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Reference Data

Carbon-13 NMR Spectra of Some 2-Ethylthio-4′-Substituted Acetophenones and Their Mono- and Di-Oxygenated Derivatives

PAULO ROBERTO OLIVATO (to whom correspondence should be addressed) and ÉLIDA BONFADA
Instituto de Química,
Universidade de São Paulo,
Caixa Postal 20.780,
01498-São Paulo-SP,
Brazil

ROBERTO RITTNER
Instituto de Quíimica,
Universidade Estadual de Campinas,
Caixa Postal 6.154,
13081-Campinas-SP,
Brazil

The ^{13}C NMR signals for some 2-ethylthio-, 2-ethylsulphinyl- and 2-ethylsulphonyl-4′-substituted acetophenones were assigned. The carbonyl carbons exhibit a progressive upfield shift on going from the ketosulphides to the ketosulphoxides and to the ketosulphones. The α-methylene carbons for the three classes of compounds are shielded by almost the same amount in relation to the corresponding calculated values. The chemical shifts of the aromatic ring carbons are in close agreement with those calculated using substituent chemical shifts.

KEY WORDS ^{13}C NMR, 2-Ethylthio-, 2-ethylsulphinyl- and 2-ethyl-sulphonyl-4′-substituted acetophenones

INTRODUCTION

The ^{13}C NMR data for the methylene and carbonyl carbons ($-CH_2CO-$) of 2-ethylthio-4′-substituted acetophenones (I) have already been published.[1] Here we report the ^{13}C NMR data for 2-ethylsulphinyl- (II) and 2-ethylsulphonyl-4′-substituted acetophenones (III) together with the data for the aromatic carbons for the compounds of series I. The aim of this work was to optimize the preparative conditions for the new aromatic ketosulphoxides and ketosulphones and to record their IR, ^1H and ^{13}C NMR spectra for their full characterization.

RESULTS AND DISCUSSION

^{13}C NMR spectra

The ^{13}C NMR experimental and calculated chemical shifts of the 2-ethylthio-, 2-ethylsulphinyl- and 2-ethylsulphonyl-4′-substituted acetophenones are given in Table 1. The signals of the aromatic carbons were assigned by single-frequency off-resonance decoupling (SFORD) and known chemical shift rules.[2] The substituent chemical shifts were taken from the tabulation of Ewing[3] and, for $-C(O)CH_2SEt$, $-C(O)CH_2S(O)Et$ and $-C(O)CH_2S(O)_2Et$ groups, were estimated from the chemical shifts of the unsubstituted 2-ethylthio- (**1**), 2-ethylsulphinyl- (**8**) and 2-ethylsulphonyl-acetophenones (**15**). Good agreement between both data sets is obtained (Table 1), indicating that the assignments are correct.

The computed chemical shifts for the α-methylene carbon for the I, II and III series were obtained through the equation

$$\delta_{CH_2} = -2.3 + \alpha_A + \alpha_X \qquad (1)$$

where α_X is the α-effect of the $-SO_nEt$ ($n = 0$, 1 and 2) substituents [estimated from the α-methylene carbon chemical shifts of diethyl sulphide, diethyl sulphoxide and diethyl sulphone (Table 2)], α_A is that of the *para*-substituted phenacyl group (estimated from the α-methyl chemical shift of *para*-substituted acetophenones[1]) and -2.3 is the chemical shift for the methane carbon atom.[5]

The calculated methylene chemical shift for 2-ethylsulphinyl- (**8–14**) and 2-ethylsulphonyl-acetones (**15–21**) deviate from the experimental values by *ca.* 7 ppm for both series (Table 1), similar to the 2-ethylthio-4′-substituted acetophenones. This non-additivity effect has been attributed[6] to an interplay of $\pi^*_{CO}/\sigma_{C-SO_n}$ and $\pi_{CO}/\sigma^*_{CS-O_n}$ orbital interactions which should occur in the $C(O)CH_2SO_nEt$ ($n = 0$, 1 and 2) systems.

The carbonyl carbon exhibits a progressive upfield shift on going from the ethylthio- (**1–7**) to the ethylsulphinyl- (**8–14**) and to the ethylsulphonyl-acetophenones (**15–21**) (Table 1), which can be mainly ascribed to the increasing inductive effect of the respective substituents, i.e. [$\sigma_{I(SEt)} = 0.25$, $\sigma_{I(SOEt)} = 0.50$ and $\sigma_{I(SO_2Et)} = 0.60$].[7]

^1H NMR Spectra

The ^1H NMR spectra were intended mainly for identification purposes only. However, it should be mentioned that the α-methylene protons [$C(O)CH_2S$] for the ketosulphoxides correspond to an AB system (**8–12**), which closely approaches the A_2 case for the spectra of **13** and **14**, where the centre lines lie so close to one another that the spectral resolution was not sufficient to separate them. The *S*-ethyl methylene proton signals for **8–14** are a complex multiplet (AB part of an ABX_3 system) for the spectra at 60 MHz. It was possible to record the spectra of **9** and **12** at 200 MHz, which allowed the observation of a doublet of quartets for each diastereotopic methylene proton of the *S*-ethyl group (Table 3).

EXPERIMENTAL

Physical data

All the 4′-substituted aromatic ketosulphoxides and ketosulphones are new compounds and were identified by the physical and spectral data given in Tables 3 and 4. The unsubstituted sulphoxide **8** was previously obtained by Nokami *et al.*,[8] but was not characterized. The melting point for the unsubstituted sulphone **15** given by Böhme and Krause[9] (110 °C) was in disagreement with that obtained here (58–59 °C). The elemental analyses for **8** and **15** were therefore also included in Table 4, to confirm their identification. Sulphoxides **8–14** are very hygroscopic and do not exhibit sharp melting points; compounds **8–21** had to be kept in a freezer owing to their lack of stability at room temperature.

Compounds

The 2-ethylsulphinyl-4′-substituted acetophenones (**8–14**) were obtained from an adaptation of the method of Leonard and Johnson,[10] i.e. by the reaction of the corresponding 2-ethylthio-4′-substituted acetophenones,[1] in acetonitrile solution, with an equimolar aqueous solution (0.5 M) of sodium metaperiodate at room temperature for 4–8 h. The reaction was followed by thin-layer chromatography on silica gel, using chloroform as the eluent. The crude product was recrystallized from chloroform–hexane.

The 2-ethylsulphonyl-4′-substituted acetophenones (**15–21**) were prepared essentially by the method of Drabowicz *et al.*,[11] i.e. from a methanolic solution of the corresponding 2-ethylthio-4′-substituted acetophenones containing selenium dioxide and hydrogen peroxide (35%) in a molar ratio of 1 : 1 : 5 at 15 °C for *ca.* 3 h. Ethyl sulphone (m.p. 68–69 °C; lit.[12] m.p. 70 °C) was prepared from ethyl sulphide following the same method.[11]

Ethyl sulphoxide (b.p. 82–83 °C/7 Torr; lit.[13] b.p. 88–89 °C/15 Torr) was prepared by the method of Drabowicz and Mikołajczyk,[14] i.e. from an equimolar methanolic solution of ethyl sulphide, selenium dioxide and hydrogen peroxide (30%) at room temperature.

The physical constants of **8–21**, their elemental analyses and their IR data are given in Table 4.

Spectra

The ^{13}C NMR spectra for 0.5 M solutions in $CDCl_3$, in 5 mm o.d. sample tubes, were

Reference Data

Table 1. ^{13}C chemical shifts[a] of 2-ethylthio-[$X\phi C(O)CH_2SC_2H_5$] (1–7), 2-ethylsulphinyl-[$X\phi C(O)CH_2S(O)C_2H_5$] (8–14) and 2-ethyl sulphonyl-4′-substituted acetophenones [$X\phi C(O)CH_2S(O)_2C_2H_5$] (15–21) in $CDCl_3$

	Substituent	Acetyl carbons		Aromatic carbons				*S*-Ethyl carbons		Other carbons
Compound	X	CH_2	C=O	C-1′	C-2′,6′	C-3′,5′	C-4′	CH_2	CH_3	C(X)
1	H	36.6	194.3	135.2	128.6	128.4	133.0	26.2	14.0	
		46.2[b]								
2	OMe	36.5	193.2	128.2	130.8	113.6	163.5	26.2	14.0	55.2
		45.9		127.4	129.6	114.0	164.4			
3	Me	36.6	194.1	132.7	128.1	129.1	143.9	26.2	14.0	21.4
		46.1		132.1	128.5	129.1	142.3			
4	Cl	36.6	193.1	133.5	130.6	130.2	139.5	26.1	13.9	
		46.2		133.2	130.0	128.8	139.3			
5	Br	36.5	193.2	133.8	130.1	131.8	128.2	26.2	13.9	
		46.1		133.6	130.2	132.0	127.2			
6	CN	36.6	192.6	138.2	129.0	132.2	117.6	26.1	13.8	116.2
		46.3		139.4	129.3	132.0	117.3			
7	NO_2	36.8	192.0	139.3	129.2	123.1	149.6	26.2	14.0	
		46.6		141.2	129.5	123.5	152.9			
8	H	59.3	191.8	135.9	128.7	128.7	134.0	46.1	6.2	
		65.5								
9	OMe	59.1	190.0	129.0	131.0	113.9	164.2	45.9	6.2	45.9
		65.2		128.2	129.7	114.2	165.4			
10	Me	59.4	191.4	133.7	128.4	129.5	145.3	46.2	6.2	21.5
		65.4		132.9	128.6	129.3	143.3			
11	Cl	59.0	190.8	134.4	130.1	129.0	140.8	46.1	6.3	
		65.5		134.0	130.1	129.1	140.3			
12	Br	59.0	191.0	134.8	130.2	132.0	129.5	46.1	6.4	
		65.4		134.3	130.3	131.9	128.2			
13	CN	58.8	191.1	138.8	129.2	132.4	117.1	46.1	6.4	117.4
		65.6		140.2	129.4	132.3	118.3			
14	NO_2	59.0	191.0	140.4	129.9	123.7	150.6	46.2	6.4	
		65.9		142.0	129.6	123.8	153.9			
15	H	58.8	189.0	135.8	129.1	128.7	134.3	48.2	6.4	
		66.8								
16	OMe	58.8	187.2	128.9	131.8	114.1	164.6	48.1	6.3	55.4
		66.5		128.0	130.1	114.3	165.7			
17	Me	58.8	188.6	133.4	129.5	129.3	145.6	48.1	6.4	21.5
		66.6		132.7	129.0	129.4	143.5			
18	Cl	59.0	188.0	134.2	130.8	129.1	141.1	48.2	6.4	
		66.7		133.9	130.5	129.1	140.6			
19	Br	58.9	188.2	134.5	130.6	132.1	130.0	48.2	6.4	
		66.6		134.2	130.7	131.9	128.5			
20	CN	59.0	188.1	138.5	129.6	132.6	117.7	48.3	6.5	17.7
		66.9		140.1	129.8	132.3	118.6			
21	NO_2	59.3	188.0	140.0	130.3	123.9	151.0	48.5	6.4	
		67.1		141.9	130.0	123.8	154.2			

[a] In ppm relative to TMS.
[b] The second entries throughout are those calculated using substituent chemical shifts.

recorded at 20 MHz on a Bruker AC-80 spectrometer in the Fourier transform (FT) mode. The conditions were as follows: deuterium of $CDCl_3$ as both internal lock and internal reference fixed at the centre of the triplet (76.89 ppm); temperature, *ca.* 32 °C; pulse width, 5.6 μs; flip angle, 90°; acquisition time, 1.6 s; spectral width, 5000 Hz; pulse repetition time, 6.6 s; number of transients, 30000; and 16K data points. Spectra were recorded both in the proton-noise and in the single-frequency off-resonance decoupled modes.

The IR spectrometer was a Perkin-Elmer Model 283 and the ^1H NMR data were obtained on a Varian T-60 spectrometer for all compounds except **9** and **12**, for which a Bruker AC-200 spectrometer in the FT mode was used, using 5 mm o.d. sample tubes.

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Table 2. ^{13}C chemical shifts[a] of $(CH_3CH_2)_2SO_n$ compounds

n	CH_2	CH_3
0	25.5	14.8
1	44.8	6.4
2	46.0[b]	6.2

[a] In ppm relative to TMS, for $CDCl_3$ solutions.
[b] A wrong value (40.4 ppm) was quoted by Breitmaier and Voelter[2] for the chemical shift of the α-methylene carbon of diethyl sulphone (see Ref. 4).

Reference Data

Table 3. ^1H NMR data[a] for 2-ethylsulphinyl-, $X\phi C(O)CH_2S(O)C_2H_5$ (8–14), and 2-ethylsulphonyl-4′-substituted acetophenones $X\phi C(O)CH_2S(O)_2C_2H_5$ (15–21)

	Aromatic		Acetyl[c]				Ethyl		
Compound[b]	δ-2′,6′	δ-3′,5′	δ-H_A	δ-H_B	^2J	δ-CH_2[c]	^2J	δ-CH_3	^3J
8	7.40–8.22(m)[d]		4.27	4.32	14.0	2.85		1.38	7.0
9	7.83	6.83	4.17	4.28	14.0	2.80, 2.88	13.2	1.30	7.5
10	7.70	7.20	4.20	4.34	14.6	2.87		1.40	7.8
11	7.74	6.80	4.19	4.29	15.2	2.79		1.44	7.2
12	7.87	7.66	4.25	4.34	14.0	2.83, 2.97	13.2	1.40	7.4
13	8.04	7.76	4.30	4.30	—	2.92		1.40	7.6
14	8.22	8.35	4.30	4.30	—	2.97		1.44	7.2
15	7.20–8.12(m)[d]		4.57			3.20		1.44	7.1
16	7.90	6.93	4.43			3.20		1.43	7.5
17	7.90	7.20	4.43			3.17		1.38	7.3
18	7.96	7.55	4.45			3.20		1.44	7.3
19	7.91	7.73	4.53			3.26		1.46	7.2
20	8.15	7.91	4.94			3.44		1.54	7.6
21	8.28	8.40	4.60			3.23		1.47	7.0

[a] ^1H chemical shifts in ppm relative to TMS and coupling constants in Hz, for $CDCl_3$ solutions.
[b] For the numbering of the compounds, see Table 1.
[c] See text for the discussion of signal multiciplicities.
[d] m = multiplet.

Table 4. Physical, infrared[a] and elemental analysis data for the 2-ethylsulphinyl-, $X\phi C(O)CH_2S(O)C_2H_5$, and 2-ethylsulphonyl-4′-substituted acetophenones, $X\phi C(O)CH_2S(O)_2C_2H_5$

				Molecular		Analysis (%)		
Compound[b]	M.p. (°C)[c]	ν_{CO} (cm^{-1})	ν_{SO_n} (cm^{-1})[d]	formula		C	H	N
8	74–85	1676	1052, 1023	$C_{10}H_{12}O_2S$	Calc.	61.20	6.12	
					Found	61.01	5.92	
9	78–81	1666	1047, 1027	$C_{11}H_{14}O_3S$	Calc.	58.39	6.23	
					Found	58.11	6.49	
10	94–97	1671	1051, 1020	$C_{11}H_{14}O_2S$	Calc.	62.84	6.71	
					Found	62.93	6.61	
11	78–83	1677	1093, 1053	$C_{10}H_{11}ClO_2S$	Calc.	52.05	4.80	
					Found	51.89	4.64	
12	84–90	1678	1074, 1054	$C_{10}H_{11}BrO_2S$	Calc.	43.65	4.03	
					Found	44.00	4.17	
13	67–75	1683	1057, 1022	$C_{11}H_{11}NO_2S$	Calc.	59.72	5.01	6.33
					Found	59.71	5.07	6.72
14	91–98	1686	1059, 1051	$C_{10}H_{11}NO_4S$	Calc.	49.78	4.59	5.81
					Found	49.72	4.55	5.51
15	58–59	1679	1324, 1144	$C_{10}H_{12}O_3S$	Calc.	56.66	5.66	
					Found	56.60	5.60	
16	103–104	1668	1321, 1145	$C_{11}H_{14}O_4S$	Calc.	54.54	5.81	
					Found	54.35	5.84	
17	68–70	1673	1323, 1144	$C_{11}H_{14}O_3S$	Calc.	58.40	6.25	
					Found	58.56	6.24	
18	94–96	1680	1325, 1146	$C_{10}H_{11}ClO_3S$	Calc.	48.70	4.49	
					Found	49.14	4.72	
19	91–95	1679	1323, 1144	$C_{10}H_{11}BrO_3S$	Calc.	41.25	3.80	
					Found	41.20	3.77	
20	130–139	1686	1325, 1145	$C_{11}H_{11}NO_3S$	Calc.	55.70	4.67	5.90
					Found	55.63	4.65	6.16
21	105–108	1690	1324, 1145	$C_{10}H_{11}NO_5S$	Calc.	46.70	3.00	5.40
					Found	46.79	3.23	5.65

[a] In $CHCl_3$.
[b] For the numbering of the compounds, see Table 1.
[c] Compounds **8–14** were recrystallized from chloroform–hexane, **15**, **16** and **21** from benzene and **17–20** from toluene.
[d] For **15–21**, the higher frequency band corresponds to the ν_{SO_2} asymmetric vibration and the lower frequency to the symmetric vibration.

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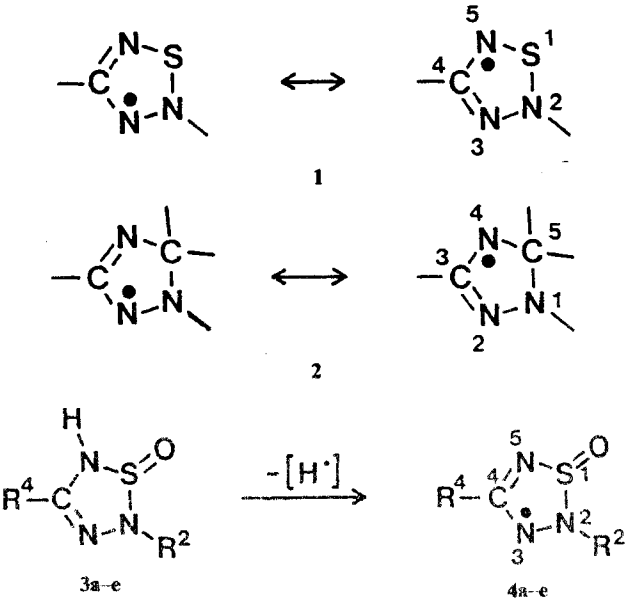
ESR and ENDOR Study of 2,3-Dihydro-1-oxo-1λ^4,2,3,5-thiatriazol-3-yl Radicals

FRANZ A. NEUGEBAUER
Abt. Organische Chemie,
Max-Planck-Institut für medizinische Forschung,
Jahnstr. 29,
W-6900 Heidelberg,
Germany

Dehydrogenation of 2,5-dihydro-1,2,3,5-thiatriazole 1-oxides with thermally formed bis(4-methylphenyl)aminyl generated 2,3-dihydro-1-oxo-1λ^4,2,3,5-thiatriazol-3-yl radicals. ESR, ENDOR and triple resonance studies in combination with ^{15}N labelling yielded the magnitude and assignment of all ^{1}H and ^{14}N hyperfine coupling (HFC) constants. The radicals have a basic five-π-electron amidrazon-2-yl structure with the highest spin density at N-2.

KEY WORDS ESR Nitrogen-centred radicals 2,3-Dihydro-1-oxo-1λ^4,2,3,5-thiatriazol-3-yl radicals



3a–e **4a–e**

a: $R^2 = R^4 = C_6H_5$
b: $R^2 = R^4 = C_6D_5$
c: $R^2 = C_6H_5$, $R^4 = C_6D_5$
d: 3-^{15}N, $R^2 = R^4 = C_6H_5$
e: 3,5-$^{15}N_2$, $R^2 = R^4 = C_6H_5$

INTRODUCTION

We have recently reported[1] studies of 2,5-dihydro-1,2,3,5-thiatriazol-5-yl radicals (**1**), which combine the basic structural features of 1,2,3,5-dithiadiazolyl and tetrazolinyl radicals, i.e. the thioaminyl and the hydrazyl moiety, in a five-membered cyclic π-electron system. *S*-Oxidation should have a pronounced effect on the properties of these radicals. Replacement of —S— by —SO— is expected to disconnect the cyclic conjugation and may lead to a five-π-electron amidrazon-2-yl moiety as the basic structural element. Related radicals are known, e.g. the stable 4,5-dihydro-1*H*-1,2,4-triazolyl radicals (**2**).[2]

Hydrogen abstraction from the parent 2,5-dihydro-1,2,3,5-thiatriazole 1-oxides (**3**) should lead to the formation of 2,3-dihydro-1-oxo-1λ^4,2,3,5-thiatriazol-3-yl radicals (**4**).

RESULTS AND DISCUSSION

Reaction of **3a–e** with thermally formed bis(4-methylphenyl)aminyl generated the radicals **4a–e**. Only radicals with aryl substituents in positions 2 and 4 are persistent. Attempts to detect radicals with alkyl groups in these positions by ESR in the liquid phase were not successful.

ENDOR studies of **4a** and **d** (Fig. 1) clearly revealed all ^{1}H HFC constants and the largest ^{14}N splitting and, in addition, general triple experiments[3] provided the relative signs. The multiplicities of different sets of equivalent protons were derived from the ESR spectra, which were sufficiently resolved and are all well simulated using the data given in Table 1. Examples are shown in Figs. 2 and 3.

^{15}N labelling gave an unambiguous assignment of all N HFC constants. The simulation of the 300 K ESR spectra of **4d** and **e** yielded $a(^{15}$N-3) = 6.2 and $a(^{15}$N-5) = 3.44 G. Consequently the large nitrogen splitting of *ca.* 8 G must stem from N-2. a(N-2) and a(N-3) clearly decrease with decreasing temperature (see Table 1). All ^{14}N HFC constants are considered to be positive as for **1**[1] and **2**.[2] A comparison of the proton HFC data of **4c** with those of **4d** reveals that the larger ^{1}H splittings [**4c** (230 K): −2.58 (1H), −2.29 (2H) and +0.74 G (2H)] belong to the 2-phenyl protons. Their further assignment to specific positions is based on the relative signs and the number of equivalent protons. This pattern corresponds to that found for the *N*-phenyl protons in **1** [2,5-dihydro-2,4-diphenyl-1,2,3,5-thiatriazol-5-yl,[1] ENDOR, dimethoxyethane, 220 K: a(N-2) = 7.61, a(N-3) = 4.12, a(N-5) = 5.08, a(H-2′,4′,6′) = −1.79