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Dipole Moments and Spectroscopic Properties of Methyl-4-nitropyridine N-Oxides

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Summary. Molecular dipole moments and dipole moments of interaction of seven methyl derivatives of 4-nitropyridine N-oxides were determined in benzene solution. Polar and spectroscopic (^{13}C NMR and UV/Vis) manifestations of intramolecular interaction indicate that the methyl groups modify the electronic interaction between the NO and NO_2 groups mainly through steric strain.

Keywords. Methyl-4-nitropyridine N-oxides; Dipole moments; Intramolecular charge-transfer; Steric interaction.

Die polaren und spektroskopischen Eigenschaften von Methyl-4-nitropyridin-N-oxiden

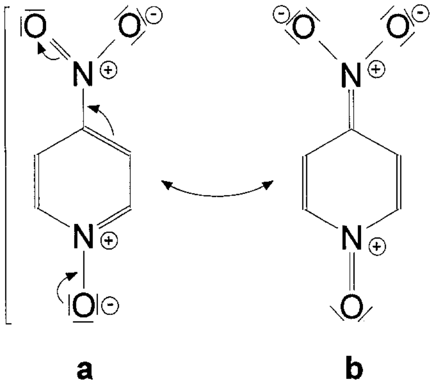
Zusammenfassung. Dipolmomente und Wechselwirkungsdipolmomente von sieben 4-Nitropyridin-N-oxiden wurden in benzolischen Lösungen gemessen. Die polaren und spektroskopischen Daten (^{13}C NMR und UV/Vis) deuten darauf hin, daß die Methylgruppen die elektronische Wechselwirkung zwischen N-oxid und Nitrogruppe hauptsächlich durch sterische Hinderung beeinflussen.

Introduction

Studies of pyridine 1-oxides play an important role in heterocyclic chemistry. Ample evidence suggests that the N–O moiety of pyridine N-oxide possesses a unique functionality which can act effectively in both directions as a push electron donor and a pull electron acceptor group [1–7]. This strong push-pull property has an essential chemical consequence; it accounts for the equally easy synthesis of 4-substituted derivatives of pyridine N-oxide with donor as well as acceptor groups. The properties of 4-nitropyridine N-oxide and its methyl derivatives are especially interesting because of their antifungal activity [8, 9] and optical non-linearity on the molecular as well as the macroscopic level [10, 11].

An indispensable prerequisite for achieving large second-order nonlinear optical response in an organic molecule is the existence of intramolecular charge-transfer (ICT), resulting from the electron donor and acceptor groups communicating through a π-conjugated molecular framework. The electronic structure of 4-nitropyridine N-oxide can be envisaged by the resonance forms **a** and **b** in Scheme 1.

The contribution of the resonance forms **a** and **b** depends on the nature of the substituent at position 4. The strong electron-acceptor nitro group favors the charge



Scheme 1

transfer form **b**. Moreover, from the point of view of nonlinear efficiency a favorable non-centrosymmetric molecular orientation in the crystalline is expected due to the small dipole moment in the ground state.

The distribution of electron density (or electrostatic potential on the molecular surfaces) has been obtained for several methyl derivatives of 4-nitropyridine N-oxide by means of quantum mechanical calculations [10, 12, 13]. Additional information about their electronic structure was obtained by X-ray and neutron scattering techniques [14, 15]. The results point to a predominant contribution of resonance form **b** and a push character of the NO group.

In the literature there are no data about the dipole moment and the spectroscopic properties of methyl derivatives of 4-nitropyridine N-oxide, although these compounds have been synthesized long ago [16–20]. The aim of this paper is to determine the mutual communication of NO and NO_2 groups and its modification by the steric effects of the methyl groups.

Results and Discussion

The values of the dipole moments of pyridine N-oxide, 4-nitropyridine N-oxide and their methyl derivatives **1**–**7**, nitrobenzene, 2,5-dimethyl-nitrobenzene, and 2,4,6-trimethyl-nitrobenzene are summarized in Table 1. The dipole moments of the last two compounds were calculated on the basis of literature data [24] according to Eq. 1.

The dipole moment of 4-nitropyridine N-oxide was found to be higher than that calculated with another procedure (0.69 D) [1]. The dipole moments of some of the methyl derivatives of 4-nitropyridine N-oxide were determined by molecular orbital calculations with a different level of sophistication (*e.g.* IEH, MINDO/2) and can be compared with the experimental values. The dipole moments of 4-nitropyridine N-oxide calculated by IEH and MINDO/2 methods have been derived as 1.71 D and 1.04 D, and those of **1** as 1.83 D and 1.79 D [12]. Obviously, semiempirical methods overestimate the dipole moment of 4-nitropyridine N-oxide. *Ab initio* calculations performed at the SCF level with two small basis sets have yielded dipole moments of 4-nitropyridine N-oxide of 1.53 D and 0.47 D [10]. The value of the dipole moment of **2** depends on the conformation of methyl group. Depending on

Table 1. Dipole moments of pyridine N-oxide, 4-nitropyridine N-oxide, **1**–**7**, and nitrobenzenes

Compound	$\alpha\varepsilon_1$	β	γn_1^2	P (cm^3)	μ (D)	μ_{int} (D)
Pyridine N-oxide	25.200	0.3175	0.1703	367.6	4.22	–
4-nitropyridine N-oxide	1.235	0.7998	0.2401	15.1	0.85	0.59
1	2.320	0.7610	0.7666	23.1	1.06	0.74
2	2.231	0.7877	0.7994	21.3	1.01	0.42
3	4.488	0.7719	0.8901	53.4	1.60	0.77
4	1.535	0.7304	0.8351	10.6	0.72	0.40
5	2.923	0.7008	0.7386	32.4	1.25	0.90
6	2.593	0.7139	0.5975	29.7	1.20	0.29
7	2.721	0.7622	0.7101	29.9	1.20	0.72
Nitrobenzene	22.265	0.4289	0.1658	324.6	3.96	–
2,5-dimethylnitrobenzene	21.551	0.4909	0.3253	314.1	3.90	–
2,4,6-trimethylnitrobenzene	18.825	0.3905	0.0386	278.2	3.67	–

the conformation and the base set, the calculated dipole moment of **2** has been found in the regions of 1.05–1.28 D and 0.22–0.48 D [10]. The first of them is in agreement with the experimental dipole moment. It should be mentioned that the dipole moment of 3.5 D obtained for **6** by means of crystallographic density maps has been overestimated [15].

The dipole moment of interaction (μ_{int}), being the difference between the experimental dipole moment and the one calculated by means of a vector calculus of the parent compounds (Table 1), provides a measure of the inner mutual interaction of substituents as well as their interaction with the ring. The dipole moment of toluene (0.36 D) was used in calculations as the partial dipole moment of the methyl group. Of course, the choice of the partial dipole moment of the nitro group plays a dominant role in calculations of μ_{int}. This moment depends on the degree of conjugation of NO_2 group with the aromatic system. The conjugation is strongly modified by the *ortho*-steric effects of the methyl groups. Thus, in the case of **2** and **6** effective dipole moment values of 2,5-dimethylnitrobenzene and 2,4,6-trimethylnitrobenzene were used (Table 1). It is also well known that the presence of two methyl groups in position 2 and 3 in relation to the 4-nitro group brings about a considerably greater inhibition of its conjugation with the aromatic ring than in 3-methyl derivatives (the so-called "*ortho* xylene effect" [25]). It can be supposed that the effective dipole moment of the NO_2 group in **3** and **7** would be of the same order as that for **6**. Thus, for the calculations we used the dipole moment of a weak conjugated NO_2 group (3.67 D). The dipole moment of 2,6-dimethylpyridine N-oxide in benzene has been found to amount to 3.61 D [26]; hence, μ_{calc} and μ_{int} for **5** are 0.35 D and 0.90 D. This last value is by about 0.25 D smaller than the one calculated from the composition dipole moments of nitrobenzene, pyridine N-oxide, and toluene. Considering non-additivity of the dipole moment of 2,6-dimethylpyridine N-oxide itself, it must be most likely connected with the interaction of methyl substituents and free electron pairs of the NO group oxygen. The dipole moment of interaction contains resonance as well as inductive factors, the latter being only slightly modified by the introduction of methyl groups into the 4-nitropyridine

N-oxide system. The values of μ_{int} suggest that methyl groups exert a rather weak electron donor effect. The essential factor influencing the charge transfer effect (contribution of resonance form **b**) is steric hindrance. This effect is marked most clearly in **6**, for which $\mu_{\text{int}} = 0.29$ D proves the electronic transmission between NO and the non-coplanar NO_2 group. The interaction is weakened in comparison with the other methylated derivatives (highest contribution of form **a**). Note that rotation of the nitro group is possible only in the case of form **a**. The non-additivity of dipole moments increases in the sequence 4-nitropyridine N-oxide $> \mathbf{2} > \mathbf{6}$ and is in full agreement with the electronic transition parameters of these compounds [27].

The calculated oscillator strength corresponding to the intramolecular charge-transfer transition (ICT) was found to be significantly smaller for **6** than for the two other derivatives, amounting to 0.523, 0.482, and 0.179 for the above series, respectively. The angles of twist between the plane of the NO_2 group and the heterocyclic ring estimated on the basis of molar extinction coefficients were derived to amount to 0°, 11°, and 55.3°, being in agreement with the angles (0°, 16.7°, and 50.3°) which have been derived by means of X-ray crystallography [14]. The ICT band of **6** displays a hypsochromic shift in relation to 4-nitropyridine N-oxide and **2**, although the difference of the transition energies is not as dramatic as in the intensities. The transition energies of the ICT for all derivatives are summarized in Table 2.

Up to our expectation, the transition energies for **5** and **6** were found to be different. Figure 1 shows the correlation between the dipole moments of interaction and the CT transition energies. The relation between μ_{int} and ν_{ICT} gives a straight line with $\mu = 14.01 - 4.7 \cdot 10^{-4} \nu$ (correlation coefficient $R = 0.74$).

It is worthwhile to emphasize that the differences in μ_{int} as well as in ν_{ICT} are rather small, and thereby the correlation between them must be treated with caution. Nevertheless, a tendency of the transition energy to decrease along with increasing charge transfer effect was observed.

We expected the previously determined chemical shifts for carbons of the investigated compounds [28], especially for the *ipso* carbon, to provide additional information about the electronic structure. Inspection of the last column of Table 2 points out that (with exception of **5** and **6**) variations in the chemical shifts of C-4 are

Table 2. Dipole moment of interaction (μ_{int}), wavenumber of intramolecular charge-transfer transition (ν_{ICT}), and $^{13}C_4$ NMR chemical shift (δ) of 4-nitropyridine N-oxides

Compound	μ_{int} (D, benzene)	ν_{ICT} (cm^{-1}, benzene)	δ (ppm, $CDCl_3$) [28]
4-nitropyridine N-oxide	0.59	28450	142.21[a]
1	0.74	28220	142.24
2	0.42	28660	143.58
3	0.77	28450	144.70
4	0.40	28290	143.13
5	0.90	28130	141.26
6	0.29	29210	147.10
7	0.72	28400	144.62

[a] from [5]

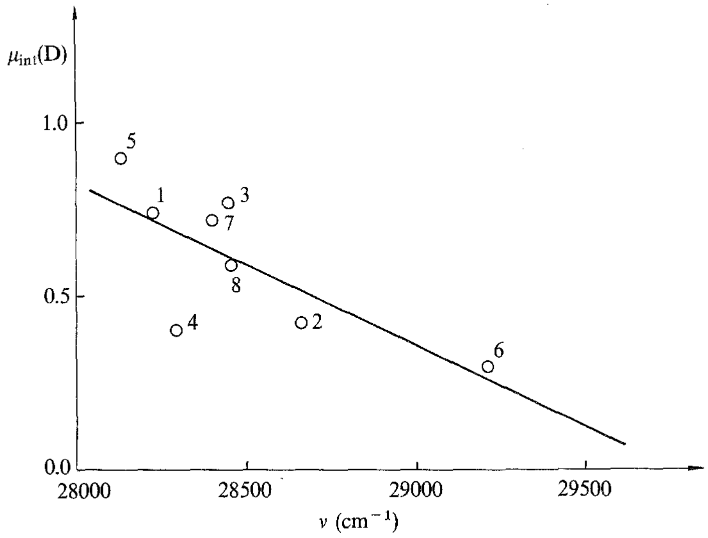


Fig. 1. Correlation between the interaction dipole moments and the wavenumbers of the intramolecular charge-transfer transitions of methyl-4-nitropyridine N-oxides (points **1**–**7**) and 4-nitropyridine N-oxide (points **8**)

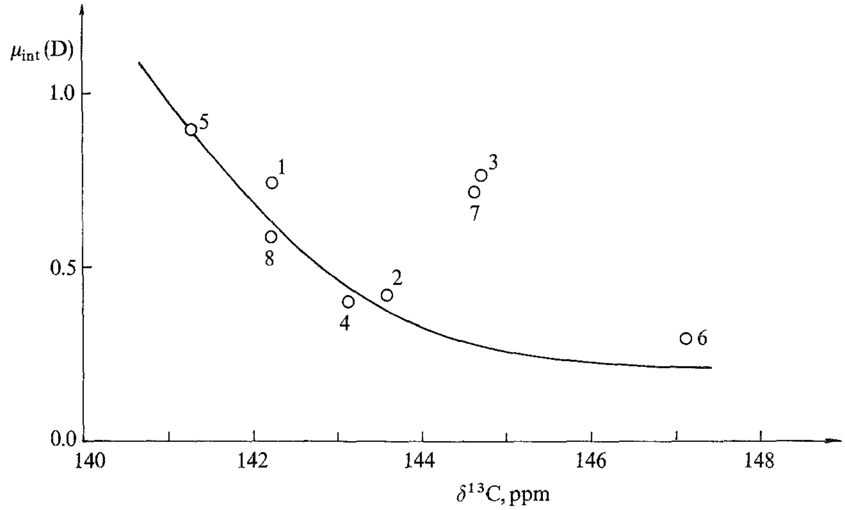


Fig. 2. Correlation between the interaction dipole moments and the $^{13}C_4$ chemical shifts of methyl-4-nitropyridine N-oxides (points **1**–**7**) and 4-nitropyridine N-oxide (points **8**)

rather small. The most striking one is the downfield shift of C-4 in the ^{13}C NMR spectrum of **6** in relation to the other methyl derivatives. This would suggest again the contribution of the resonance form **a** in this derivative to be the highest, although the charge density is not the only factor inducing *ipso* shifts. Figure 2 illustrates the correlation between μ_{int} and $\delta(^{13}C_4)$. The best correlation between μ_{int} and δ $(^{13}C_4)$ $(R = 0.97)$ was obtained by the polynomial $\mu = 717.11 - 9.84\delta + 0.03\delta^2$.

Two points corresponding to δ $(^{13}C_4)$ of **3** and **7** are off the correlation. This fact may be connected with the earlier mentioned "*ortho* xylene effect". The inhibition of resonance in 2,3-dimethyl-4-nitrobenzene is significantly larger than in the 3-methyl derivative and difficult to be taken into consideration in the calculation of μ_{int}. It cannot be excluded that other electronic effects, *e.g.* a slight change in the geometry of the molecule or the interaction of methyl groups with the oxygen atom of the N-oxide group, can influence the shift of the carbon signal to a significantly larger extent than the polar properties of the molecule.

In conclusion, it may be stated that the introduction of methyl groups into 4-nitropyridine N-oxide modifies the charge transfer mainly by means of steric interactions. The simultaneous introduction of two methyl groups in positions 3 and 5 weakens the push properties of the nitro group to a significant degree. On the basis of the value of μ_{int}, it can be expected that the contribution of the resonance form **b** would be the highest in the resonance hybrid of **5**. In the other methylated derivatives, the charge transfer effects behave similar. However, with respect to their usefulness as potential optical non-linear materials, this class of compounds seems to be highly interesting because of their possibility to crystallize in non- centrosymetric spatial groups.

Experimental

2-Methyl-4-nitropyridine N-oxide (**1**), 3-methyl-4-nitropyridine N-oxide (**2**), 2,3-dimethyl-4-nitropyridine N-oxide (**3**), 2,5-dimethyl-4-nitropyridine N-oxide (**4**), 2,6-dimethyl-4-nitropyridine N-oxide (**5**), 3,5-dimethyl-4-nitropyridine N-oxide (**6**), and 2,3,6-trimethyl-4-nitropyridine N-oxide (**7**) were obtained according to Refs. [16–20] and recrystallized from ethanol. The compounds were stored over $CaCl_2$ in a vacuum desiccator. The melting points are as follows: **1**, 159 °C (Ref. [17]: 156 °C); **2**, 137 °C (Ref. [18]: 129–133 °C); **3**, 92 °C (Ref. [19]: 91.5–93 °C); **4**, 153 °C (Ref. [19]: 151–152 °C); **5**: 163 °C (Ref. [20]: 163 °C); **6**: 175 °C (Ref. [16]: 174–175 °C); **7**: 117 °C (Ref. [19]: 115–117 °C).

The measuring techniques of dielectric permittivity, refractive index, and density were described earlier [21]. The molar dipole polarization at infinite dilution was calculated using *Hedestrand*'s procedure [22]

$$P_{2\infty} = \frac{3M_1}{d_1}\left(\frac{\alpha\varepsilon_1}{(\varepsilon_1+2)^2} - \frac{\gamma n_1^2}{(n_1^2+2)^2}\right) + \frac{M_2-\beta M_1}{d_1}\left(\frac{\varepsilon_1-1}{\varepsilon_1+2} - \frac{n_1^2-1}{n_1^2+2}\right) \tag{1}$$

with the coefficients α, β, and γ defined as follows:

$$\alpha\varepsilon_1 = \left(\frac{\partial\varepsilon_{12}}{\partial x_2}\right)_{x_2\to 0} \quad ; \quad \beta_1 = \frac{1}{d_1}\left(\frac{\partial d_{12}}{\partial x_2}\right)_{x_2\to 0} \quad ; \quad \gamma n_1^2 = \left(\frac{\partial n_{12}^2}{\partial x_2}\right)_{x_2\to 0}$$

The subscripts 1, 2, and 12 refer to solvent, solute, and solution, x, ε, d, n, and M are mole fraction, dielectric permittivity, density, refractive index and molecular mass.

The measurements were performed in benzene solutions with concentrations in the range of $5\cdot 10^{-4} - 7\cdot 10^{-3}$ mole fractions at 25 ± 0.02 °C. The average of the absolute deviations of the dipole moments from their mean did not exceed 0.03 D.

The UV/Vis spectra were recorded by means of a Specord M 40 spectrophotometer using quartz cells ($c \cong 10^{-4} M$, benzene, $v \pm 50\,\mathrm{cm}^{-1}$). Benzene and nitrobenzene were purified according to standard methods [23].

References

[1] Katritzky AR, Randall EW, Sutton LE (1957) J Chem Soc 1769

[2] Katritzky AR, Palmer CR, Swinbourne FJ, Tidwell TT, Topsom RD (1969) J Am Chem Soc **91**: 636

[3] Herlocker DW, Drago RS, Meek VI (1966) Inorg Chem **5**: 2009
[4] Sawada M, Takai Y, Kimura S, Misumi S (1986) Tetrahedron Lett **27**: 3013
[5] Brycki B, Nowak-Wydra B, Szafran M (1988) Magn Reson Chem **26**: 303
[6] Szafran M, Brycki B, Dega-Szafran Z, Nowak-Wydra B (1991) J Chem Soc Perkin Trans 2, 1161
[7] Chmurzyński L, Liwo A, Tempczyk A (1989) Z Naturforsch **44b**: 1263
[8] Fukui K, Imamura A, Nagata C (1960) Bull Chem Soc Japan **33**: 122
[9] Okabayashi IT (1953) J Ferment Technol **31**: 373
[10] Berthier G, Defranceschi M, Lazzeretti P, Tsoucaris G, Zanasi R (1992) J Mol Struct **254**: 205
[11] Zyss J, Chemla DS, Nicoud JF (1981) J Chem Phys **74**: 4800
[12] Kulkarni GV, Ray A, Patel CC (1981) J Mol Struct **71**: 253
[13] Lane P, Murray JS, Politzer P (1991) J Mol Struct **236**: 283
[14] Shiro M, Yamakawa M, Kubota T (1977) Acta Cryst **B33**: 1549
[15] Baert F, Schweiss P, Heger G, More M (1988) J Mol Struct **178**: 29
[16] Essery JM, Schofield K (1960) J Chem Soc **9**: 4953
[17] Den Hertog HJ, Kolder CR, Combe WP (1951) Rec Trav Chim **70**: 593
[18] Taylor EC, Crovetti AJ (1954) J Org Chem **19**: 1633
[19] Evans RF, Kynaston W (1961) J Chem Soc **7**: 5556
[20] Profft E, Krueger W, Kuhn P, Liez W (1969) German patent, 69, 126 C.A. 72 90309w (1970)
[21] Pawełka Z (1988) J Chem Soc Faraday Trans 2, **84**: 1683
[22] Hedestrand G (1929) Z Phys Chem **B2**: 428
[23] Weissberger LA, Proskauer ES (1955) Techniques of organic chemistry, organic solvents vol VIII. Interscience, New York
[24] Kofod H, Sutton LE, Verkade PE, Wepster BM (1959) RECUEIL **78**: 790
[25] Van Helden R, Verkade PE, Wepster BM (1954) RECUEIL **73**: 39
[26] Giera J, Sobczyk L, Lux F, Paetzold R (1980) J Phys Chem **84**: 2602
[27] Yamakawa M, Kubota T, Ezumi K, Mizuno Y (1974) Spectrochim Acta **30**: 2103
[28] Puszko A, Wasylina L (1995) Chem Papers (in press)

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