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^{17}O NMR SPECTROSCOPY: UNUSUAL SUBSTITUENT EFFECTS IN para-SUBSTITUTED BENZYL ALCOHOLS AND ACETATES

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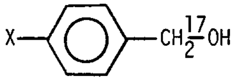
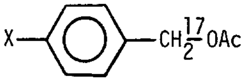
Summary: The ^{17}O chemical shifts for para-substituted benzyl alcohols and acetates were measured: electron donating substituents resulted in deshielding and electron withdrawing groups resulted in shielding of the chemical shift; the data are correlated by DSP treatment.

Despite the relatively low sensitivity of ^{17}O in NMR spectroscopy, its large chemical shift range makes it an important nucleus for study of the effects of small but systematic changes in molecular structure on electron distributions and bonding of organic molecules. The ^{17}O chemical shifts depend upon both paramagnetic and diamagnetic contributions; however, the paramagnetic term is usually considered to be the most important.[1] In fact, ^{17}O chemical shift data for benzaldehydes and acetophenones have been explained solely in terms of the paramagnetic contibution.[2] Reports of the effect of aromatic ring substituents on the ^{17}O NMR chemical shifts of oxygen nuclei in side chains are limited to benzaldehydes,[2] acetophenones[2,3] and nitrobenzenes,[4] all systems in which the aromatic ring and the side chain are in conjugation by π bonds. We report the first oxygen-17 chemical shift data for the effect of substituents on side chain oxygen nuclei for which there is no conjugative link between the aromatic ring and the side chain oxygen.





Samples of benzyl alcohols and benzyl acetates, enriched (~5%) with ^{17}O, were prepared to facilitate the study. The alcohols were prepared by acid catalyzed exchange of the corresponding benzaldehydes with ^{17}O enriched water (40%,Merck); followed by reduction with $NaBH_4$. The enriched benzyl acetates were obtained by allowing the previously prepared benzyl alcohols to react with acetic anhydride in pyridine. The structures of the isolated ^{17}O enriched alcohols and acetates were confirmed by proton NMR spectroscopy and by comparison with authentic samples. The ^{17}O spectra were recorded on a JEOL GX-270 Spectrometer equipped with a 10 mm broad band probe operated at 36.5 MHz. The benzyl alcohol samples were 1 molar in acetone or toluene. The benzyl acetate samples were 0.1 M in acetone (dried with molecular sieves). The spectra were acquired at 40°C and referenced to external deionized water. The instrument settings were: 25 KHz spectral width, 2 K data points, 90° pulse width (28 μs pulse width), 200 μs acquisition delay, 40 μs acquisition time, and 1,000 scans for the 1 M solutions and 5,000 scans for the 0.1 M solutions. The spectra were recorded with proton decoupling and sample spinning. The signal-to-noise ratio was improved by applying a 25 Hz exponential broadening factor to the FID prior to Fourier transformation. The data point resolution was improved to ±0.2 ppm by zero filling to 8 K data points. Under these conditions, the half height band widths for the alcohols were 146 ±25 Hz and for the acetates were 170 ±25 Hz.

Table 1 contains the ^{17}O chemical shift data for *para*-substituted benzyl alcohols and *para*-substituted benzyl acetates. It can be seen from the data that electron attracting groups result in apparent shielding of the chemical shift of the oxygen located β to the aromatic ring, whereas electron donating groups result in apparent deshielding. These substituent effects on the oxygen chemical shift are reversed from those reported for acetophenones,[2,3] benzaldehydes[2] and nitrobenzenes,[4] each of which involve π-bonding between the oxygen atom and aromatic ring. The chemical shift data for the benzyl alcohols obtained from toluene and acetone solutions are in good agreement and show that the response to substituents is intrinsic and does not arise from hydrogen bonding phenomena. A ten-fold dilution of two samples of benzyl alcohols at the electronic extremes resulted in little or no change in chemical shifts. The benzyl acetates were examined to further test this point; the results obtained from the benzyl acetates show the same trend and are consistent with the conclusion that the reversed substituent effect is an intrinsic property of this system.

TABLE 1. ^{17}O Chemical Shifts for Benzyl Alcohols and Benzyl Acetates in PPM.[a]

	alcohols				acetates[b]	
Subst.	acetone[c]	ν1/2[d]	toluene	ν1/2[d]	acetone[e]	ν1/2[d]
p-NO$_2$	-4.5	146	-1.0	158	164.6	146
p-CN	-4.2	146	-0.8	158	165.1	195
p-CF$_3$	-3.3	146	1.2	110	166.5	171
p-Cl	-0.5	122	4.3	165	169.1	171
p-H	0.7	146	6.0	122	170.5	147
p-F	0.7	171	6.0	128	171.5	171
p-CH$_3$	2.0	146	7.7	159	171.6	171
p-OCH$_3$	4.7	146	10.3	220	174.3	171
p-N(CH$_3$)$_2$	7.3	116	13.0	183	177.6[f]	159

a) Shifts (±0.2 ppm) were measured at 40°C in the solvent shown; referenced to external water. b) Values for the single bonded oxygen are given. c) ^{17}O δ of acetone carbonyl 573.4 ±0.4 ppm. d) Band width (in Hz) at half height. e) ^{17}O δ of acetone carbonyl 575.6 ±0.2 ppm. f) Compound is labile.

The chemical shift data for both series of compounds are correlated reasonably well by Hammett type substituent constants.[5] The slopes of the lines have the opposite sign of similar treatment of the oxygen-17 data for acetophenone, benzaldehydes and nitrobenzenes. The treatment of the data by the dual substituent parameter[6] (DSP) approach for the acetone data produces better correlations:

alcohol series $SCS=-6.71 \pm 0.30\ \sigma_I\ -8.56 \pm 0.32\ \sigma_R^{BA}$ $f=0.095,\ r=0.997$
acetate series $SCS=-7.10 \pm 0.19\ \sigma_I\ -9.27 \pm 0.20\ \sigma_R^{BA}$ $f=0.055,\ r=0.999.$

The DSP results show that the signs of inductive and resonance terms are both negative and that both terms are of comparable magnitude. In spite of the fact that there is no direct π overlap between the aromatic ring and oxygen nuclei, resonance effects remain important in describing substituent effects on the ^{17}O chemical shift. The signs for both the resonance and inductive terms are the opposite of those reported for similar analysis of ^{17}O chemical shift data for para-substituted acetophenones.[4b]

Reversed substituent effects in aryl systems on ^{17}O chemical shifts are hitherto unreported; however reversed chemical shifts from ^{19}F studies have been observed for para-substituted benzyl fluorides;[7] specifically electron attracting substituents cause apparent shielding of the ^{19}F shift relative to the unsubstituted compound. The ^{19}F shifts[7] are about 30% more sensitive to substituent effects than the ^{17}O results reported here. Furthermore, the ^{13}C chemical shift of the methyl groups (β to the aromatic ring) of para-substituted isopropylbenzenes[8] shows a reversed effect; electron withdrawing substituents cause shielding. However, the chemical shift difference between the electronic extremes is quite small, less than 1 ppm. Factors influencing the ^{17}O chemical shifts apparently are similar to those affecting the ^{19}F and ^{13}C shifts cited above since plots (Figure 1) of the ^{17}O chemical shifts versus the ^{19}F and ^{13}C shifts give reasonable correlations.

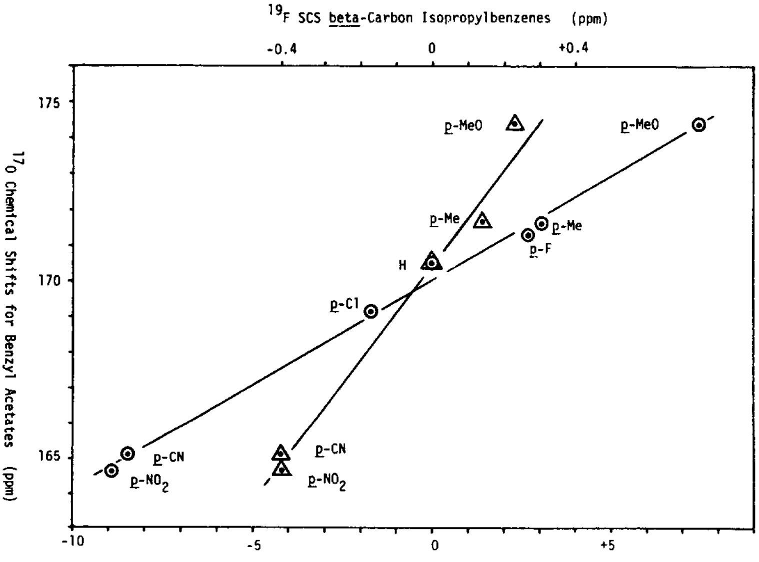


Figure 1. Plots of ^{17}O Chemical Shifts for the Ester Oxygen of Benzyl Acetates vs. ^{19}F SCS for Benzyl Fluorides (⊙ , bottom scale) and vs. ^{13}C SCS for beta-Carbon of Isopropylbenzenes (◬ , top scale).

The origin of the reversed substituent effect on ^{19}F and ^{13}C chemical shifts in aryl systems is of considerable interest.[7,8,9] Conformational[10,11] and hyperconjugational[12] factors have been suggested to be important. An explanation for these phenomena can be found upon examination of results from ^{17}O NMR studies on aliphatic ethers[13] and alcohols.[14] The ^{17}O chemical shift data for these compounds correlated with the electron populations on the oxygen atom; showing that an increase of electronic charge on the oxygen atom was accompanied by a downfield shift.[13,14]. It was concluded that increased electron population led to a more negative paramagnetic term thus resulting in deshielding of the oxygen chemical shift.[13,15] In the present study of a homologous series in which the small structural changes are remote from the oxygen atom, clearly electron donating substituents result in deshielding effects and electron attracting groups cause shielding effects. These results provide strong support for the conclusions of Fliszár.[13]

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