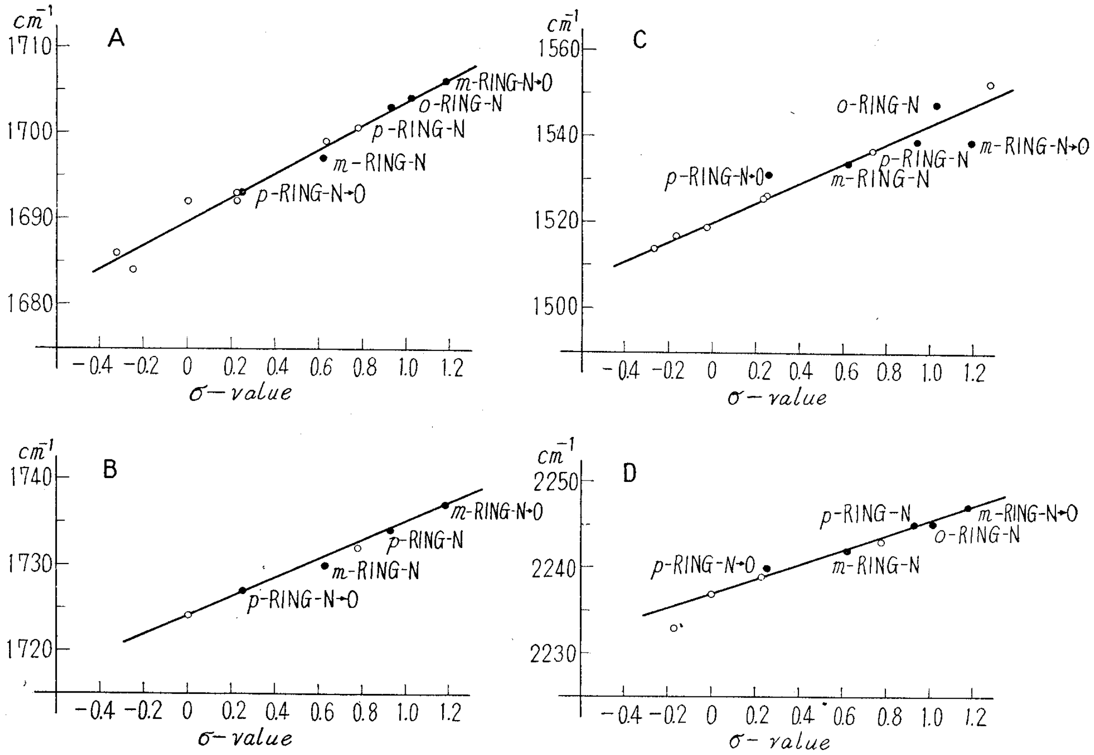

Fig. 3. Side-chain Stretching Frequency vs. Hammett's Substituent Constant
(A) acetyl derivatives, (B) ethoxycarbonyl derivatives, (C) nitro derivatives, (D) cyano derivatives
○ substituted benzene derivatives

The value of 0.25 is nearly equal to that of *para*-halogen (*p*-Br : 0.232), indicating that the overall-electronegativity of the N-oxide group toward the 4-position is weak, while the value of 1.18 is the largest σ-value so far encountered, indicating that the overall electronegativity to 3-position is extremely strong. Since mainly inductive effect would be concerned toward 3-position, the difference of these two values might provide an approximate index of the contribution of mesomerism to the overall electronegativity of N-oxide group toward the 4-position, and the value of 0.93 indicates that such contribution, i.e. that of mesomeric structures (II) and (III), to the resonance system is very large, in agreement with many other evidences.

On the other hand, Jaffe[21] recently, proposed the σ-value of 1.35 and 1.48, respectively, for 4- and 3-position of pyridine 1-oxide, from pK values of the corresponding N-oxide of pyridine-carboxylic acid, these values indicating that the N-oxide group is extremely strongly electronegative both for 4- and 3-positions. The two values for 3-position seem to approximately agree in that both represent the strong inductive effect of the N-oxide group, but those for 4-positon seem to be basically different, and the value of 1.35 seems to be too large from the point of a large contribution of mesomerism. Such a discrepancy is assumed to be caused by the difference in conditions under which these values were derived, and since Jaffe's values were derived in water and ethanol solution, i.e. under the strongly solvated conditions, present author's values, which were derived in dilute solution in non-polar solvent, are considered to be closer to the true σ-values. The more general validity of the value of 0.25 is also questionable, because the compounds used here in deriving the σ-value are all those with an electron-withdrawing substituent in the 4-position, where resonance of struc-

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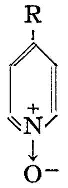
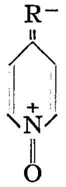
[21] H.H. Jaffe : J. Am. Chem. Soc., **76**, 3527(1954).


(VIII)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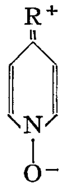
(X)

tures (VIII) and (IX) must be important. Therefore, in the case of the compounds with an electron-repelling substituent in the 4-position, other constants of larger magnitude will be needed, since in this case resonance of (VIII) and (X) must be important.

It has been shown[22] that the σ-values are monotonically related to the decrease of electron density at the particular carbon atom of the aromatic ring produced by a substituent. Therfore, it follows that the electron density decreases in the following order: 4-Position of N-oxide>3-position of pyridine>4-position of pyridine>3-position of N-oxide. This fact explains the behavior in the shift of ring C-H out-of-plane bending frequencies, and the lower frequency shifts in 3-substituted pyridine 1-oxides as compared to those in parent pyridines can be understood by the terms of the considerable increase in electron density at 4-position, while the higher frequency shifts in 4-substituted derivatives can be understood as the considerable decrease in that at 3-position.

The author expresses his deep gratitude to Prof. K. Tsuda of the University of Tokyo for kind guidance throughout the course of this work, to Dr. Takehiko Shimanouchi of the University of Tokyo for valuable advices, to Prof. E. Ochiai and Assist. Prof. T. Okamoto of the University of Tokyo for supplying some of the samples and for their kind encouragements, to Prof. J. Haginiwa of the University of Chiba and Dr. N. Sugimoto of Osaka Laboratory of Tanabe Seiyaku & Co., for supplying some of the samples, and to Mr. M. Matsui, Director of this Laboratory, and to Mr. M. Suzuki and Mr. A. Ito of this Laboratory for their helpful encouragements.

Experimental

Material—4-Nitropyridine 1-oxide (m.p. 160°) was prepared by the nitration[8] of pyridine 1-oxide. 4-Chloro- (m.p. 169.5°(decomp.)), 4-bromo- (m.p. 146°(decomp.)), 4-methoxy- (m.p. 83°), and 4-benzyloxy- (m.p. 176°)-pyridine 1-oxides were prepared from 4-nitropyridine 1-oxide following the direction of Ochiai.[8] 3-Nitro- (m.p. 172°), 3-cyano- (m.p. 178°), 3-acetyl- (m.p. 147°), 3-bromo- (m.p. ca 40°), and 3-chloro- (m.p. 60°)-pyridine 1-oxides were prepared by oxidation of the corresponding pyridines[1] with Perhydrol,[8] and were checked by elemental analysis. 4-Cyano-, sodium 4-sulfonate-, methyl, nitro, and methylamino derivatives were prepared in the Pharmaceutical Institute of the University of Tokyo. Three bipyridyl N,N-dioxides were supplied by Prof. J. Haginiwa of the University of Chiba. 4-Acetylpyridine 1-oxide was supplied by Dr. N. Sugimoto of Osaka Research Laboratory of Tanabe Seiyaku & Co. Ethoxycarbonyl, amino, and amido derivatives were prepared by Mishima of this Laboratory.

Method—Infrared spectra were measured with a Perkin-Elmer Model 21 double-beam spectrophotometer provided with a NaCl prism. Detailed conditions of the measurements of solution spectra are described under Tables I and V. The values in solution state in Tables II and III are those observed under the same conditions with the above. Because of the low solubility of the samples, a cell of 5.0-mm. thickness was used in some cases with a saturated solution in CS_2. Solid spectra were obtained by mulling the sample in Nujol.

For comparing small frequency shifts as described in Section V, measurements were made under the same conditions and at the same time for each group of compounds, and the mean value of three measurements was adopted. The frequencies of substituted pyridines were checked at the same time. Chart scale of 20 cm./μ was applied, scanning very slowly. This chart scale was also applied in determining the exact values of N-O stretching frequencies in CS_2 solution. In these cases, accuracy of the frequency is assumed to be within $\pm 1\,cm^{-1}$.

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[22] H. H. Jaffe: J. Chem. Phys., **20**, 279(1952).