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THE ANALYSIS OF ALKYL THIOCYANATES AND ISOTHIOCYANATES BY NMR

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Abstract—It is shown that the distinction and estimation of mixtures of alkyl thio- and isothiocyanates can be made easily by NMR on the basis of the different chemical shifts of protons adjacent to the —SCN and —NCS groups. Shoolery's Rule shielding constants σ(—SCN) = 2·30 and σ(—NCS) = 2·86 were found for the two groups. These values cannot, however, be applied to compounds in which conjugation effects involving the —SCN and —NCS groups are possible.

THE usual methods of preparation of organic thiocyanates (R—SCN) and isothiocyanates (R—NCS) often give rise to mixtures of these products,[1] because of resonance in the ion involved ($S^-—C{\equiv}N \leftrightarrow S{=}C{=}N^-$). Analytical methods that can distinguish the isomeric products are therefore needed, especially since many of these compounds have specific medicinal activity. IR spectroscopy has been used for this purpose[2,3] but is not entirely satisfactory, particularly for small amounts of one component in the other. In this paper, NMR measurements on several alkyl thio- and isothiocyanates are reported. To date the only published NMR spectrum of such compounds is that of C_2H_5SCN.[4]

EXPERIMENTAL

All samples were examined on a Varian A.60 NMR spectrometer; 10% solutions in CCl_4 were used with tetramethylsilane as an internal reference. The thio- and isothiocyanates were samples prepared elsewhere in this Department, and the NMR spectra themselves were used as a check for impurities.

RESULTS AND DISCUSSION

The distinction of thio- and isothiocyanates by proton NMR will depend upon the different deshielding effects of the —SCN and —NCS groups on the protons of an adjacent group, which will cause different chemical shifts for these α-group protons. Any effects on the chemical shifts of β-group protons are expected to be very much smaller.

Table 1 shows the alkyl thio- and isothiocyanates that have been examined. In the first two columns the respective chemical shifts of the protons α to the —SCN and —NCS groups are given. These are in δ units and for multiplets, the quoted value is that for the multiplet centre. The 10% solution of isopropyl isothiocyanate was progressively diluted to test for any solvent dilution effects. No chemical shift

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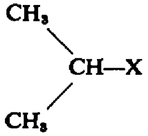
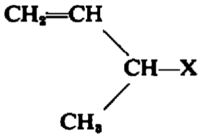
[1] N. Kharasch, *Organic Sulphur Compounds* Vol. 1. Pergamon Press (1961);
[a] R. G. R. Bacon, Chap. 27, p. 306;
[b] S. J. Assony, Chap. 28, p. 326.

[2] G. L. Caldow and H. W. Thompson, *Spectrochim. Acta* 13, 212 (1958).

[3] E. Lieber, C. N. R. Rao and J. Ramanchandran, *Spectrochim. Acta* 13, 296 (1959).

[4] [a] B. P. Dailey and J. N. Shoolery, *J. Amer. Chem. Soc.* 77, 3977 (1955);
[b] *Varian Associates NMR Spectra Catalogue* Vol. 2. Spec. No. 384.

TABLE 1. COMPARISON OF CHEMICAL SHIFT DATA FOR α-PROTONS IN ALKYL THIOCYANATES X = —SCN AND ISOTHIOCYANATES X = —NCS

Compound	Chemical shift δ X = —SCN	Chemical shift δ X = —NCS	Shielding constants σ X = —SCN	Shielding constants σ X = —NCS
1. $CH_3{-}X$	2·61	3·37	(2·38)	(3·14)
2. $CH_3CH_2{-}X$	2·98	3·64	2·28	2·94
3.  $(CH_3)_2CH{-}X$	3·48	3·95	2·31	2·78
4. $CH_3{-}CH{=}CH{-}CH_2{-}X$	3·55	4·04	2·00	2·49
5. $CH_2{=}CH{-}CH_2{-}X$		4·18		2·63
6.  $CH_2{=}CH{-}CH(CH_3){-}X$		4·35		2·33

changes could be observed, and the values in the Table can therefore be taken as very close to infinite dilution values. In the four pairs of —SCN and —NCS isomers, the resonances of the α-protons are well separated by between 0·5 and 0·75 ppm, with the resonances from the thiocyanates lying at higher fields than those of the isothiocyanates. With such a large difference in chemical shift of the α-protons of the two isomeric species, the analysis of reaction products is straightforward and the accuracy with which quantitative estimations can be made is limited only by the accuracy of the electronic integrator of the A.60 spectrometer. This is about ±1% (absolute error) throughout the whole concentration range.

In columns 3 and 4 of Table 1 effective shielding constants σ(—SCN) and σ(—NCS) have been calculated from the chemical shift data and Shoolery's Rule:[5,6]

$$\delta = 0{\cdot}233 + \sum_i \sigma i \qquad (1)$$

Values of $\sigma(CH_3) = 0{\cdot}47$ ppm and $\sigma(C{=}C) = 1{\cdot}32$ ppm have been taken from Shoolery's data.[5,6] Good agreement in the calculated σ values is found for both —SCN and —NCS in the ethyl and isopropyl derivatives. The average values are σ(—SCN) = 2·30 and σ(—NCS) = 2·86. Although Shoolery's rules are not usually applied to methyl derivatives, hypothetical values of σ (in parenthesis in Table 1) obtained from these compounds are also in reasonable agreement with the above figures.

In the four other cases where one of the substituents on the CH_2 or CH under consideration is an unsaturated group, values of σ(—SCN) and σ(—NCS) are much lower than for the ethyl and isopropyl derivatives and also the three values of σ(—NCS) are themselves scattered. There are two possible factors responsible for this:

(a) The value of σ(C=C) = 1·32 used to calculate σ(—SCN) and σ(—NCS) is only an average value and is known to vary slightly depending upon the other substituent groups on the double bond. This effect, however, should be small.

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[5] J. N. Shoolery, *Technical Information Bulletin*, *Varian Associates* Vol. 2, No. 3. Palo Alto, California (1959).

[6] L. M. Jackman, *NMR in Organic Chemistry*. Chap. 4, p. 59. Pergamon Press (1959).

(b) Deviations are expected from Shoolery's rule if the bonding of the CH_2 or CH group changes character, i.e. moves away from sp^3 hybridization. However, both —SCN and —NCS are groups containing multiple bonds and several resonance forms are known to contribute.[1] Some canonical forms, in which the bonding of the central CH or CH_2 group is no longer pure sp^3 in character, may be stabilized by conjugation with the C═C double bond. These effects would mean that Shoolery's rule could not be applied reliably to such compounds.

Earlier it was stated that the difference in the effects of the —SCN and —NCS groups on the chemical shifts of β-protons would be small. For example, the chemical shifts found for the β-methyl group protons in ethyl and isopropyl thiocyanate, and ethyl and isopropyl isothiocyanate are 1·52, 1·50, 1·44 and 1·42δ respectively. In cases where the —SCN and —NCS groups are attached to a fully substituted carbon atom therefore, NMR would provide, in general, a much less satisfactory method of analysis than the case dealt with above where α-protons are present.