^{13}C-NMR SPECTRA OF AROMATIC N-OXIDES

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The ^{13}C-NMR spectra of six aromatic N-oxides have been measured and assigned. Empirical substituent effects on carbon chemical shifts in α-, β-, and γ-positions to the NO-group are derived. A strong shielding effect for carbons in peri-position is found.

The ^{1}H-NMR spectra of aromatic N-oxides have been profoundly studied,[1] but systematic ^{13}C-NMR investigations of these compounds are relatively rare.[2-4] Since N-oxidation is expected to have a pronounced effect also on the ^{13}C-NMR parameters of aromatic amines, we decided to measure the ^{13}C-NMR spectra of a number of parent systems. In the present communication we report data for pyridine-N-oxide (*1*), quinoline-N-oxide (*2*), isoquinoline-N-oxide (*3*), quinoxaline-N-oxide (*4*), quinoxaline-di-N-oxide (*5*), and

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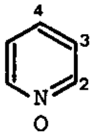
**Dedicated to Professor Tetsuo Nozoe on the occasion of his 77th birthday.*

New address: Fachbereich 8, Organische Chemie II, Gesamthochschule Siegen, Postfach 210209, D-5900 Siegen 21, Germany phenazine-di-N-oxide (*6*).



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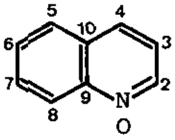

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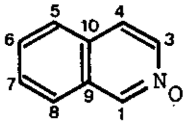

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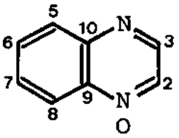

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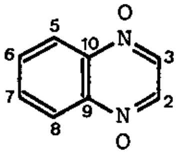

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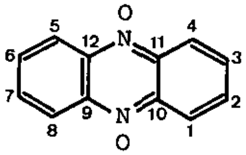

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Results

Table 1 summarizes the chemical shift data for *1* - *6*, those assigned with the help of HMO-atom,atom polarizabilities as discussed below are given in italics. In Table 2 the $^1J(^{13}C,^1H)$ data as determined directly from the splittings in the undecoupled spectra are collected. They served to support the assignments derived by independent methods or were used to distinguish resonances of tertiary carbons in the carbocyclic rings of *2* - *6* from those of these carbons in the heterocyclic rings since it was found that the magnitude of these couplings differs considerably. A number of assignments have been established using the following experimental observations: In the case of *1* the relative signal intensity and the magnitude of $^1J(^{13}C,^1H)$ allowed to distinguish C-4 from C-2, C-3, and C-2 from C-3, C-4, respectively. In the spectra of *2* and *3*, quarternary carbons were detected by off-resonance decoupling and assigned with the help of the substituent

TABLE 1. ^{13}C CHEMICAL SHIFTS (IN PPM RELATIVE TO INTERNAL TMS) FOR AROMATIC N-OXIDES 1 - 6[a]

	1	1[b]	2	3	4	5	6
C-1	---	---	---	135.9	---	---	120.3
C-2	139.1	139.8	135.2	---	130.1	130.4	131.2
C-3	126.4	128.1	121.1	136.6	146.1	130.4	131.2
C-4	126.4	132.7	125.3	*124.2*	---	---	120.3
C-5	126.4	128.1	128.1	*126.6*	*130.2*	120.6	120.3
C-6	139.1	139.8	128.6	*129.4*	*130.2*	132.1	131.2
C-7	---	---	130.0	*128.8*	*131.7*	132.1	131.2
C-8	---	---	119.2	*124.7*	*118.9*	120.6	120.3
C-9	---	---	141.2	{129.4	137.5	138.6	136.2
C-10	---	---	130.3	128.5	146.0	138.6	136.2
Conc.[c]	1.0	1.0	1.0	1.0	1.0	1.5	0.1

[a] solvent $CDCl_3$; [b] solvent D_2O; [c] in mole/l.

TABLE 2. $^{1}J(^{13}C,^{1}H)$ DATA (IN HZ) FOR AROMATIC N-OXIDES 1 - 5[a]

	C-1	*C-2*	*C-3*	*C-4*	*C-5*	*C-6*	*C-7*	*C-8*
1	---	191.5	170.8	170.8	170.8	191.5	---	---
1[b]	---	191.3	172.0	173.2	172.0	191.3	---	---
2	---	185.6	167.9	168.5	164.2	163.0	161.7	167.6
3	184.9		186.5	166.7	163.5	162.9	163.0	162.7
4	---	188.6	185.2	---	166.5	166.5	164.5	173.9
5	---	191.6	191.6	---	175.7	167.2	167.2	175.7

[a] solvent $CDCl_3$; [b] solvent D_2O

effects found for **1**. Using selective ^{1}H-decoupling the δ-values for C-2 to C-8 in **2** and for C-1 and C-3 in **3** were established since the corresponding ^{1}H-data are known.[1] In addition, line broadening observed for signals of carbons in α-position to the NO-group was of diagnostic value. Off-resonance decoupling led to the detection of quarternary ^{13}C-resonances of **4**, while the undecoupled spectrum of **5** allowed a complete assignment on the basis of the $^1J(^{13}C,^1H)$ data for C-2,3 and the fingerprints[5] observed for the resonances of C-5,8 and C-6,7. Low solubility prevented the determination of ^{13}C,^{1}H-coupling constants in the case of **6**.

The resonances of the remaining carbons were assigned tentatively using substituent effects of the N-oxide group calculated with the help of the HMO atom-atom polarizabilities of the parent amines. Recently we had shown that this procedure that follows findings by Sardella[6] yields satisfactory results in the case of methoxycoumarines.[7] Using only unequivocally assigned δ-values of compounds **1** - **3** and excluding the data for C-8 of **2** (see below) the following correlation was derived:

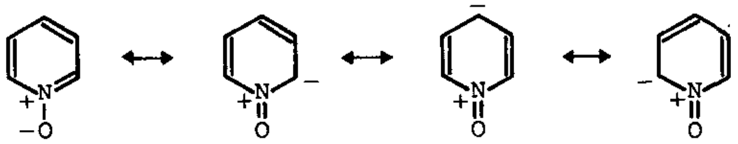
$$S_i(\sigma_j) = (-78.24 \pm 5.90)\,\pi_{ij}\ ;\ \mathrm{RMS} = 1.35\ \mathrm{ppm},\ R = 0.9790 \qquad (1)$$

where $S_i(\sigma_j)$ is the shielding-change induced for carbon j by the substituent at position i, π_{ij} the atom-atom polarizability calculated by the Hückel method, RMS the root mean square error, and R the correlation coefficient; (1) was used to predict the remaining carbon resonances (italics in Table 1), the assignment of which is further supported in several cases by $^1J(^{13}C,^1H)$ data and empirical substituent effects derived below (Table 3).

Discussion

Having now a set of chemical shift data for aromatic N-oxides at hand, empirical shielding contributions for the N-oxide group can be elucidated using as reference the ^{13}C-data for the parent heterocycles, pyridine (*7*), quinoline (*8*), isoquinoline (*9*), quinoxaline (*10*), and phenazine (*11*).[8] In order to avoid solvent effects, these chemical shifts were redetermined using the experimental conditions employed for the N-oxide measurements.

The result of this comparison is shown in Table 3. In all heterocyclic rings the α- and γ-effects are large and positive, while the β-effect is small and negative. N-oxidation thus leads primarily to carbon shielding in the α- and γ-position. In contrast, protons in the neighborhood of the NO-group are strongly deshielded.[1] As already noted,[2,4] the observation for the ^{13}C-shifts is easily rationalized on the basis of the mesomeric structures *1a* - *1c*. It is also in agreement with the calculated CNDO/2 total charge density changes ΔQ of 0.1655, -0.0620, and 0.0880 for the α-, β-, and γ-positions, respectively.



1 *1a* *1b* *1c*

Regarding the magnitude of the $\Delta\sigma$-values, however, it appears that simple additivity rules are violated. This is most clearly seen for the α-effect. For the pair *7*/*1* we find 9.9 ppm, whereas

TABLE 3. EMPIRICAL CONTRIBUTIONS $\Delta\sigma$ (PPM) TO CARBON SHIELDING CONSTANTS σ FOR N-OXIDATION AS DERIVED FROM A COMPARISON OF AROMATIC N-OXIDES 1 - 6 WITH AROMATIC AMINES 7 - 11[a]

	7/1	8/2	9/3	10/4	4/5	11/6
α-effects	9.9*(2)*	14.9*(2)*	16.7*(1)*	14.9*(2)*	15.7*(3)*	
		7.0*(9)*	6.5*(3)*	5.5*(9)*	7.3*(10)*	7.8*(9)*
β-effects	-2.2*(3)*	-0.4*(3)*	-3.9*(4)*	-1.1*(3)*	-0.3*(2)*	---
		-2.2*(10)*	-0.7*(9)*	-2.9*(10)*	-1.1*(9)*	---
		10.2*(8)*	---	10.6*(8)*	9.6*(5)*	10.7*(1)*
γ-effects	9.8*(4)*	10.2*(4)*	7.2*(10)*	-0.7*(5)*	-1.9*(6)*	-0.9*(2)*
		-0.5*(5)*	2.8*(8)*	-2.0*(7)*	-1.7*(8)*	
		-0.9*(7)*	---			

[a] position given in parenthesis

the tertiary carbons in the bicyclic systems show upfield shifts between 14.9 and 16.7 ppm. On the other hand, $\Delta\sigma$ for the quarternary carbons as well as C-3 in 3 is considerably smaller (5.5 to 7.3 ppm). These findings may be rationalized by assuming that resonance structures that affect the benzene ring are less favored.

For 2 - 5 β- and γ-effects can also be derived for carbons in the annulated benzene ring and these show interesting deviations from the corresponding effects in the heterocyclic rings of these compounds, not only in magnitude but also in sign. Most obvious is the shielding effect of ca. 10 ppm found for C-8 in 2 and 4, and C-5,8 and C-1,4 in 5 and 6, respectively. For the same carbons large differences are also found between the $S_i(\sigma_j)$ values calculated with Eq. (1) and the experimental substituent effects, as is demonstrated by the data presented in Fig. 1.

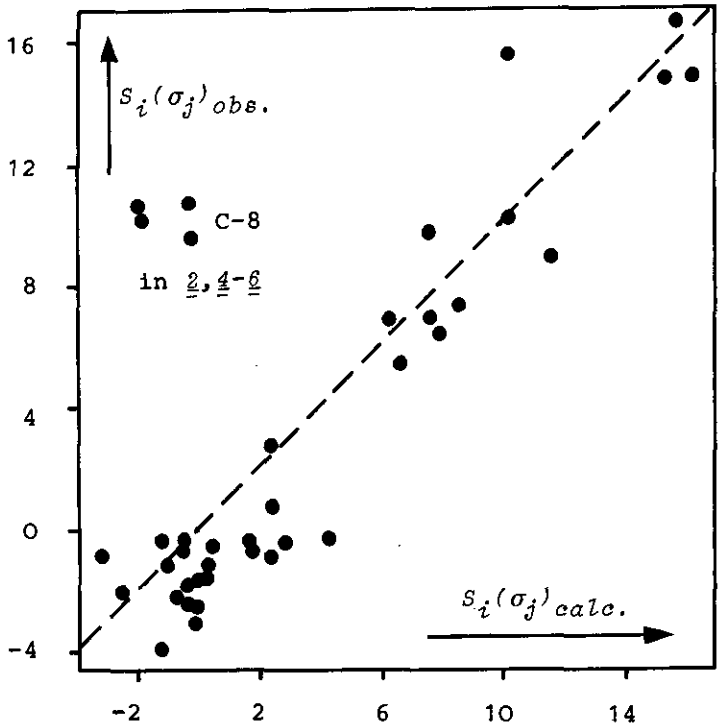


Fig. 1. Calculated vs. observed substituent effects $S_i(\sigma_j)$ of N-oxidation (obsd. data from Table 3).

At the moment it seems difficult to explain this observation within the framework of current ideas on ^{13}C-shielding. A magnetic anisotropy effect can be excluded on the basis that the protons at the peri-carbon with respect to the NO group are deshielded[1] in 2, 4, 5, and 6, the corresponding $\Delta\sigma$-values amounting to -0.63, -0.46, - 0.46, and -0.58 ppm, respectively. Similarly, calculations of the linear electric field effect[9] with an electric dipole moment of 4.24 D located in the center of the NO bond with the positive end pointing to the nitrogen yield a $\Delta\sigma$-value of -5.2 ppm for C-8 in 2, again in contrast to the experimental observations. The same treatment gave $\Delta\sigma$= -0.71 ppm for H(8) in 2, in good agreement with experiment (see above). Even if the approximations inherent in the calculations and introduced by using an idealized geometry ($R_{CC}=R_{CN}=0.140$ nm, $R_{NO}=0.129$ nm, CCC$\measuredangle$ 120°) render the carbon-result somewhat uncertain, the fact that deshielding is predicted instead of shielding completely rules out the possibility that the electric field effect plays a major role in determining the chemical shift of C-8 in **2** as well as that of the corresponding carbons in the other compounds.

We therefore believe that most probably the observed effects - incidentally related to the γ-position with respect to the oxygen - originate from steric interactions between the C(8)-H bond and the solvent shell of the strongly polar NO group. This explanation would be in qualitative agreement with the different sign of the $\Delta\sigma$-values for ^{1}H (deshielding) and ^{13}C (shielding). It is also interesting to note that the shielding in the peri-position to the NO-group is accompanied by a significant increase in the $^{1}J(^{13}C,^{1}H)$ coupling constant of this carbon (cf. Table 2), a finding which parallels earlier observations made for hydrocarbons.[10] Clearly, further investigations are necessary to substantiate the above hypothesis and appropriate experiments are presently under way.

Experimental

The compounds studied were prepared according to Ochiai.[11] ^{13}C-NMR spectra were recorded at 22.63 MHz using a Bruker HX-90 spectrometer equipped with broadband decoupler and a Nicolet 1083-computer or at 15.08 MHz using a Bruker WP-60 instrument. TMS served as internal reference; δ-values are accurate to ± 0.1 ppm. The calculations were performed using standard computer programs for the Hückel-[12] and CNDO/2-method.[13]

ACKNOWLEDGEMENT We are indebted to Dr. E. Ciganek, Wilmington, for helpful discussions and the Deutsche Forschungsgemeinschaft for financial support.

REFERENCES

1 P. Hamm and W. v. Philipsborn, Helv. Chim. Acta, 1971, **54**, 2363.

2 R. J. Cushley, D. Naugler and C. Ortiz, Can. J. Chem., 1975, **53** 3419.

3 D. E. Klinge, H. C. van der Plas and A. van Veldhuizen, Recl. Trav. Chim. Pays-Bas, 1976, **95**, 21.

4 F. A. L. Anet and I. Yavari, J. Org. Chem., 1976. **41**, 3589.

5 H. Günther, H. Schmickler and G. Jikeli, J. Magn. Resonance, 1973, **11**, 344.

6 D. J. Sardella, J. Amer. Chem. Soc., 1976, **98**, 2100.

7 H. Günther, J. Prestien and P. Joseph-Nathan, Org. Magn. Resonance, 1975, **7**, 339.

8 J. B. Stothers, "Carbon-13 NMR Spectroscopy", Academic Press, New York, 1972, Chapter 7.

9 J. G. Batchelor, J. Amer. Chem. Soc., 1975, **97**, 3410.

10 H. Günther, G. Jikeli, H. Schmickler and J. Prestien, Angew. Chem., 1973, 85, 826; Angew. Chem. Int. Ed. Engl., 1973, 12, 762.

11 E. Ochiai, J. Org. Chem., 1953, 18, 534.

12 E. Heilbronner and P. A. Straub, Hückel Molecular Orbitals, Springer Verlag, Berlin, 1966.

13 J. A. Pople and P. L. Beveridge, Approximate Molecular Orbital Theory, McGraw Hill, New York, 1970; QCPE program No. 91.

Received, 7th September, 1978