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SUBSTITUENT EFFECTS IN ^{13}C NMR SPECTROSCOPY
METHYL, ETHYL, 2-PROPYL AND 2-METHYL-2-PROPYL CARBOXYLATES

S. W. PELLETIER,* Z. DJARMATI and C. PAPE
Natural Products Laboratory, Department of Chemistry, University of Georgia, Athens, GA 30602, U.S.A.

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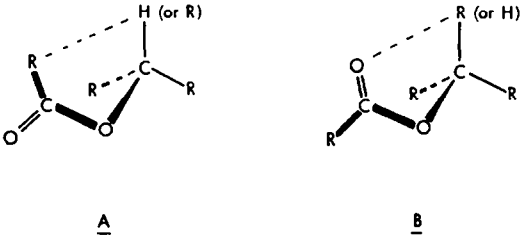
Abstract—The ^{13}C chemical shifts of 28 carboxylic esters have been determined by high-resolution NMR spectroscopy with the aid of proton decoupling. A linear relationship is shown to exist between the ^{13}C chemical shifts of the carbinyl carbon (C-1) of the esters and the pK_a values of the acids from which they are derived. This is a consequence of the polar character of the $-\overset{\delta+}{C}-\overset{\delta-}{O}COR$ bond. Similarly, if the carboxyl group is kept constant, but the alcoholic part of the ester is varied from primary to secondary and tertiary alcohols, the esterification effect on C-1 can be correlated with the increasing stability of the $+\delta$ charge on the carbinyl carbon. The smallest esterification effect at C-1 (1.3 ppm, relative to the parent alcohol) is observed for methyl pivalate (pK_a 5.03 for the parent acid), and the highest effect (17.7 ppm) for 2-methyl-2-propyl trichloroacetate (pK_a 0.70). In contrast, the C-2 esterification effect has been found to be essentially constant (-3.8 ± 0.7 ppm), which is in agreement only with a conformation of the ester group in which the carbinyl carbon is *cis* with respect to the CO group.

^{13}C NMR spectra of many carboxylates, varying either the acid or the alcoholic part alone, are well known. Previous CMR studies have focused on acetates of various simple alcohols[1a] and hydroxylated natural products.[2] However, in cases where the acidic part was varied in esters of methanol, no esterification effect at C-2 could be investigated.[3,4] Methyl acetate, phenylacetate, chloro-, dichloro- and trichloro-acetate have been studied, showing the esterification effect at C-1 to be less than 5 ppm.[3] In sharp contrast, a later investigation of fourteen methyl esters (including the previous ones of Ref. 3) claimed a C-1 effect as large as 43.2 ppm.[4] The present study was undertaken to resolve this discrepancy.

^{13}C chemical shifts of 28 carboxylic esters are summarized in Table 1, along with the effects produced by replacing the OH group with various carboxyl groups. Local polarization of the surrounding solvent molecules by the electric dipole of the solute can make a considerable contribution to ^{13}C chemical shifts.[5] To keep the solvent effect constant in our investigation, the ^{13}C spectra for all compounds listed in Table 1 were recorded under similar conditions in deuterochloroform, even if the shifts for some of these compounds were available in the literature. Changes in electron density near the carbinyl carbon can be estimated from the pK_a values of the parent acids of the esters, which range from 0 to 5.

The resonances reported in Table 1 for esters of methanol clearly support an upper bound of approximately 5 ppm for the C-1 esterification effect. The higher published values[4] appear to result from an interchange of the assignments for C-1 and the alkyl carbon in di- and tri-chloroacetate.

The C-1 esterification effects in methyl, ethyl and 2-propyl esters are small in contrast to 2-methyl-2-propyl esters. The observed C-1 effect upon substitution of an acetoxyl for an OH group in primary or secondary alcohols (~3 ppm), in contrast to tertiary alcohols (~11 ppm), has been correlated by Christl *et al.*, with other steric effects on ^{13}C shifts,[1] assuming that the ester group is in conformation *A* (Fig. 1). However, an X-ray crystallographic investigation of delphisine hydrochloride,[6] results obtained for simple carboxylic esters from



A B

studies of dipole moments,[7] IR spectra[8] and an electron diffraction investigation,[9] have all demonstrated that the ester group is nearly planar and is in conformation **B**. The conclusion from these studies seems to be that aliphatic esters do not manifest the free rotation about the carbonyl carbon–ether oxygen bond that is necessary for a γ-interaction shown in conformation **A**. An explanation of this behavior is the resonance energy (about 20 kcal/mole[10]) of the simple esters, which suggests that the conjugation of the carbonyl double bond with the unshared electron pairs of the ether O atom must be important. Conformation **A** is found only in δ- and ϵ-lactones where the ring makes conformation **B** impossible. The explanation of the C-1 esterification effect must be found elsewhere.

Our investigation includes methyl, ethyl, 2-propyl and 2-methyl-2-propyl esters of seven different acids, chosen to cover a wide range of pK_a values. The ionic character of the carbinyl carbon–ether oxygen bond is thus varied systematically, allowing a separation of steric and resonance influences on the C-1 effect. An essentially linear relationship exists between ^{13}C chemical shifts of the carbinyl carbon (C-1) of the esters and the pK_a values of the acids from which they are derived. Free rotation can occur around the carbinyl carbon–ether oxygen bond, and the C-2 esterification effect will originate either in steric compression by the CO group (in conformation B) or the alkyl group (in conformation A). The C-2 esterification effect (-3.8 ± 0.7 ppm) is essentially constant with the changing of the alkyl part (R) of the carboxyl group, suggesting that the steric compression results from the carbonyl rather than the alkyl group.

Table 1. ^{13}C shifts† of some methyl, ethyl, 2-propyl and 2-methyl- 2-propyl carboxylates

$R^*-CO-\overset{1}{O}CH_3$

R*	C-1	CO	R	pK_a of the parent acid
$C(CH_3)_3$	51.5(1.3)	178.8	38.7(s), 27.3(q)	5.03
CH_3	51.5(1.3)	171.3	20.6	4.75
C_6H_5	51.9(1.7)	166.9	132.8(d), 130.2(s) 129.5(d), 128.3(d)	4.19
$p\text{-}NO_2C_6H_4$	52.8(2.6)	165.1	150.5(s), 135.5(s), 130.7(d), 123.5(d)	3.41
CH_2Cl	53.0(2.8)	167.8	40.7	2.85
$CHCl_2$	54.2(4.0)	165.0	64.1	1.48
CCl_3	55.7(5.5)	162.5	89.6	0.70

$R^*-CO-\overset{1}{O}\overset{2}{C}H(CH_3)_2$

R*	C-1	C-2	CO	R
$C(CH_3)_3$	67.1(3.1)	21.7(-3.6)	177.9	38.6(s), 27.2(q)
CH_3	67.5(3.5)	21.8(-3.5)	170.4	21.4
C_6H_5	68.2(4.2)	21.9(-3.4)	165.9	132.5(d), 130.9(s), 129.4(d), 128.2(d)
$p\text{-}NO_2C_6H_4$	69.7(5.7)	21.8(-3.5)	164.0	150.4(s), 136.3(s), 130.5(d), 123.4(d)
CH_2Cl	70.0(6.0)	21.6(-3.7)	166.7	41.3
$CHCl_2$	71.9(7.9)	21.4(-3.9)	164.0	64.7
CCl_3	74.1(10.1)	21.2(-4.1)	161.3	90.3

$R^*-CO-\overset{1}{O}\overset{2}{C}H_2CH_3$

R*	C-1	C-2	CO	R
$C(CH_3)_3$	60.2(2.4)	14.2(-4.0)	178.4	38.7(s), 27.2(q)
CH_3	60.3(2.5)	14.2(-4.0)	170.9	21.0
C_6H_5	60.9(3.1)	14.3(-3.9)	166.4	132.7(d), 130.6(s) 129.5(d), 128.3(d)
$p\text{-}NO_2C_6H_4$	61.9(4.1)	14.3(-3.9)	164.5	150.5(s), 135.9(s), 130.6(d), 123.4(d)
CH_2Cl	62.3(4.5)	14.1(-4.1)	167.4	41.0
$CHCl_2$	63.7(5.9)	13.9(-4.3)	164.5	64.4
CCl_3	65.5(7.7)	13.7(-4.5)	161.9	90.0

$R^*-CO-\overset{1}{O}\overset{2}{C}(CH_3)_3$

R*	C-1	C-2	CO	R
$C(CH_3)_3$	79.4(10.4)	27.9(-3.4)	177.8	39.2(s), 27.2(q)
CH_3	80.1(11.1)	28.1(-3.2)	170.4	22.5
C_6H_5	80.7(11.7)	28.2(-3.1)	165.6	132.3(d), 132.1(s), 129.4(d), 128.1(d)
$p\text{-}NO_2C_6H_4$	82.5(13.5)	28.0(-3.3)	163.6	150.3(s), 137.4(s), 130.4(d), 123.3(d)
CH_2Cl	82.9(13.9)	27.9(-3.4)	166.2	41.9
$CHCl_2$	84.9(15.9)	27.6(-3.7)	163.3	65.4
CCl_3	86.7(17.7)	27.4(-3.9)	160.2	90.9

†In ppm downfield relative to TMS. The parenthetical values are esterification effects relative to the parent alcohol; a minus sign denotes an upfield change on substitution.

*The ^{13}C resonance occurs for methanol at 50.2, for ethanol at 57.8 and 18.2, for 2-propanol at 64.0 and 25.3 and for 2-methyl-2-propanol at 69.0 and 31.3 ppm.

EXPERIMENTAL

^{13}C spectra were determined at 25.03 MHz in the Fourier mode using a JEOL-PFT-100 spectrometer in conjunction with an EC-100-20K memory computer. The spectrometer features a deuterium lock system, a JNM-SD-HC random noise (2500 Hz band-width) proton decoupler, and JNM-DP-1 digital pulse programmer. Spectra of the compounds were determined in ~1 molar deuterochloroform solution (which also provided the lock signal) with 5% TMS added as internal reference. All samples were contained in precision ground 10 mm o.d. tubes. The spectrometer was used in the crosscoil configuration. On the average, a 12 μs pulse, corresponding to an approximate tilt angle of 45° was employed. For the average spectral width of 5000 Hz the delay between pulses was 3 sec.

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