

On the ^1H NMR Spectra of 2-Substituted Benzoquinones

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Abstract: *The novel complete analysis of the ^1H NMR spectra of six monosubstituted benzoquinones is reported herein, together with a brief but complete review of the scanty previously published data on benzoquinone and its monosubstituted derivatives.*

Resumo: *No presente trabalho é apresentada uma análise detalhada, até aqui inédita, dos espectros de RMN de ^1H de seis benzoquinonas monossubstituídas, juntamente com uma revisão breve, mas completa, dos poucos e dispersos dados de RMN de ^1H , devidos a benzoquinona e seus derivados, que se encontram na literatura.*

Introduction

Benzoquinones are the synthetic precursors of many natural and unnatural products, ranging from ubiquinone¹ to cholesterol² and from hypostrophene³ to pentaprismane.⁴ Substituted benzoquinones are antimetabolites^{5,6} of Coenzyme Q (CoQ), exhibiting antitumoral,⁵ antimalarial⁵ and / or Leishmanicidal⁷ activities, while other quinones present renewed technological interest for the chromium-free (in fact, all-metal-free) tanning^{8,9} of leather. Moreover, a mono-substituted benzoquinone, 2-(hydroxymethyl)benzoquinone isovalerate (**1**), was recently shown to be the sex pheromone of the german cockroach,¹⁰ providing new perspectives for its combat.

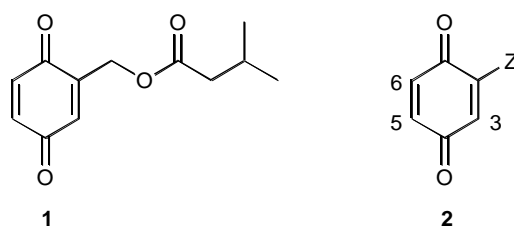
Despite their importance, and although there are numerous articles in the literature on the simpler benzoquinones, only scanty complete ^1H NMR data exist in the literature, because most articles neglect the fact that they do give rise to (usually deceptively simple) second order NMR spectra:

(i) the definitive analysis of the ^1H NMR spectrum of the parent, unsubstituted benzoquinone (**2a**), including the determination of all the ^1H – ^1H coupling constants (from a AA'A''X analysis of the downfield ^{13}C satellite of the observed singlet, because all protons in **2a** are isochronous and anisogamous¹¹), was reported by Crecely *et al.*,¹² in 1968;

(ii) in 1966, Norris and Sternhell published their pioneer article¹³ on the ¹H NMR spectra of benzoquinones, which includes complete data on 2-bromobenzoquinone (**2b**). Subsequently, Govil's landmark article¹⁴ containing the definitive analyses of the ¹H NMR spectra of 2-chlorobenzoquinone (**2c**) and toluquinone (**2d**) appeared, in 1967, and, in 1975, Hudlicky and

Bell¹⁵ reported the data on 2-fluorobenzoquinone (**2e**).

Thirty years would elapse before the publication, in 2005, of the unanalysed 600 MHz ¹H NMR spectrum of blattellaquinone (*i.e.* **1**) by Nojima *et al.*,¹⁰ the latest data reported on monosubstituted benzoquinones, up to now.



In the course of our on-going investigations¹⁶⁻¹⁹ on enediones we have prepared various different monosubstituted benzoquinones, and hence we had the opportunity of performing a complete analysis of their corresponding ¹H NMR spectra. Moreover, we considered this should be of interest because (i) monosubstituted benzoquinones present second-order ABX spectra (even at 600 MHz¹⁰), which are amenable to straightforward direct solution,²¹ and (ii) we had six highly purified simple monosubstituted benzoquinones at hand, so that, by reporting our results, we would be able to actually double the amount of high quality data available, thus helping to make the knowledge about such compounds more representative.

Experimental

Quinones **2f**,¹⁶ **2i**,²¹ **2g-h**¹⁹ and **2j-k**¹⁹ were prepared according to literature procedures and sublimed and/or recrystallized until 99.5% purity (by ¹H NMR) was attained.

Bruker AC200-F and Varian Unity Inova 300 spectrometers were employed for the acquisition of the ¹H spectra (5% solutions in CDCl₃, TMS=0) at 200/300 MHz, respectively. Proton NMR parameters were: spectral width, 2280.5 Hz; data points, 16K, zero-filled to 32K; acquisition time, 3.52 s; digital resolution, 0.28 Hz; number of scans: 64. All NMR experiments were run using standard instrument (Bruker or Varian, respectively) software.

For each of the quinones **2f-k**, the ABX spectral lines were measured using the

spectrometer software, and for **1** they were measured by hand, on a suitably enlarged printout of the published spectrum. The lines were then transferred to an Excel spreadsheet and directly solved by our implementation of the algorithm described by Garbisch, Jr.²¹ However, since line broadening introduces some measurement uncertainty, the results from the direct solution were then input to the program LAOCN9,²² a PC compatible implementation of Laocoon-III,²⁴⁻²⁵ so as to iteratively minimize the probable error²³ of the

estimates, which was found to lie in the 0.01-0.03 Hz range, in all cases.

Results and discussion

Table 2 displays the previously existing data (acquired in hexadeuterobenzene solution) on quinones **2c-d**, as well as our own solution to the published¹⁰ spectrum of blattellaquinone (**1**), while all the data on the quinones **2** (in deuteriochloroform solution) are collected in Table 2, with the previously published data as the first five entries, followed by the novel data on the quinones **2f-k**.

Table 1. ¹H NMR of Benzoquinones^a - Literature Data and Experimental Results

Comp.	Subst. (Z)	Chemical Shifts (δ , ppm)			Coupling Constants /Hz			Notes
		H-3	H-5	H-6	⁴ J _(3,5)	³ J _(5,6)	⁵ J _(3,6)	
1	<i>i</i> -BuCO ₂ CH ₂	6.36	5.95	5.92	2.2	10.2	-0.3	b,c,d
2c	Cl	6.32	5.93	6.01	2.2	10.2	-0.3	e
2d	H ₃ C	6.17	6.23	6.25	2.5	10.0	-0.1	e, f

^a in C₆D₆, TMS = 0; ^b *i*-BuCO₂CH₂-2: δ = 0.79 (s, 6H, 2Me), 1.92 (d, 2H, O=CCH₂, J = 7.8 Hz), 1.99 (m, 1H, CH), 4.72 (d, 2H, OCH₂, J = 2.0 Hz); ^c This work, by interpreting the spectrum presented as part of the available Supporting Online Material for ref. 10; ^d Ref. 10; ^e Ref. 14; ^f H₃C-2: δ = 1.65 (d, J_(3,Me) = 1.6 Hz).

It is perhaps more evident in Table 2 than in Table 1 that, along the series, the chemical shifts of H-3, the proton vicinal to the substituent, is quite sensitive to the inductive and mesomeric effects of that substituent. On the other hand, the ¹H-¹H coupling constants do vary very little, being generally indifferent to

such substituent effects, so that our results reinforce Govil's¹⁴ conclusion that, in monosubstituted benzoquinones, the coupling constants are quite insensitive to the change of substituent, although it seems to us very far from clear why this should be so.

Table 2. ¹H NMR of Benzoquinones^a - Literature Data and Experimental Results

Comp.	Subst. (Z)	Chemical Shifts (δ, ppm)			Coupling Constants /Hz			Notes
		H-3	H-5	H-6	⁴ J _(3,5)	³ J _(5,6)	⁵ J _(3,6)	
2a	H	6.72	6.72	6.72	2.5	10.2	+0.1	b,c,d
2b	Br	7.28	6.80	6.95	2.6	10.5	-0.6	e
2c	Cl	7.00	6.81	6.91	2.3	10.1	-0.2	c
2d	H ₃ C	6.63	6.73	6.78	2.5	10.0	-0.1	c, f
2e	F	6.40	6.76	6.79	2.2	10.5	-0.3	g
2f	H ₃ CO	5.95	6.72	6.73	2.2	10.1	-0.1	h,i
2g	H ₅ C ₆ O	5.70	6.70	6.78	2.4	10.1	-0.2	h,j
2h	H ₅ C ₆ HN	6.19	6.71	6.73	2.4	10.1	-0.6	h,k
2i	H ₅ C ₆ S	5.88	6.68	6.83	2.4	10.1	-0.1	h,l
2j	<i>p</i> -H ₃ COC ₆ H ₄ S	5.83	6.66	6.79	2.4	10.1	-0.1	h,m
2k	<i>p</i> -ClC ₆ H ₄ S	5.85	6.68	6.82	2.4	10.0	-0.1	h,n

^a in CDCl₃, TMS = 0; ^b H-2: δ = 6.72; ^c Ref. 14; ^d Ref. 12; ^e Ref. 13; ^f H₃C-2: δ = 2.06 (d, J_(3,Me) = 1.6 Hz); ^g Ref. 15; ^h This work; ⁱ H₃CO-2: δ = 3.84 (d, J_(3,Me) = 0.3 Hz); ^j H₅C₆O-2: δ = 7.08 (dd, 2H_o, J_o = 7.7 Hz, J_m = 1.8 Hz), 7.28 (dt, H_p, J_o = 7.8 Hz, J_m = 1.8 Hz), 7.44 (dd, 2H_m, J_o = 7.7 and 7.8 Hz); ^k H₅C₆HN-2: δ = 7.20 (bt, H_p, J_o = 7.4 Hz), 7.21 (bd, 2H_o, J_o = 7.9 Hz), 7.40 (dd, 2H_m, J_o = 7.4 and 7.9 Hz); 7.50 (bs, HN); ^l H₅C₆S-2: δ = 7.50 (bs, 5H); ^m *p*-H₃CO-C₆H₄S-2: δ = 3.86 (s, MeO), 6.98 (bd, 2H, J_o = 8.7 Hz), 7.38 (bd, 2H, J_o = 8.7 Hz); ⁿ *p*-Cl-C₆H₄S-2: δ = 7.45 (bd, 2H, J_o = 9.1 Hz), 7.47 (bd, 2H, J_o = 9.1 Hz);

Conclusion

Our results contribute to make the knowledge about the ¹H NMR properties of monosubstituted benzoquinones more representative, while confirming they are an interesting class of compounds, in which the ¹H -¹H coupling constants are seemingly oblivious to substituent effects, a fact that remains to be explained.

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25. The probable error is usually taken to be a fair estimate of the actual experimental uncertainty; actually, -0.6745σ is the lower quartile mark and $+0.6745\sigma$ is the upper quartile mark: the area under the normal distribution curve comprised between these marks is 50% of the total area.