CORRELATION ANALYSIS OF IR AND NMR SPECTRAL CHARACTERISTICS OF GLYCIDYL ETHERS

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Abstract: Infrared, ^{13}C NMR and natural abundance ^{17}O NMR spectra were measured for a series of eleven glycidyl ethers. Three sufficiently sensitive spectral characteristics of the glycidyl group, i.e. the wave numbers of antisymmetric C-O-C stretching vibration, chemical shifts of the α-carbon atom and that of the acyclic oxygen atom gave statistically significant mutual correlations and correlations with inductive substituent constants.

Introduction

Glycidol (2,3-epoxy-1-propanol) and glycidyl ethers (namely alkyl and aryl derivatives) are widely used in the preparation of a new generation of drugs with cardiovascular activity.[1] They are of interest as a surface active agents , textile and dye auxiliaries, plasticizers and stabilisers for resins and heat transfer agents.[1] Due to high chemical reactivity of such epoxides they are very useful chemical intermediates, e.g. for preparation of acyclic nucleosides.[2]

The literature on glycidol derivatives is extensive, only spectral properties have not been systematically studied so far. We decided to measure the infrared, ^{13}C and ^{17}O NMR spectra of a series of eleven glycidyl ethers with a goal to find linear correlation between the spectral data and substituent constants characterising the inductive effects of alkyl and aryl groups attached to the glycidyl moiety.

Experimental

Alkyl glycidyl ethers were prepared according to the general procedure of Ulbrich[3] using BF_3.etherate as catalyst. The epoxides were obtained after final rectification in 40-75% yields.

Aryl glycidyl ethers were synthesized in single-step method [4] from phenols and epichlorohydrine in aqueous NaOH solution in the presence of phase-transfer catalysts (tetrabutylammonium hydrogensulfate or triethylbenzylammonium chloride). The final purification of epoxides performed by liquid chromatography on silica gel, and eluting with toluene-ethylacetate (95:5) afforded 70-80% yield of products.

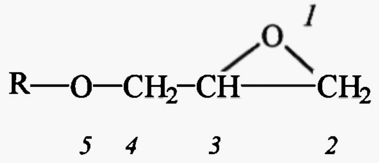
The purity of obtained glycidyl ethers was tested by gas chromatography (Shimazu GC-7A, 1.5m column, 2% OV-17, 80-230 °C, 12 °C/min).

The infrared spectra of glycidyl ethers were taken in the region of 1300-800 cm^{-1} on a Zeiss M80 Specord spectrometer using solutions in n-hexane and NaCl cells of 0.1mm thickness. The concentration of the solutions were chosen to give maximal absorption between 70% and 80%. The peak positions were determined with an accuracy of $\pm$ 0.2 cm^{-1} . The NMR spectra were measured at 25 °C on a Varian VXR 300 instrument operating at 75.429 MHz for ^{13}C nuclei and 40.66 MHz for ^{17}O nuclei. For ^{13}C NMR spectroscopy solutions in $CDCl_3$ were used with tetramethylsilane as an internal standard. Natural abundance ^{17}O NMR spectra were recorded using a spectral width of 15.36 kHz, 90° puls angle, 50 ms acquisition time, 1.5 K data points and 25 000 scans. The spectra were measured in CD_3CN containing D_2O as an internal standard. The half-width at peak half-height for all O^{17} signals were 380 ± 100 Hz.

Results and Discussion

The selected spectral data for the glycidyl ethers are listed in Table 1. Glycidyl ethers consist of two separated etheric moieties - the acyclic and the cyclic one. The cyclic etheric fragment i.e. the ethylene oxide ring in accordance with [5,6] exhibits in its infrared spectrum two characteristic absorption bands in the regions around 847 and 1260 cm^{-1} belonging to the C-O-C stretching vibrations of the symmetry B_1 and A_1, respectively. The wave numbers of both of these absorption bands are very little sensitive to the substituent effects of alkyl and aryl groups R attached to the glycidyl moiety. The acyclic part of compound **1-11** shows a strong absorption band in the region

Table 1. Selected Spectral Characteristics for Glycidyl Ethers



Compd.			δ (^{13}C)^b			δ (^{17}O)^b
No.	R	ν_{as} (C-O-C)^a	C-1	C-3	C-2	O-5
1	$(CH_3)_3C$	1112.4	72.42	50.46	43.99	-14.58
2	$CH_3(CH_2)_5$	1107.0	71.14	50.43	43.70	-14.30
3	$(CH_3)_2CH$	1113.6	68.71	51.08	44.92	-12.90
4	$CH_3(CH_2)_3$	1120.0	70.90	50.48	43.64	-14.32
5	CH_3	1112.4	72.99	51.14	44.95	-8.55
6	cyclo-C_6H_{11}	1104.0	70.71	50.60	44.01	-12.70
7	$CH_2C_6H_5$	1100.4	70.77	50.31	43.58	-7.08
8	4-CH_3O-C_6H_4	1049.6	69.21	49.96	44.22	-3.50
9	C_6H_5	1046.4	68.41	49.61	43.58	-4.20
10	4-Cl-C_6H_4	1040.8	68.80	49.67	44.05	2.14
11	4-NO_2-C_6H_4	1029.5	69.44	49.78	44.40	5.00

a) IR stretching vibration wave numbers in cm^{-1}.
b) ^{13}C and ^{17}O NMR chemical shifts in ppm.

of 1120-1020 cm^{-1} , which according to[7-10] can be assigned to the antisymmetrical stretching vibration of C-O-C group. The absorption bands of the corresponding symmetrical C-O-C stretching mode are poorly identifiable and are widely scattered across the "fingerprint region". It follows from what we have mentioned above that the substituent sensitive IR spectral characteristic of glycidyl ethers is the antisymmetrical C-O-C stretching vibration: ν_{as} (C-O-C). As it follows from Table 1, the above quantity changes with the substituents R in the range of 100 cm^{-1} which means that it is extremely touchy to the structural effects of the side chain.

The ^{13}C NMR spectra of glycidyl ethers 1-11 showed that only the ^{13}C NMR chemical shifts of the α-carbon atom (C-4) are sensitive enough to the substituent effects of the group R, the change in δ values being 4.0 ppm. The alteration of the chemical shifts of the C-2 and C-3 atoms, composing the ethylene oxide ring, induced by substituents are rather small and insignificant.

The ^{17}O NMR signals of ethylene oxide and some dialkyl and aryl-alkyl ethers measured as neat liquids were reported previously.[12, 13] Since the ^{17}O NMR data of cyclic and acyclic ethers have not been measured so far in CD_3CN, which is recommended [14] as the most suitable standard solvent for ^{17}O NMR spectroscopy, we used epichlorohydrin as a model compound for assignment of the signals belonging to the chemical shifts of the epoxy ring oxygens. The ^{17}O NMR chemical shift of the ethylene oxide ring of this compound in CD_3CN is observed at -10.4 ppm. The analogous signals of the oxygen atom in the cyclic part of glycidyl ethers **1-11** ranges from -15 ppm to -9 ppm and show a low substituent sensitivity. On the other hand, a considerable substituent effect susceptibility (ca. 20 ppm) exhibit the chemical shifts of the oxygen atom in the acyclic part of glycidyl ethers **1-11**.

The statistical treatment of the correlation analysis of selected characteristics of glycidyl ethers is summarised in Table 2. The ν_{as} (C-O-C) wave numbers correlate significantly with substituent constants of inductive effects [15] for all eleven compounds, whereby the σ_I values fit better the regression line than the Taft σ^* constants. The slope of the correlation $k = -320.5$ cm^{-1} is extremely large, which is in harmony with a high sensitivity of the C-O-C stretching vibration dependently on the inductive effects of substituents R. The sign of the above slope is negative, which is in opposite to the behaviour of an electrono-withdrawing carbonyl group in analogous ν(C=O) vs. σ_I correlations, e.g. for a series of α-chloroacetates.[16] The δ (^{13}C-4) chemical shift of eight glycidyl ethers exhibit also satisfactory correlations with inductive substituent constants of groups R, whereby again the δ (^{13}C-4) vs σ_I dependence is statistically more significant. The ν_{as} (C-O-C) wave numbers correlate well with the δ (^{13}C-4) chemical shifts of eight glycidyl ethers, which is consistent with our previous assignment of the absorption bands in the region of 1120-1020 cm^{-1} to the C-O-C stretching vibration of the R-O-C^1 moiety. Finally, the ^{17}O NMR chemical shifts of the acyclic moiety in the glycidyl ethers give an excellent correlation with inductive σ_I values of substituents R and satisfactory dependences on the ^{13}C NMR and IR chracteristics. The high value of the slope of δ(^{17}O-5) vs σ_I correlation (k=64.16 ppm) demonstrates a remarkable substituent sensitivity of the ^{17}O isotope nucleus which is consistent with that of the C-O-C stretching vibration monitored by IR spectroscopy.

Table 2. Correlation Analysis of Selected Spectral Characteristics for Glycidyl Ethers

$$y = kx + q$$

y	x	n^a	r^b	k	q	s^c	F^d
ν_{as} (C-O-C)	σ_I	11	0.960	-320.5 ± 31.1	1096.8	10.4	106
ν_{as} (C-O-C)	σ^*	11	0.944	-68.8 ± 8.0	1098.9	12.2	74
δ (^{13}C-4)	σ_I	8^e	0.920	-13.31 ± 2.31	70.7	1.4	33
δ (^{13}C-4)	σ^*	8^e	0.929	-3.00 ± 0.49	70.8	0.5	38
ν_{as} (C-O-C)	δ (^{13}C-4)	11	0.962	22.4 ± 4.0	-490.3	12.4	31
δ (^{17}O-5)	σ_I	11	0.981	64.16 ± 4.21	-10.1	1.4	232
δ (^{17}O-5)	σ^*	11	0.909	12.98 ± 1.98	-10.3	3.0	43
ν_{as} (C-O-C)	δ (^{17}O-5)	11	0.925	-4.72 ± 0.65	1048.6	14.1	77
δ (^{17}O-5)	δ (^{13}C-4)	8^e	0.859	-4.00 ± 0.97	272.7	3.5	17

a) Number of compounds used in the correlation. b) Correlation coefficient. c) Standard deviation. d) F-ratio of the correlation. e) Data for compounds **3**,**5** and **11** were rejected as outliers.

The experimental results showed that for a systematic preparation of a rather extended series of glycidyl ethers the method using phase-transfer catalyst can be recommended as a fast and convenient approach. On the basis of the correlation analysis a conclusion can be drawn that the selected IR, ^{13}C and ^{17}O NMR data for the R-O-CH_2 moiety are very sensitive to the inductive effects of the groups R, which could be also a reason the alteration of the activities of glycidyl ethers in the wide variety of their biological functions studied previously.

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