Carbon-13, Nitrogen-15, Oxygen-17 and Sulphur-33 NMR Chemical Shifts of Some Sulphur Amides and Related Compounds

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¹⁵N, ¹⁷O and ³³S NMR chemical shifts were determined for some aliphatic and aromatic sulphonamides, sulphinamides, sulphenamides and related sulphones and sulphoxides. The ¹⁷O and ³³S NMR chemical shifts change only slightly for the sulphonyl compounds. In the sulphinyl compounds, on the other hand, the presence of nitrogen causes a noticeable shift to higher frequencies in the ¹⁷O resonance. The differences between the ¹⁷O chemical shifts of sulphinyl and sulphonyl compounds are more noticeable than those between sulphinamides and sulphoxides. The ¹⁵N NMR chemical shifts of sulphin- and sulphen-amides reflect well the effect of the environments of both nitrogen and the adjacent sulphur atom. The correlations between ¹⁵N, ¹⁷O and ³³S NMR chemical shifts of the ¹³C nuclei are also presented.

INTRODUCTION

Organosulphur compounds have wide pharmacological and industrial uses. Among these, the sulphur amides are particularly important because of their biological activity, and these compounds contain several magnetic isotopes available for NMR studies. Thus, multinuclear NMR spectroscopy is a potentially valuable tool for the elucidation of their bonding and structural features.

The structure of the sulphur amides suggests the utilization of ¹⁷O, ¹⁵N and ³³S spectroscopy, even though there are some well known difficulties in recording these spectra. The ¹⁷O and ¹⁵N nuclei have an extremely low natural abundance (0.037 and 0.36%), respectively) and a low receptivity relative to ¹³C (0.0611 and 0.0214). In addition, the ¹⁷O nucleus has a moderately large quadrupole moment, which often causes broadening of the resonance lines. The ³³S nucleus is also quadrupolar, and ³³S spectroscopy is expected to be even more difficult than ¹⁷O spectroscopy, particularly since the abundance of the ³³S nucleus is 0.76% and the receptivity, relative to carbon, is only 0.0973. In the case of small sulphur-containing molecules with a symmetrical electronic distribution around the sulphur atom, however, ³³S spectroscopy should provide useful information.

Few reports are available on the ³³S NMR spectroscopy of organosulphur compounds,¹⁻⁴ and they deal mainly with sulphoxides and sulphones, rather than with sulphur amides. The number of ¹⁷O and ¹⁵N NMR studies on sulphur amides is greater,⁵⁻⁷ and some ¹⁷O NMR studies on related sulphur compounds exist.⁸⁻¹¹ There is still, however, a need for informa-

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tion on the multinuclear NMR spectra of sulphenyl, sulphinyl and sulphonyl compounds. In particular, very few sulphinyl and sulphenyl amides have so far been studied. The purpose of this work was to investigate the value of ¹⁷O, ¹⁵N and ³³S chemical shifts, as well as the ¹³C NMR data, in elucidating the structures of sulphur amides and related compounds. The compounds studied are shown on p. 425.

EXPERIMENTAL

The amides were prepared from the corresponding acid chloride and dimethyl- or diethylamine in anhydrous diethyl ether at -10 °C. Sulphonyl chlorides were commercial products; sulphinyl chlorides were obtained by chlorination of the appropriate disulphide in acetic anhydride at -10 °C and sulphenyl chlorides by chlorination of diphenyl disulphide in carbon tetrachloride. The purification methods and physical constants for the synthesized amides, and also for the commercial sulphones and sulphoxides, have been previously reported.¹²

Dimethyl sulphoxide- d_6 , chloroform- d_1 and acetone- d_6 (Uvasol reagents from E. Merck) were used as received.

Samples were prepared in various concentrations because of the limited solubility of the compounds. The effects of the concentration and the solvent were found to be slight. All the materials used were in their natural isotopic abundances.

The NMR measurements were carried out on a Jeol JNM-FX 100 NMR spectrometer using proton noise decoupling. An external ⁷Li lock was used to stabilize the field frequency ratio. Typical spectral parameters

¹³C, ¹⁵N, ¹⁷O, ³³S NMR CHEMICAL SHIFTS OF SOME SULPHUR AMIDES AND RELATED COMPOUNDS



were operating frequency 7.60, 13.46, 10.04 and 25.00 MHz, spectral width 20, 10, 6 and 6 kHz, pulse width 20, 30, 10 and 7 μ s and pulse repetition 0.04, 0.05, 15 and 2 s for ³³S, ¹⁷O, ¹⁵N and ¹³C nuclei, respectively. The chemical shifts of the ³³S nuclei were measured relative to external aqueous CsSO₄ solution, those of ¹⁷O nuclei relative to external water, those of ¹⁵N relative to external nitromethane doped with Cr(acac)₃ and those of ¹³C relative to tetramethyl-silane.

RESULTS AND DISCUSSION

¹⁷O, ¹⁵N and ³³S chemical shifts are largely dominated by the paramagnetic term and, therefore, depend on the charge density of the atom and the extent of the multiple bond character between atoms.¹³

The ¹⁷O NMR chemical shifts of the sulphinyl compounds studied lie between 2 and 79 ppm, and those of the sulphonyl compounds between 137 and 165 ppm (Table 1). The oxygen atom is more shielded in the sulphinyl compounds than in the sulphonyl compounds, which is in agreement with the difference in charge density of the oxygen atoms in these com-

Table 1. Oxygen-17 and ³³S NMR chemical shifts of some sulphur amides and related compounds

Compound	δ(¹⁷ Ο) (ppm) ^a	δ(³³ S) (ppm) ⁶	Solvent
CH ₃ SOCH ₃	13 ^{9,10}		Neat
CH ₃ SON(CH ₃) ₂	79		Neat
C ₆ H ₅ SOC ₆ H ₅	2 ⁹		Dichloromethane
C ₆ H ₅ SON(CH ₃) ₂	65		Neat
CH ₃ SO ₂ CH ₃	165 ⁹		Acetone
	163 ⁹	319; 320 ¹	Chloroform
CH ₃ SO ₂ N(CH ₃) ₂	157		Dimethyl sulphoxide
	156	324	Chloroform
C ₆ H₅SO₂C ₆ H₅	137 ⁹		Acetone
	139 ⁹	312; 312 ¹	Chioroform
$C_6H_5SO_2N(CH_3)_2$	139	332	Chloroform
	140	332	Acetone
C ₆ H ₅ SO ₂ NH ₂	159		Acetone

^a The ¹⁷O chemical shifts are quoted relative to external H₂O. ^b The ³³S chemical shifts are quoted relative to external neat CS₂; conversion factor between CS₂ and CsSO₄ = 334.2 ppm. pounds. The charge density of the oxygen atoms is also reflected in the different complex formation abilities of sulphinyl and sulphonyl compounds¹⁴ and affects the polarity of the sulphur—oxygen bond, which principally determines the dipole moment of the whole molecule.¹²

The ¹⁷O chemical shifts of sulphinamides (65-79 ppm) are greater than those of the corresponding sulphoxides (2-13 ppm),9 whereas ¹⁷O chemical shifts of sulphonamides are close to the values of the sulphones. Likewise, the ³³S chemical shifts are very similar for the sulphonamides and corresponding sulphones (Table 1). The ¹⁷O chemical shifts of diphenyl sulphone⁹ and N,N-dimethylbenzenesulphonamide are both 139 ppm; the dipole moments are almost the same (5.05 and 5.09 D, respectively),¹² and also their abilities to form complexes with various proton donors.¹⁴ All these molecular properties indicate a similar charge distribution in these sulphones and sulphonamides. Slight differences in the chemical shifts of some of the sulphonamides studied and the corresponding sulphones do, nevertheless, exist. For example, the value of the ¹⁷O NMR chemical shift for N,Ndimethylmethanesulphonamide (156 ppm) is smaller than the value for dimethyl sulphone (163 ppm) in chloroform. Further, there seems to be a detectable difference in the ¹⁷O chemical shifts between aromatic and aliphatic sulphonamides, the chemical shifts of aromatic sulphur amides being smaller than those of aliphatic sulphur amides.

The ¹⁵N NMR chemical shifts of the sulphenyl, sulphinyl and sulphonyl compounds (Table 2) follow the order sulphenamide < sulphinamide < sulphonamide. It is apparent that the ¹⁵N NMR chemical shifts are sensitive to the environments of both the nitrogen and the adjacent sulphur atom. An N,N-dimethyl substituent shifts the ¹⁵N resonance in benzenesulphonamide to lower frequency, from -284.3 ppm for benzenesulphonamide to -298.1 ppm for N,N-dimethylbenzenesulphonamide in dimethyl sulphoxide. This is in agreement with the increase in electron density effected by the dimethyl substituent at the nitrogen atom.

The ^{15}N NMR chemical shifts of N,N-dimethylbenzenesulphonamide in dimethyl sulphoxide, chloroform and 2,2,2-trifluoroethanol are also given in Table 2. Chloroform seems to produce a small and

Compound	<u>-δ(¹⁵N)</u> (ppm) ^a	Solvent ^b
C ₆ H ₅ SN(CH ₂ CH ₃) ₂	335.1	Neat
	334.4	Chloroform
CH ₃ SON(CH ₃) ₂	308.9	Neat
C ₆ H ₅ SON(CH ₃) ₂	305.1	Neat
CH ₃ SO ₂ N(CH ₃) ₂	300.7	Dimethyl sulphoxide
	301.6	Chloroform
$C_6H_5SO_2N(CH_3)_2$	298.1	Dimethyl sulphoxide
	298.9	Chloroform
	299.4	2,2,2-Trifluoroethanol
C ₆ H ₅ SO ₂ NH ₂	287.9	Acetone
	284.3	Dimethyl sulphoxide
^a The ¹⁵ N chemical CH_3NO_2 doped with C_2 doped with C_2 with C_3 and C_2 molar f	shifts are quot Cr(acac) ₃ . Traction of amide	ted relative to external

Table 2.	Nitrogen-15	NMR	chemical	shifts	of	sulphur-
	containing ar	nides				

2,2,2-trifluoroethanol a greater shift to lower frequencies for the ¹⁵N resonance compared with that for dimethyl sulphoxide. These further shifts may be due to hydrogen bond formation with the oxygen atom of the sulphonyl group in proton-donating solvents, which would serve to decrease the double-bond character of the sulphur—nitrogen bond, as the possible resonance structures of sulphonamides and sulphinamides demonstrate:^{12,15}



The shielding of the nitrogen nucleus is greater, however, when the hydrogen atoms of the NH_2 group are replaced by the *N*,*N*-dimethyl substituent than when the shielding is caused by hydrogen bonding to the oxygen atom in proton-donating solvents. The corresponding ¹⁷O shifts are in the opposite order to the ¹⁵N shifts, being 159 ppm for benzenesulphonamide and 139 ppm for N,N-dimethylbenzenesulphonamide. This may point to the ability of the sulphur atom to utilize its d orbital.

The ¹³C chemical shifts of various sulphur compounds are presented in Table 3. A clear shift to higher values, from 128.5 ppm for benzene,¹⁶ is seen in the chemical shifts of the aromatic carbons C-1 and C-4 [except in $C_6H_5SN(CH_2CH_3)_2$] and a shift to lower values in C-2. Such behaviour indicates the electron acceptor effect of the sulphur atom on the benzene ring in these compounds. This electron acceptor effect is greater in the sulphonamides studied than in the sulphinamides.¹⁷ The effect of the sulphinamide group is mostly inductive in origin as the changes in the chemical shifts of C-1 are clearly larger than those for C-4, C-2 and C-3 (Table 4). In sulphonamides the chemical shifts of C-1 decrease and those of C-4, C-2 and C-3 increase compared with those of the sulphinamides, indicating more mesomeric character in these compounds. The benzene ring absorptions of sulphenamide differ from those of sulphinamides; in sulphenamide C-1 is also less shielded, as in sulphinand sulphonamides, but all other carbons are more shielded than in benzene.

The environment of the nitrogen nucleus, however,

Table 4. Substitue some su 128.5 ppr	nt-indu Iphur-o n)	iced sl contair	hifts of ning co	aroma ompour	tic carbons of $ds (\delta_{benzene} =$
Compound	C-1	C-2,6	C-3,5	C-4	Solvent
$C_6H_5SN(CH_2CH_3)_2$	13.0	-3.8	-0.1	-3.3	Neat
	13.0	-3.5	-0.1	-3.2	Chloroform
C ₆ H₅SOCH ₃	17.8	-4.9	0.9	2.5	Chloroform
C ₆ H ₅ SON(CH ₃) ₂	15.8	-2.6	0.4	2.3	Neat
	14.7	-2.7	0.4	2.4	Chloroform
C ₆ H ₅ SO ₂ CH ₃	12.5	-1.3	0.8	5.0	Chioroform
$C_6H_5SO_2N(CH_3)_2$	6.7	-1.0	0.8	4.4	Dimethyl
					sulphoxide
	6.7	-0. 9	0.6	4.3	Chloroform
$C_6H_5SO_2C_6H_5$	12.17	-1.2	1.4	5.4	Dimethyl sulphoxide
	13.3	-0.9	0.7	4.6	Chloroform

Table 3. ¹³ C chemical shifts (ppm) relative to TMS i	in some sulphur-containing compounds
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	C	C—S				C-	N		
Compound	Aliphatic	Aromatic	C-2,6	C-3,5	C-4	C(-CH ₂)	С(—СН ₃)	Solvent	Ref.
C ₆ H ₅ SN(CH ₂ CH ₃) ₂		141.5	124.7	128.4	125.2	52.2	13.7	Neat	
0 0 2 02		141.5	125.0	128.4	125.3	52.2	13.8	Chloroform	
CH ₃ SOCH ₃	40.5							Neat	16
0 0	40.1							Chloroform	17
CH ₃ SON(CH ₃) ₂	39.0						36.1	Neat	
0 01	40.2						37.2	Chloroform	
C ₆ H ₅ SOCH ₃	44.0	146.3	123.6	129.4	131.0			Chloroform	18
C ₆ H ₅ SON(CH ₃) ₂		144.3	125.9	128.9	130.8		36.7	Neat	
		143.2	125.8	128.9	130.9		36.6	Chloroform	
CH ₃ SO ₂ CH ₃	42.7; 42.6							Chloroform	17
CH ₃ SO ₂ N(CH ₃) ₂	32.2						37.3	Dimethyl sulphoxide	
	32.2						36.7	Chloroform	
C ₆ H ₅ SO ₂ CH ₃	44.3	141.0	127.2	129.3	133.5			Chloroform	18
C ₆ H ₅ SO ₂ C ₆ H ₅		141.2	127.3	129.9	133.9			Dimethyl sulphoxide	19
		141.8	127.6	129.2	133.1			Chloroform	
C ₆ H ₅ SO ₂ N(CH ₃) ₂		135.2	127.5	129.3	132.9		37.6	Dimethyl sulphoxide	
		135.2	127.6	129.1	132.8		37.8	Chloroform	
$C_6H_5SO_2NH_2$		144.6	126.6	129.5	132.6			Acetone	

also influences the aromatic carbons adjacent to the sulphur atom, as Tables 3 and 4 show. The carbon adjacent to the nitrogen atom is nearly independent of the oxidation state of sulphur, as ¹³C chemical shifts for carbons joined directly to the nitrogen atoms are similar for sulphen-, sulphin- and sulphonamide.

The ¹⁵N NMR chemical shifts of the sulphur amides vary much less than the ¹⁷O NMR chemical shifts. The accuracy of ¹⁵N NMR chemical shifts is better, however, since the linewidths of the resonance signals of the spin $\frac{1}{2}$ nucleus of ¹⁵N are smaller than those of the quadrupolar ¹⁷O and ³³S nuclei. The ³³S resonance linewidths of the sulphones and sulphonamides studied are only 50–200 Hz, however, owing to the highly symmetric electronic distribution in these compounds. These linewidths are an order of magnitude smaller than the value of 2500 Hz reported for dimethyl sulphoxide.¹³ The above results suggest that the sensitivity of ¹⁷O, ¹⁵N and ³³S NMR chemical shifts to structural and bonding changes in sulphur amides and related compounds is high enough to allow the characterization of these compounds, and differentiation between them, on the basis of their chemical shifts. Although the commonly measured ¹³C NMR chemical shifts for sulphur amides and related compounds with various oxidation states of sulphur usually suffice to characterize these compounds, it is clear from this study that the chemical shifts of other nuclei provide more specific information.

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