

Solvent induced nitrogen NMR shielding variation of α -phenyl-*N*-methylnitron

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Abstract

Nitrogen NMR shieldings of phenyl-*N*-methylnitron are shown to be quite sensitive to solvent effects. The dominant contribution to the solvent induced range of nitrogen shieldings is produced by the hydrogen bond donor ability of the solvents. This indicates that hydrogen bonding to an oxygen atom contiguous with a nitrogen atom can exert effects on the nitrogen shielding which are comparable with those exerted by direct hydrogen bonding to the nitrogen lone pair electrons in imine systems. Minor shielding changes due to solvent polarity polarizability are quite well reproduced by nitrogen shielding calculations incorporating the solvation model.

1. Introduction

Nitrogen NMR shielding (chemical shifts) of solutes is quite sensitive to solvent induced effects and can be used as a means of insight into molecular interactions [1]. Particularly significant effects are observed in nitrogen NMR spectroscopy, when a nitrogen atom is involved in a conjugated or unsaturated system and bears a lone pair of electrons which can act as a hydrogen bond acceptor site [1–3]. The result of such hydrogen bonding effects is to produce a large increase in nitrogen shielding. This can be used as a source of identification for hydrogen bond acceptor sites in nitrogen containing molecules. However, we have previously found one example where comparable nitrogen shielding effects are produced by hydrogen bonding not to the nitrogen atom itself but to

the contiguous oxygen atom in the *N*-oxide moiety of pyridine *N*-oxide [4].

Nitrones such as phenyl-*N*-methylnitron (Fig. 1) are *N*-oxides of the corresponding imines. In general simple nitrones are unstable molecules; however the molecule under current investigation (Fig. 1) is very stable at room temperature. Recently we have investigated the nitrogen shielding variation of acetone *N*-methylimine [5]. The result of that study has been the discovery of the largest effect to date of nitrogen shieldings due to solvent-to-solute hydrogen bonding. In the current investigation we aim to evaluate whether the analogous imine *N*-oxide (nitron) function can give rise to similar effects. In this way we propose to establish whether the effects observed for pyridine *N*-oxide are an exception or whether they represent a more general phenomenon, namely, whether the hydrogen bonding interactions presented in Fig. 2 produce comparable changes in the shieldings of

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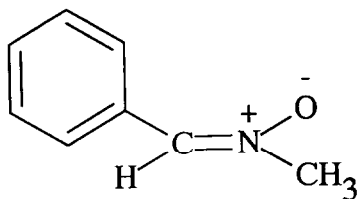


Fig. 1. The structure of phenyl-*N*-methylnitronium.

imine and corresponding *N*-oxide type nitrogen atoms. In the present work we use the sign convention whereby a plus sign corresponds to an increase in nuclear shielding, as used previously [1–5]. This is opposite to that used for chemical shifts. Consequently we use the term “nuclear shielding” rather than “chemical shift”. The two terms are equivalent with the exception of the sign change.

2. Experimental

A previously published procedure was used for the preparation of α -phenyl-*N*-methylnitronium [6]. Particular attention was paid to the use of very pure and dry solvents in the NMR experiment as described elsewhere [3]. All solution preparation and handling was carried out in glove bags under a dry argon atmosphere.

The nitrogen shieldings of 0.2 M solutions of phenyl-*N*-methylnitronium in a variety of solvents were determined by ^{14}N NMR measurements on

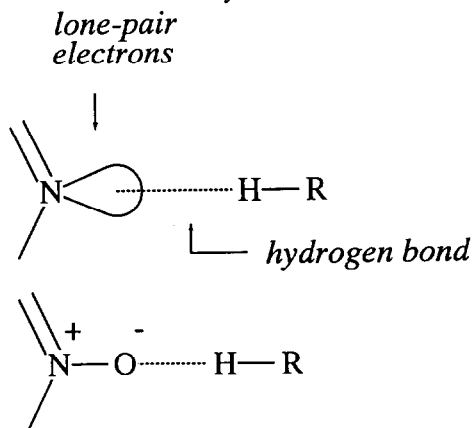


Fig. 2. A schematic representation of hydrogen bonding modes with solvent molecules for imine type nitrogen atoms and the corresponding *N* oxides. Upper, imine or pyridine type nitrogen; lower, corresponding *N*-oxide type nitrogen.

a Bruker AM 500 spectrometer at 36.14 MHz and $35 \pm 0.2^\circ\text{C}$. The temperature was controlled by a VT unit. Possible random and systematic errors arising upon comparing nitrogen shieldings of phenyl-*N*-methylnitronium in different solvents were reduced to below 0.1 ppm.

External neat liquid nitromethane was used as the nitrogen shielding reference by means of 10 mm/4 mm o.d. coaxial tubes. The inner tube contained 0.3 M nitromethane in acetone- d_6 whose nitrogen shielding is +0.77 ppm with respect to neat liquid nitromethane [1, 2]. This value was employed as a conversion constant and was obtained in the absence of bulk susceptibility effects by means of an NMR experiment using concentric spherical sample/reference containers. Consequently in the current work the solution in the inner NMR tube served as a precise reference for the neat nitromethane standard and provided a necessary source of deuterium lock for the NMR spectrometer. The exact resonance frequency of the ^{14}N signal of neat nitromethane was 36.141 524 MHz from which it was possible to obtain a value of 36.136 826 MHz for the resonance frequency of a bare nitrogen nucleus [1]. This latter value was used in conjunction with the relevant resonance frequency differences in order to produce the nitrogen NMR shieldings relative to that of the primary standard, neat nitromethane.

Lorentzian lineshape fitting of the relevant ^{14}N NMR signals was used to produce the exact resonance frequencies of the sample, in various solvents, and of the external standard. Bulk susceptibility corrections were then applied to the nitrogen shieldings obtained as described elsewhere [1, 2]. Since dilute solutions were used in the present work it was assumed that their susceptibilities were equal to those of the respective solvents at 35°C . INDO/S-SOS molecular orbital calculations of the nitrogen shielding [7] within the solvation framework [7, 8] were performed on the University of Surrey central HP System using INDO optimized geometries.

3. Results and discussion

The results of high precision ^{14}N NMR shielding

Table 1
Solvent effects on the nitrogen NMR shielding of phenyl-*N*-methylnitron^a

Solvent	Nitrogen shielding (ppm)	
	Measured	Calculated
Dioxane	+ 100.27	+ 100.79
Et ₂ O	+ 100.49 ^b	+ 100.14
Cyclohexane (0.01 M)	+ 100.76	+ 100.88
Acetone	+ 100.91	+ 101.61
DMSO	+ 101.09	+ 100.51
Benzene	+ 101.38	+ 101.23
CCl ₄	+ 102.50	+ 101.05
CH ₂ Cl ₂	+ 103.37	+ 104.40
CHCl ₃	+ 105.06	+ 105.77
EtOH	+ 110.17	+ 110.01
MeOH	+ 111.05	+ 111.88
H ₂ O	+ 117.25	+ 115.44
CF ₃ CH ₂ OH	+ 119.73	+ 120.28
Correlation coefficient		0.991

^aAll data are corrected for bulk susceptibility effects and relate to 0.2 M solutions at +35.0 ± 0.2°C.

^bMeasured at +30.00 ± 0.2°C.

measurements on phenyl-*N*-methylnitron made in the present work are given in Table 1. The variation in solvent induced nitrogen shieldings is about 20 ppm which is very significant. However, aprotic

solvents make only a small contribution to this solvent induced shielding variation. The major contributors are solvents which can act as hydrogen bond donors. This observation indicates that hydrogen bonding from solvent molecules to the oxygen atom of the *N*-oxide moiety of the nitron plays a dominant role in determining the observed nitrogen shielding variation. A more detailed analysis of the solvent induced nitrogen shielding changes can be performed by means of an empirical scale of solvent properties, namely those given in Table 2. These can be used in conjunction with master equation (Eq. (1)) [9].

$$\sigma(i,j) = \sigma_0(i) + a(i)\alpha(j) + b(i)\beta(j) + s(i)[\pi^*(j) + d(i)\delta(j)] \quad (1)$$

where *i* and *j* denote solute and solvent respectively, σ is the nitrogen shielding, α represents the hydrogen bond donor strength of the solvent, β represents its hydrogen bond acceptor strength, π^* is its polarity polarizability, and δ is a correction for polychlorinated solvents ($\delta = 0.5$) and aromatic solvents ($\delta = 1$). The solute terms are *a*, *b*, *s* and *d* which represent the corresponding responses of the solvent employed and σ_0 is the nitrogen shield-

Table 2
Solvent parameters used and least-squares-fitted solute parameters for a set of master equations (Eq. (1))

Solvent	α	β	π^*	δ	Dielectric constant ^a
Cyclohexane	0	0	0	0	1.87
Et ₂ O	0	0.47	0.27	0	3.89
CCl ₄	0	0	0.29	0.5	2.21
Benzene	0	0.10	0.59	1	2.25
Dioxane	0	0.37	0.55	0	2.19
Acetone	0.07	0.48	0.72	0	19.75
DMSO	0	0.76	1.00	0	45.80
CH ₂ Cl ₂	0.22	0	0.80	0.5	8.54
CHCl ₃	0.34	0	0.76	0.5	4.55
EtOH	0.86	0.77	0.54	0	24.20
MeOH	0.98	0.62	0.60	0	30.71
H ₂ O	1.13	0.18	1.09	0	76.70
CF ₃ CH ₂ OH	1.51	0	0.73	0	
<i>a</i> (ppm/unit scale)	<i>b</i> (ppm/unit scale)	<i>s</i> (ppm/unit scale)	<i>d</i> (dimensionless)	σ_0 (ppm)	
+11.86 (±0.77)	-2.41 (±1.29)	+1.47 (±1.0)	-0.35 (±0.89)	+1.88 (±0.84)	

^aThe constants were recalculated for a temperature of 35°C from the data given in ref. 10.

Table 3

Nitrogen shielding increments upon increasing the dielectric constant (ϵ) of the medium, calculated within the solvaton model framework

ϵ	Nitrogen shielding (ppm)
2	0 (arbitrary)
4	+ 1.19
10	+ 1.90
20	+ 2.13
40	+ 2.24

ing in the reference state which is approximated by a cyclohexane solution.

Table 2 also contains the least-squares fitted values of the solute nitrogen shielding responses. Table 1 gives the linear correlation coefficient for the experimental shielding values with respect to those produced by means of Eq. (1). As shown in Table 2 the value of d is negligible and those for b and s are barely significant. However, the s term, which represents the response of the nitrogen shielding to solvent polarizability polarity defined in terms of the π^* scale, is positive in sign and reflects the weak tendency of the nitrogen shielding of the nitron to increase with an increase in solvent polarizability polarity. The sign and magnitude of s is well reproduced by some INDO/SOS molecular orbital nuclear shielding calculations, performed in the present work, within the framework of the solvaton model [7, 8]. The results of these calculations are given in Table 3. The sign of s for phenyl-*N*-methylnitrone is found to be the same as that reported for acetone *N*-methylimine studied in a similar range of solvents [5]; however the value of s for phenyl-*N*-methylnitrone is much smaller.

We now turn to a consideration of the a term reported in Table 2. This represents the dominant contribution to the nitrogen shielding variation, upon change in solvent, for the nitron, and corresponds to the response of the nitrogen nucleus to a change in solvent to solute hydrogen bonding. The magnitude of a is roughly one half of that observed for acetone *N*-methylimine [5]. However, it is still quite appreciable and accounts for about 17 ppm of the observed nitrogen shielding variation from the

total of about 20 ppm for the solvents used in the present work. This value of a is smaller than those observed for pyridine and pyridazine [3] but is comparable with those for other aromatic imines [3]. In the case of pyridine *N*-oxide the value of a is about 16 [4] showing, thus, that the case of pyridine *N* oxide is not exceptional. Consequently caution is required in interpreting a large increase in nitrogen shielding upon increasing the hydrogen bond donor strength of the solvent, as being due to hydrogen bonding to an imine type of nitrogen atom, since we now have additional evidence to show that hydrogen bonding to a contiguous oxygen atom can have a comparable effect on the nitrogen shielding (i.e. the two types of hydrogen bonding shown in Fig. 2 can affect the nitrogen shielding to a similar extent).

3. Acknowledgement

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4. References

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