

The Synthesis and Infrared Spectra of Isomeric Pyridine Monoamidoximes and Some Derivatives

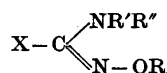
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Pyridine-2-, -3- and -4-amidoxime were synthesized from 2-, 3- and 4-cyanopyridine. Recrystallization of the amidoximes from deuterium oxide gave the $-C:(NOD)(ND_2)$ derivatives. The hydrochloride salts were prepared both by saturating an acetic acid solution of the amidoxime with gaseous hydrogen chloride and by evaporation to dryness of a solution of the amidoxime in hydrochloric acid. Reaction of the amidoximes with hexamethyldisilazane resulted in the *O*-trimethylsilyl ethers. These ether derivatives synthesized for this investigation have not been previously reported in the literature. The infrared spectra of the compounds prepared were analyzed to assign and assess the absorption frequencies of N—H, N—D, O—H, O—D, acyclic C=N, N—O, the pyridine ring stretching and the C—H out of plane wagging vibrations for this series of isomeric pyridine monoamidoximes and derivatives. In the case of the trimethylsilyl ether derivatives additional frequencies specific to these compounds are presented.

Current research by the author on the synthesis and spectra of transition metal ion complexes with pyridine-2-amidoxime has disclosed a lack of published infrared data on this ligand. A survey of the literature shows considerable research has been conducted on the infrared spectra of aldoximes.¹⁻⁷ By comparison, only two comprehensive reports on the IR spectra of amidoximes were found.^{8,9} Other papers presented infrared data on amidoximes as evidence of amino-imino tautomerism,^{10,11} as a minor part of other research on amidoximes,¹²⁻¹⁴ or included in a study of selected infrared absorption frequencies.^{15,16} In addition, it was

found that results obtained by different investigators were sometimes inconsistent. As part of a continuing study of the amidoxime functional group, the research presented herein has a three-fold purpose: (a) To attempt to assign IR absorption frequencies associated with the major absorption bands of the three pyridine monoamidoximes and four derivatives of each; (b) to compare these assignments with those which have been published; and (c) to discuss similarities and differences between aldoximes and amidoximes. The latter purpose is relevant because the pyridine-2- isomers of both compounds form coordination compounds involving a five-membered ring which utilizes the hetero-



Compound No.	X	R	R'	R''
1	2-pyridyl	H	H	H
2	2-pyridyl	D	D	D
3	2-pyridyl	K	H	H
4	2-pyridyl	Si(CH ₃) ₃	H	H
5	Dihydrochloride salt of 1			
6	3-pyridyl	H	H	H
7	3-pyridyl	D	D	D
8	3-pyridyl	K	H	H
9	3-pyridyl	Si(CH ₃) ₃	H	H
10	Dihydrochloride salt of 6			
11	4-pyridyl	H	H	H
12	4-pyridyl	D	D	D
13	4-pyridyl	K	H	H
14	4-pyridyl	Si(CH ₃) ₃	H	H
15	Dihydrochloride salt of 11			

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Scheme 1.

cyclic ring and the oxime nitrogens as electron donor atoms. A knowledge of the IR spectral characteristics of the free ligand would be most useful in determining the mode of chelation. The compounds studied in this investigation are denoted 1–15 as shown in Scheme 1.

EXPERIMENTAL

IR spectra were recorded on Perkin-Elmer PE 297, PE 421 and JASCO IRA-1 spectrophotometers using KBr pellets for solid compounds and liquid films between NaCl discs for liquid compounds. The wavenumber scale was calibrated using both 0.05 mm polystyrene film and indene. Melting points and boiling points are uncorrected. Elemental analyses were performed by Schwarzkopf Microanalytical Laboratory Woodside, NY, USA and are within $\pm 0.4\%$ of the calculated values if not otherwise stated.

Preparations. The synthesis on compounds 1,¹⁷ 6¹⁸ and 11¹⁹ was performed by published methods. Compounds 2, 7 and 12 were prepared by recrystallization of 1, 6 and 11 three times from 99.8 atom % deuterium oxide.

Pyridine-2-amidoxime, potassium salt (3). Potassium hydroxide (4.6 g, 0.10 mol) and 1 (6.85 g, 0.05 mol) were dissolved in 200 ml of absolute alcohol. After the addition of 150 ml of benzene, the water was removed by azeotropic distillation and the solution evaporated to dryness. Although the yellow solid contained some pyridine-2-amidoxime, it was considered sufficiently pure for infrared examination. The potassium salts of the other two isomers, 8 and 13, were similarly prepared.

Pyridine-2-amidoxime dihydrochloride (5). (Method A). 1 was dissolved in excess hydrochloric acid and evaporated to dryness. After recrystallizing from hot absolute alcohol, the white crystalline solid was dried over P₂O₅. Anal. C₅H₇N₃OC1₂: C, H, N, Cl. (Method B). 1 was dissolved in a minimum amount of glacial acetic acid and the solution was saturated with hydrogen chloride gas. The precipitated hydrochloride salt was filtered, then recrystallized and dried as in Method A. Method B gave a purer initial product but in lesser yield than Method A. The dihydrochlorides of the other two isomers, 10 and 15, were similarly prepared.

Pyridine-2-amidoxime O-trimethylsilyl ether (4). 1 (1.37 g, 0.01 mol) was dissolved in excess hexamethyldisilazane containing 3–4 drops of trimethylchlorosilane as a catalyst. The solution was heated for one hour at 70 °C with stirring and then vacuum distilled to give a colorless liquid (1.15 g, 55 % yield), b.p. 224–226 °C. Anal. C₈H₁₅N₃O Si: C, N, Si.

Pyridine-3-amidoxime O-trimethylsilyl ether (9). 6 (1.37 g, 0.01 mol) was reacted as for 4 above. The solution was vacuum distilled to give a low melting solid (1.10 g, 52 % yield),

b.p. 145–147/10 mm. Anal. C₈H₁₅N₃O Si: C, N, Si.

Pyridine-4-amidoxime O-trimethylsilyl ether (14). Starting with 11 and using the procedure as for compound 9 resulted in a white solid which was recrystallized from benzene (0.84 g, 40 % yield), m.p. 192–193 °C. Anal. C₈H₁₅N₃O Si: C, N, Si. (Regardless of the experimental conditions employed, the reaction of the amidoxime with hexmethyldisilazane resulted in only a single product, the mono-(O-trimethylsilyl)-amidoxime.)

RESULTS AND DISCUSSION

Tables 1 and 2 list the absorption frequency assignments which were made in this study. Instances where assignments could not be made or are uncertain are indicated by '?'. Blank spaces in the chart are left for assignments which are not applicable. The frequencies chosen for study are those which may be involved to the greatest extent when pyridine monoamidoximes undergo complexation reactions.

The asymmetric (ν_a) and symmetric (ν_s) NH₂ stretching vibrations are presented in Table 1. The parent amidoximes (1, 6 and 11) all have frequencies within the range expected when the KBr pellet technique is used. The two NH₂ stretching vibrations for 11 agree well with the reported¹³ values of 3445 and 3300 cm⁻¹. Average force constant calculations for ν_a and ν_s for NH₂ gave values of 6.5 and 6.0×10^5 dyn/cm, respectively. Force constants for the same vibrational frequencies in ND₂ gave values of 6.9 and 6.1×10^5 dyn/cm. It is known that ν_a for the free NH₂ group in amines and amides occurs above 3500 cm⁻¹ and ν_s at 3400 cm⁻¹. The observed shift of these two vibrations to lower frequencies suggests that the NH₂ group is bound. Inspection of the OH frequency in 1, 6 and 11 also discloses vibrations considerably lower than usually found for free OH groups. These two frequency shifts to lower wavenumbers can be interpreted as being the result of intramolecular hydrogen bonding between the oxime proton and the amine nitrogen for amidoximes in the solid state. These same vibrations, OH, ν_a and ν_s , determined using carbon tetrachloride as a solvent were found to be at 3602, 3507 and 3387 cm⁻¹ which indicates little or no intramolecular hydrogen bonding in aprotic solvents. The out of plane C–H vibration corresponds to the number of adjacent

Table 1. Infrared frequency assignments (cm^{-1}).

Compound No.	NH_2		ND_2		OH	OD	C=N
	ν_a	ν_s	ν_a	ν_s			
1	3468	3335			3070		1648
2			2610	2463		2320	1635
3	3445	3335					1652
4	3510	3395					1643
5	?	?			?		1742
6	3415	3260			3145		1646
7			2550	2385		2340	1626
8	3424	?					1678
9	3465	3310					1637
10	?	?			?		1716
11	3445	3300			3160		1638
12			2600	2462		2325	1618
13	3461	3315					1685
14	3426	3320					1654
15	3462	3296			3163		1725

ring hydrogens. Although this vibration appears to be somewhat influenced by the particular derivative, all of the 2-, 3- and 4-isomers fall within the 770–735, 810–750 and 860–800 cm^{-1} ranges for these assignments.²⁰

Between 1610 and 1410 cm^{-1} monosubstituted pyridine rings should give rise to four ring stretching frequencies.²⁰ 2-Substituted pyridine ring bands are expected at 1615–1585, 1576–1568, 1477–1465 and 1438–1428 cm^{-1} ; 3-substituted at 1600–1590, 1582–1572, 1485–

1465 and 1425–1417 cm^{-1} ; and 4-substituted at 1608–1598, 1569–1553, 1520–1480 and 1419–1411 cm^{-1} . The four pyridine ring bands for compounds 1–5 lie in the range 1620–1589, 1577–1567, 1488–1465 and 1452–1412 cm^{-1} ; for compounds 6–10 the ranges are 1611–1596, 1573–1529, 1490–1465 and 1425–1408 cm^{-1} ; and for compounds 11–15 the ranges are 1607–1602, 1553–1542, 1512–1480 and 1418–1410 cm^{-1} . The pyridine ring stretching frequencies for the cyanopyridines have been

Table 2. Infrared frequency assignments (cm^{-1}).

Compound No.	Ring I	Ring II	Ring III	Ring IV	N–O	C–H (out of plane)
1	1600	1575	1488	1450	956	741
2	1597	1576	1486	1452	973	752
3	1592	1576	1482	1443	939	740
4	1589	1577	1478	1439	929	750
5	1614	1576	1465	1412	1089	763
6	1611	1573	1490	1410	950	814
7	1597	1568	1478	1413	959	775
8	1610	?	1465	1410	950	815
9	1596	1562	1479	1525	924	752
10	1603	1529(?)	1467	1408	1110	800
11	1602	1552	1502	1411	958	837
12	1607	1548	1512	1418	968	860
13	1602	1545	1505	1412	949	839
14	1605	1542	1480	1414	924	840
15	1605	1553	?	1410	1100	844
2-Cyanopyridine	1598	1572	1463	1443		
3-Cyanopyridine	1600	1576	1485	1426		
4-Cyanopyridine	1595	1545	1495	1410		

included for comparison purposes. With three exceptions, the experimental values agree well with the expected values. Pyridine ring band II for compound 10 is almost certainly incorrect, however no other frequency was observed. No assignment could be made for band II of compound 8 and band III of compound 15. These bands may be very weak and merely not of sufficient intensity to be observed. In general, it appears that the observed and predicted values for these ring bands are in close agreement even for a derivative substituent as polar as the amidoxime group.

The C=N (acyclic) vibrational frequency was assigned after first locating the four ring bands from the previous discussion. In all cases there was a band of strong intensity at a frequency greater than 1615 cm^{-1} , the upper limit for ring stretching band I.²⁰ This band was assigned as the C=N frequency. The literature states²¹ that the intensity of this vibration for oximes can vary from weak to very strong, depending upon the bond environment. The results of this investigation show a strong vibration in all cases and this intensity is probably the result of conjugation with the pyridine ring. One investigator² has assigned the C=N frequency for pyridine-2-aldoxime a value of 1520 cm^{-1} . This very low value is attributed to interaction of the oxime proton with the heterocyclic nitrogen resulting in partial ionization. Such a possibility should be more pronounced in the *anti*-pyridine-2-aldoxime isomer than in the *syn* isomer. One could predict a similar effect in pyridine-2-amidoxime, however this was not the case. Recent work by this investigator¹⁷ indicates that pyridine-2-amidoxime exists predominantly in the *syn* configuration which does not allow the ring nitrogen-oxime hydrogen interaction to occur and hence a normal C=N frequency. A second investigator²² assigned the C=N vibrations in pyridine-2-, -3- and -4-aldoxime frequencies of 1620, 1620 and 1640 cm^{-1} , respectively. These are in much closer agreement with the assignments made here for the corresponding amidoximes. It is possible that the two different values reported for the acyclic C=N band in pyridine-2-aldoxime involved *syn* and *anti* isomers, although no mention was made of this fact in the papers.

The two reported values for the C=N

frequency in pyridine-2-amidoxime are 1630¹⁴ and 1605 cm^{-1} .¹⁵ When compared to the value of 1648 cm^{-1} assigned in this research one sees a wide variation among the three. This difference cannot be explained however, it cannot be ascribed to solvent differences because all three values were obtained using a KBr pellet.

The general effect of deuteration on the C=N band in amidoximes has been reported both to increase¹⁵ and decrease¹¹ the frequency of this vibration. In this work it was observed that deuteration shifted the C=N band to lower frequencies by 17–20 cm^{-1} . The greatest apparent shift in C=N frequencies occurs in the dihydrochloride salts which show an increase of 70–90 cm^{-1} over that observed for the parent amidoximes. This large shift can be attributed to a $-\overset{+}{\text{C}}=\overset{+}{\text{N}}-$ stretching mode present in the dihydrochlorides and compares favorably with previous observations^{23,24} for *N*-alkyl amidinium chlorides. It has also been observed²⁵ that the potassium salts of oximes have C=N frequencies in the range of 1660–1618 cm^{-1} . In this study it was found that the potassium salts had C=N bands of 1685–1652 cm^{-1} . Although these values are somewhat higher than those reported for oximes, the observed trend of increasing wavenumbers is present in both classes of compounds. The dihydrochloride salts of three amidoximes exhibit four general characteristics in their IR spectra when compared to the parent compounds. These spectral differences involve the NH_2 , OH and NO frequencies as well as the previously discussed C=N vibration. Although it was possible to determine the ν_a and ν_s bands for compound 15, the same could not be done for compounds 5 and 10. In general, hydrochloride salts exhibit a series of bands in the form of a broad absorption between 3150 and 2500 cm^{-1} . This broad peak has been described as the 'ammonium band' with intermolecular bonding effects leading to a multiplicity of absorptions to include the OH frequency²⁶. In compounds 5, 10 and 15 a large increase was noted in the N–O frequency. A similar increase was also noted for pyridine-2-amidoxime.²

Only a single literature reference¹⁴ could be found concerning the synthesis of trimethylsilyl ethers which was contained as part of a

paper on metal derivatives of amidoximes. The three trimethylsilyl derivatives prepared in this study all show an intense band at 1250 cm^{-1} due to the $\text{CH}_3\text{-Si}$ symmetric deformations. The strong band occurring at $929\text{--}924\text{ cm}^{-1}$ is due to the N-O vibration which is a decrease of about 30 cm^{-1} when compared to the parent amidoxime. This decrease may be ascribed to the mass effect of the trimethylsilyl group. It is interesting to note that this frequency decrease in the N-O vibration is not apparent in any of the deuterated or potassium derivatives which lends support to a mass effect due to the bulk of the trimethylsilyl group. A similar effect on the C=N vibration of oximes has been reported,²⁷ however this was not the case in this work. The absorption of the $(\text{CH}_3)_3\text{Si}$ group in compounds 4, 9 and 14 was assigned values of 749 , 752 and 748 cm^{-1} , respectively. This is quite consistent with the frequency range of $750 \pm 10\text{ cm}^{-1}$ found in the literature for this vibration.²⁸

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