Nitrogen-15 Magnetic Resonance Spectroscopy. VII.
Chemical Shifts of para-Substituted Nitrobenzenes

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Abstract: The 15N chemical shifts of a series of para-substituted nitrobenzenes have been measured. Comparison with the para-14C chemical shifts in monosubstituted benzenes and with 19F chemical shifts in para-substituted fluorobenzenes, indicates that similar factors determine the chemical shifts of these three nuclei. With p-nitroaniline, the 15N chemical shift appears to have an extra paramagnetic contribution, since this is the only compound studied that does not fit the correlation with 13C and 19F chemical shifts.

The series of nitro compounds were chosen for study for two reasons: firstly, convenience of preparation, and secondly, because the main contribution to the paramagnetic term (σ_AAA) is expected to arise from the σ → π* transitions of the nitrogen atoms. The energy of the latter transitions should remain roughly constant throughout the series. Also the variation in the ring current (σ_A ring) and anisotropy terms (∑σ_{AB}) are expected to remain constant throughout the series. (The main contribution to ∑σ_{AB} arises from the n → π* transition of the oxygen lone pairs, and the energy of this transition is little affected by substituents in the para position, e.g., nitrobenzene n→π* 330 μμ, p-nitrophenol n→π* 334 μμ.)

Results and Discussion

Table I gives the 15N chemical-shift differences of a series of para-substituted nitrobenzenes relative to 15N nitrobenzene as 15 mole % solutions in dimethyl sulfoxide. Bulk susceptibility corrections were not applied, since these are likely to be well within the experimental error (±0.16 p.p.m.), for the relatively dilute solutions employed. The low sensitivity (10^-3) that of 1H at constant field) precludes any accurate measurement of chemical shifts over a wide range of concentrations.

The first point to note from Table I is the relatively small range of chemical shifts, namely 8.23 p.p.m. This may be compared with the corresponding 19F and 13C chemical shifts in para-substituted fluorobenzenes of 24.35 p.p.m. and 13C chemical shifts in para-substituted toluenes of 1 p.p.m. for the same substituents. The intermediate range of the 15N chemical shifts is as expected if the paramagnetic terms σ_AAA dominate the shielding constants for these nuclei, and is indicative that the mean electronic excitation energies are at least approximately constant in the series.

Previous investigations have correlated the 13C chemical shifts of the para-carbon atom in monosubstituted benzenes with the 19F chemical shifts of para-

\[ \sigma_A = \sigma_{AA} + \sigma_{AB} + \sum_{AB} \sigma_{AB} + \sigma_{A, ring} \]

where \( \sigma_{AA} \) and \( \sigma_{AB} \) are the diamagnetic and paramagnetic contributions from the electrons of atom A; \( \sigma_{AB} \) is the contribution from the electrons of atom B, and \( \sigma_{A, ring} \) is the contribution due to ring currents. Investigations in this and other laboratories have shown that in the case of carbon, nitrogen, and fluorine, the main contributions to the shielding constant of the nucleus comes from the paramagnetic term \( \sigma_{AA} \). If the comparison of shielding parameters is confined to a suitable series of closely related compounds, e.g., substituted benzene derivatives, then contributions from the substituent anisotropy (∑σ_{AB}) and ring current (σ_{A,ring}) terms may be expected to remain essentially constant. If the mean electronic excitation energies, ∆E, involved in the closure approximation for the \( \sigma_{AA} \)'s are also constant, then the contribution to the shielding constants from \( \sigma_{AA} \) and \( \sigma_{AB} \) may be related in a simple way to the local electron density at the nucleus. Such correlations have been reported for 13C chemical shifts in monosubstituted benzenes and 19F chemical shifts in para-substituted fluorobenzenes.

By contrast there has been no detailed investigation of 15N chemical shifts in an analogous series of compounds despite the obvious theoretical interest of such an investigation. With this in mind we have examined 15N chemical shifts of a series of para-substituted 15N nitrobenzenes in the hope of demonstrating similar correlations to those found previously for the 13C and 19F chemical shifts.

(1) Supported in part by the Public Health Service Research Grant 11072-02 from the Division of General Medical Sciences and the National Science Foundation.


(3) M. Karplus and J. A. Pople, ibid., 38, 2803 (1963).


(13) See ref. 3, p. 2805.


Figure 1. Plot of $^{13}$C chemical shifts in monosubstituted benzenes vs. $^{15}$N chemical shift of nitro group in para-substituted nitrobenzenes. Data for $^{13}$C are from ref. 11.

Table I. $^{15}$N Chemical Shifts of the Nitro Group in para-Substituted Nitrobenzenes

<table>
<thead>
<tr>
<th>Substituent</th>
<th>Chemical shift, p.p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH$_2$</td>
<td>4.38</td>
</tr>
<tr>
<td>OMe</td>
<td>4.38</td>
</tr>
<tr>
<td>F</td>
<td>3.57</td>
</tr>
<tr>
<td>NHCOCH$_3$</td>
<td>3.07</td>
</tr>
<tr>
<td>Cl</td>
<td>2.09</td>
</tr>
<tr>
<td>Br</td>
<td>1.32</td>
</tr>
<tr>
<td>H</td>
<td>0.00</td>
</tr>
<tr>
<td>CN</td>
<td>-2.58</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>-3.85</td>
</tr>
</tbody>
</table>

*Experimental error is approximately ±0.16 p.p.m. A positive value of the chemical shift indicates a shift upfield from nitrobenzene.

The $^{15}$N chemical shifts are shown plotted against the $^{13}$C chemical shifts in monosubstituted benzenes and $^{19}$F chemical shifts in para-substituted fluorobenzenes in Figures 1 and 2. There is a good over-all correlation in the two graphs except possibly for the $^{15}$N chemical shift in p-nitroaniline. This would seem to confirm that similar factors are operative in determining the chemical shift of $^{15}$N, $^{19}$F, and $^{13}$C nuclei.

By analogy with the theory developed for the corresponding fluorine chemical shifts, the $^{15}$N nitro chemical shift differences in para-substituted nitrobenzenes, should depend on the following factors: (1) the $\pi$-electron density of the nitrogen atom; (2) the $\pi$-electron density at the adjacent carbon and oxygen atoms; (3) the N–C $\pi$ bond order; (4) the N–O $\pi$ bond order. The presence of the two oxygen atoms in the nitro group means that the expression for the shielding parameter of the nitrogen atom will be considerably more complex than that for fluorine. However, whatever the contributing factors are, they are not all expected to operate in the same direction.

For example, a relatively strong mesomeric substituent, such as methoxyl, should increase the electron density at the carbon atom (1), and also at the carbon and oxygen atoms (2), thus resulting in an upfield shift relative to nitrobenzene. The same substituent is expected to increase the N–C $\pi$ bond order (3), while the N–O $\pi$ bond order should decrease (4), the first term causing a downfield shift, the latter an upfield shift.

Despite the possible subtle interplay of these factors, there is a good correlation with the corresponding $^{19}$F and $^{13}$C chemical shifts, only p-nitroaniline is possibly anomalous. The amino group is known from spectroscopic data to have a much larger (+M) effect than the other substituents, and this and dipole moment data indicate that there is considerable interaction between the amino and nitro groups. Since the increase in C–N $\pi$ bond order is expected to be larger than the decrease in N–O $\pi$ bond order, the extra paramagnetic shift implies that the former term more than compensates for the increased electron densities at the carbon, nitrogen, and oxygen atoms in p-nitroaniline. An alternative explanation would be that for p-nitroaniline, the charge-transfer states are much lower in energy than for the other nitrobenzenes. The mean electronic excitation energy $\Delta E$ for the $\sigma \rightarrow \pi^*$ transition might thus be expected to be smaller in this case, leading to an increased paramagnetic contribution to the shielding constant.

Experimental Section

The nitrogen-15 spectra were obtained with a Varian Model V-4300B spectrometer, operated at 6.08 Mc.p.s. and 14,100 gauss.


(21) C/ ref. 20, Chapter 10.
as described previously. Most of the following compounds were prepared on a 0.5-g. scale.

p-Nitro-p-m-chloroacetanilide was prepared by the nitration of acetanilide with 38% nitric acid (Merck Sharp and Dohme 97% \(^{14}N\)), according to the procedures given by Vogel.\(^{13}\)

p-Nitro-p-aniline was obtained by the acid hydrolysis of p-nitro-p-anisidine.\(^{23}\)

Nitrobenzene-\(^{15}N\) was prepared by the nitration of benzene with 38% nitric acid according to the method given by Vogel.\(^{24}\)

p-Bromonitrobenzene-\(^{15}N\) was prepared by the nitration of bromobenzene with 38% nitric acid according to the method given by Vogel.\(^{24}\)

p-Chloronitrobenzene-\(^{15}N\) was prepared by the nitration of chlorobenzene with 38% nitric acid using similar conditions to those in the p-bromonitrobenzene-\(^{15}N\) preparation.

Nitrobenzene-\(^{16}N\) was prepared by the nitration of benzene with nitric acid using similar conditions to those of the previous preparation.\(^{23}\)

Most of the following compounds were prepared on a 0.5-g. scale.

\(p\)-Fluoronitrobenzene-\(^{15}N\) was prepared from fluorobenzene and 38% nitric acid in the presence of sulfuric acid at 70.° The product was isolated in the same way as for the nitrobenzene-\(^{15}N\) preparation.

\(p\)-Nitro-b-anisole was prepared by the reaction of \(p\)-bromonitro-\(p\)-benzene with sodium methoxide in dimethyl sulfoxide solution at room temperature. The reaction mixture was poured onto crushed ice and the pale yellow crystals of nitro-b-anisole were removed by filtration. The yield was almost quantitative.

\(p\)-Dinitro-b-benzene (labeled with \(^{15}N\) in one nitrogen) was prepared by diazotized \(p\)-nitro-b-aniline according to the procedure given by Hodgson, et al.\(^{25}\)

\(p\)-Nitro-b-benzonitrile was prepared from \(p\)-nitro-b-aniline by the Sandmeyer reaction in a manner analogous to that previously described by Bogert and Hand.\(^{26}\)

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**Neighboring Carboxyl Group Participation in the Hydrolysis of Monoesters of Phthalic Acid. The Dependence of Mechanisms on Leaving Group Tendencies**

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**Abstract:** The hydrolyses of the following monohydrogen phthalate esters have been investigated in the region of the carboxyl group \(pK_a\)'s: I, methyl; II, \(2\)'-monochloroethyl; III, propargyl; IV, \(2\)'-\(2\)'-\(2\)'-trifluoroethyl; and V, phenyl. In addition, the hydrolysis of (VI) \(O\)-phthaloyl-N-acetylserinamide was also investigated. The \(pK_a\)'s of the alcohols employed in the preparation of the esters fall in the order \(I > II > III > VI > IV > V\). Esters I and II hydrolyzed with neighboring COOH group participation while esters IV and V hydrolyze with COO\(^-\) participation. Thus, the mechanism changes with increase in leaving tendencies. The crossover between mechanisms occurs for esters of alcohols with \(pK_a\)'s values of ca. 13.5 so that esters III and IV are equally prone to COOH and COO\(^-\) neighboring group catalyzed hydrolysis. These results are considered in the light of the possible participation of carboxyl groups in the mechanism of esterases. Extrapolation from this study suggests that such participation could be effective but defies detection through conventional examination of pH-rate profiles.

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