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^{13}C NMR SPECTRA OF SOME NATURALLY OCCURRING BINAPHTHOQUINONES AND RELATED COMPOUNDS

AKELLA V. B. SANKARAM*, VADDU V. NARAYANA REDDY† and MADUGULA MARTHANDAMURTHI

Regional Research Laboratory, Hyderabad 500007, India

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Key Word Index—^{13}C NMR spectra; naphthoquinones; binaphthoquinones; isodiospyrin; rotundiquinone; 3,8′-biplumbagin; 3,3′-biplumbagin; 7-methyljuglone; plumbagin; 7-methyljuglone methyl ether; plumbagin methyl ether; benzene-induced solvent shifts.

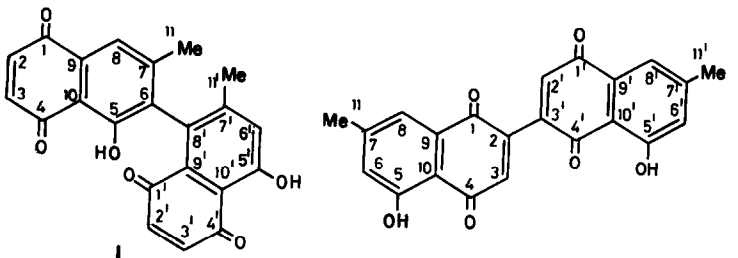
Abstract—^{13}C NMR chemical shift assignments have been shown to be diagnostic for the establishment of the dimeric linkage of some naturally occurring binaphthoquinones. The unsymmetric ^{13}C and ^{1}H spin–spin coupled pattern observed in the ^{1}H coupled ^{13}C NMR spectrum of plumbagin for C-6 has also been noticed earlier with the related compound juglone. The nature of these effects has been substantiated for the first time using benzene induced solvent shifts and D_2O exchange. ^{13}C chemical shift assignments of plumbagin reported earlier for C-6 and C-8 have been revised.

INTRODUCTION

Several naturally occurring binaphthoquinones based on 7-methyljuglone and plumbagin have been reported [1–8] and in this paper the applicability of proton noise decoupled ^{13}C NMR spectroscopy as a diagnostic tool in elucidating the dimeric linkage with the help of some model compounds is discussed. As expected symmetric dimers show the same number of ^{13}C NMR signals as the parent monomers, confirming the magnetic equivalence of like carbons of both the moieties. The unsymmetric dimers, on the other hand, give double the number of the carbon signals except when there is an accidental overlap.

*To whom correspondence should be addressed.

†Part of the work described is taken from the Ph.D. thesis of V. V. Narayana Reddy, "Chemical Examination of Some *Diospyros* Species", Osmania University, Hyderabad, 1982.



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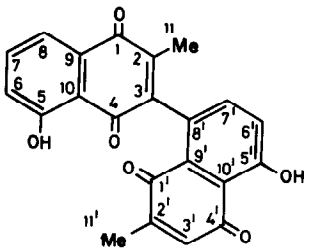

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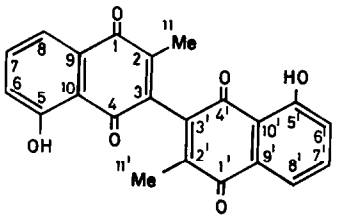

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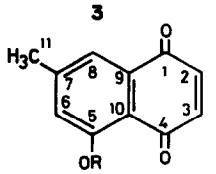

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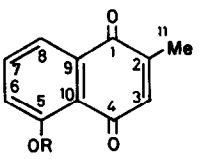
7 R = Me



6 R = H
8 R = Me

Table 1. ^{13}C NMR chemical shifts of some naturally occurring binaphthoquinones and related compounds

C	1*	2*	3	4	5	6 (^{1}H coupled spectrum)	7	8
1	184.43	184.21	184.53	183.56	184.52	183.94 (narrow multiplet)	185.24	185.70
	or	or	or					
1′	184.92	185.85	185.05	183.56	—	—	—	—
2	139.63	143.34	147.78	147.76	139.35	149.16 (q, $^2J_{CH_3}$ = *ca* 7 Hz)	139.83	145.39
	or	or	or					
2′	140.19	138.64	149.86	147.76	—	—	—	—
3	137.71	138.17	142.54	139.85	138.76	134.91 (q, $^1J_{H\text{-}3}$ = *ca* 165 Hz, $^3J_{CH_3}$ = *ca* 6 Hz)	140.81	137.89
	or							
3′	138.76	143.84	137.86	139.85	—	—	—	—
4	190.10	187.37	188.64	187.71	189.76	189.63 (s)	183.78	184.27
	or	or	or					
4′	190.38	188.46	190.44	187.71	—	—	—	—
5	158.79	161.95	161.87	161.83	161.83	160.64 (q, $^3J_{H\text{-}7}$ = *ca* 8 Hz, $^2J_{OH}$ = *ca* 4 Hz)	159.61	159.96
	or	or	or					
5′	162.07	162.35	162.29	161.83	—	—	—	—
6	135.20	124.47	124.00	124.56	124.13	123.64 (m,$^1J_{H\text{-}6}$ = *ca* 168 Hz,$^3J_{H\text{-}8}$ = *ca* 8 Hz)	119.63	119.39
		or	or					
6′	125.71	124.66	124.56	124.56	—	—	—	—
7	145.52	148.93	135.10	136.62	148.49	135.67 (d, $^1J_{H\text{-}7}$ = *ca* 166 Hz)	146.29	134.54
	or		or					
7′	148.18	148.93	136.10	136.62	—	—	—	—
8	121.37	120.75	119.20	119.20	120.47	118.71 (q, $^1J_{H\text{-}8}$ = *ca* 168 Hz, $^3J_{H\text{-}6}$ = *ca* 7 Hz)	—	—
		or						
8′	130.40	121.37	126.55	119.63	—	—	118.22	117.90
9	128.65	131.69	130.24	132.19	131.69	131.55 (d $^3J_{H\text{-}7}$ = *ca* 6 Hz)	133.61	134.54
	or	or	or					
9′	129.00	131.85	132.65	132.19	—	—	—	—
10	113.31	113.31	115.45	114.92	113.12	114.59 (d, $^3J_{H\text{-}6}$ = $^3J_{H\text{-}8}$ = $^3J_{OH}$ = *ca* 4 Hz)	117.28	120.28
	or		or					
10′	114.36	113.31	115.82	114.92	—	—	—	—
11	20.40	22.23	14.32	14.45	22.17	16.09 (dq $^1J_{H\text{-}11}$ = *ca* 129 Hz, $^3J_{H\text{-}3}$ = *ca* 5 Hz)	22.16	15.62
	or		or					
11′	20.55	22.23	16.55	14.45	—	—	—	—
12	—	—	—	—	—	—	56.24	56.51

*The assignments of C-6 and C-8′ for **1**, C-2 and C-3′ and C-3 and C-2′ for **2** may be interchanged. Coupled spectra could not be obtained due to solubility difficulties with dimers.

The signals of ^1J coupled carbons can be distinguished from the weak tertiary carbon signals and the >C=O signals in the proton noise decoupled ^{13}C NMR spectra due to the NOE effects. The dimeric linkage can be established elegantly by the downfield shift of the signals of the carbons involved with a reduction in intensity. This method is particularly useful for compounds where solubility demands longer instrument times for the ^{1}H coupled ^{13}C NMR spectra and is complementary to the ^{1}H NMR spectral information by providing the carbon skeleton.

The ^{13}C{^{1}H}NMR spectrum of 7-methyljuglone (**5**) (Table 1) shows eleven lines corresponding to its molecular formula $C_{11}H_8O_3$. The chemical shifts are assigned in analogy with juglone [9]. The signals of the unsubstituted carbons C-2, C-3, C-6 and C-8 are most intense and can be distinguished from the weak lines C-1 (>C=O), C-4 (>C=O), C-5, C-7, C-9 and C-10. The methyl carbon is also moderately intense.

Twenty two lines are seen in the ^{13}C{^{1}H}NMR spectrum of isodiospyrin [1, 3] (molecular formula $C_{22}H_{14}O_6$) supporting the unsymmetric structure **1**. The presence of the single intense lines at δ125.71 (C-6′) and 121.37 (C-8) instead of the single pairs of closely spaced lines seen in the C-6 and C-8 regions of 7-methyljuglone confirms the presence of a 6,8′-linkage between the two monomeric moieties of **1**. As expected, the signals from the substituted carbons C-6 and C-8′ are shifted downfield to δ135.20 and 130.40 respectively, with a reduced intensity. The other ^{13}C chemical shift assignments are consistent with structure **1**.

The chloroform extract of the root bark of *Diospyros chloroxylon* yielded an orange crystalline solid, which has similar spectral data to those reported for the unsymmetric dimer rotundiquinone (**2**) [4, 5]. Its ^{13}C{^{1}H}NMR spectrum contains eighteen lines indicative of its unsymmetric nature. Furthermore, the two intense signals at δ138.64 (C-3 or C-2′) and 138.17 (C-3 or C-2′) (Table 1, 7-methyljuglone) due to ^1J coupled carbons confirm the linkage between C-2 of one naphthoquinone moiety and C-3′ of the other. The signals with a reduced intensity at δ143.34 and 143.84 are assignable to C-2 and C-3′, which cannot be differentiated. The C-7 and C-7′, C-10 and C-10′, and C-11 and C-11′ resonated at

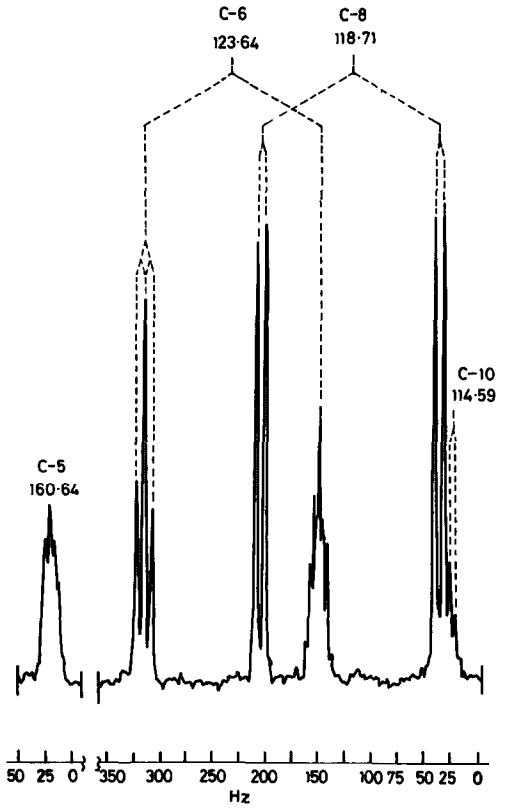


Fig. 1. ^{13}C NMR spectrum of plumbagin (before D_2O exchange, $CDCl_3$, C-5, C-6 and C-8 regions).

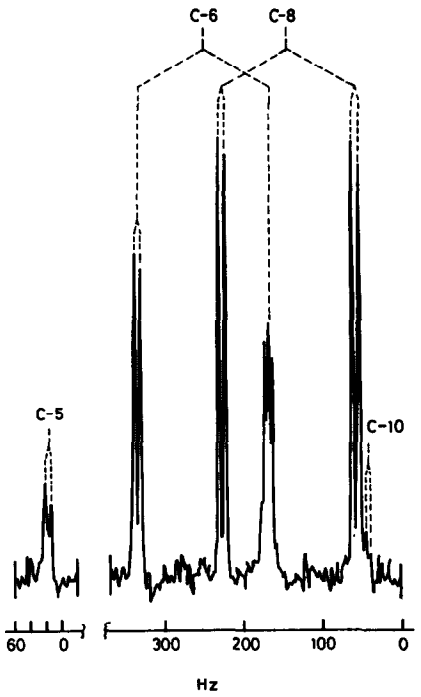


Fig. 2. ^{13}C NMR spectrum of plumbagin (after D_2O exchange, $CDCl_3$, C-5, C-6 and C-8 regions).

δ148.93, 113.31 and 22.23 respectively. Remaining chemical shift assignments are consistent with structure **2** (Table 1).

The chemical shift assignments for C-6 (δ119.0) and C-8 (δ123.7) reported earlier in the case of plumbagin (**6**) appeared to be incorrect [10]. Long range couplings of the hydroxyl protons with the neighbouring carbon atoms in the ^{13}C NMR spectra of phenolic compounds are well documented, ^3J couplings with *anti* geometry of the coupled nuclei (^{1}H and ^{13}C) are larger than those with the *syn* relationship [11]; ^2J couplings of ^{13}C nuclei with the hydroxyl protons have also been noticed while ^4J and ^5J couplings have not been encountered [12]. Thus the signal for C-6 of plumbagin (**6**) is expected to show $^1J_{H\text{-}6}$ and $^3J_{H\text{-}8}$ as well as $^3J_{OH}$ whereas the signal for C-8 should be split by $^1J_{H\text{-}8}$ and $^3J_{H\text{-}6}$. The signal at δ123.64 is split with a ^1J coupling ($^1J_{H\text{-}6}$ = *ca* 168 Hz) and both the lines are further split. The downfield branch is a triplet apparently due to two ^3J couplings (^3J = *ca* 8 Hz) and the upfield branch appears as a multiplet implicating more complex perturbations (Fig. 1). On D_2O exchange the triplet and multiplet patterns of both the branches simplify to a doublet ($^3J_{H\text{-}8}$ = 7.3 Hz) and triplet respectively eliminating the $^3J_{OH}$ couplings (Fig. 2). The reasons for the triplet appearance of the upfield branch are not readily obvious but may be correlated to the higher order effects of the involved ABC proton spins H-7 (B) and H-8 (C) which have close chemical shifts (Fig. 3) and appear to perturb differentially both the branches of C-6 (X) pre-

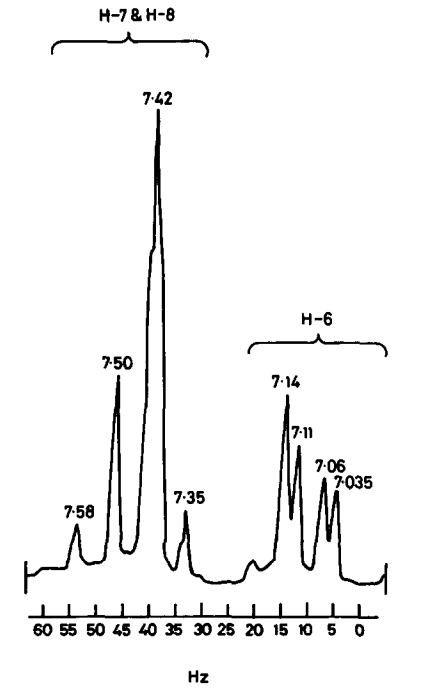


Fig. 3. ^{1}H NMR spectrum of plumbagin (after D_2O exchange, $CDCl_3$, H-6, H-7 and H-8 region).

senting an anomalous picture deviating from the first order pattern as in the case of juglone [11]. The signal at δ118.71 shows ^1J and ^3J couplings and the multiplicity is unchanged on D_2O exchange. The assignments of C-6 and

C-8 therefore have to be reversed. The D_2O exchange also simplifies the C-5 signal at δ160.64 from a multiplet to a doublet eliminating ^2J couplings with the hydroxyl protons preserving the ^3J coupling with the C-7 proton; the line broadening could be due to the effect of H-8 which has close chemical shift to H-7 and unresolved ^2J coupling. The signal of C-9 (δ131.55) is merged in the upfield quartet of C-2. The multiplicities of the remaining carbon atoms confirm the earlier assignments.

The ABC system constituting the H-6, H-7 and H-8 (Fig. 3) changes to an approximately AMX on gradual addition of C_6D_6 (Fig. 4) and the corresponding ^1H coupled ^{13}C spectrum shows both the branches of C-6 as symmetric doublets. C-5 is also seen as a symmetric doublet eliminating the higher order proton perturbation effects (Fig. 5). The relative assignments of C-3 and C-7 are obvious from the observed spin spin couplings.

The symmetric dimeric linkage of 3,3′-biplumbagin [7], molecular formula $C_{22}H_{14}O_6$, is reflected in its $^{13}C\{^1H\}$NMR spectrum which displays eleven lines for the 22 carbons. Ten of these lines correspond closely to those of plumbagin in both chemical shift and intensity (Table 1). The eleventh line corresponding to C-3 in the $^{13}C\{^1H\}$NMR spectrum of plumbagin is absent and it is replaced by a line at δ139.85 with reduced intensity due to substitution and thus a dimeric linkage between 3- and 3′-positions of both the plumbagin moieties is obvious (Table 1).

3,8′-Biplumbagin (**3**), $C_{22}H_{14}O_6$, has been obtained as one of the products of reaction between plumbagin (**6**) and its hydroquinone (UV, IR, ^1H NMR and MS of **3** and of its dimethyl ether [6]). Its $^{13}C\{^1H\}$NMR spectrum also showed 22 lines confirming the unsymmetric linkage between the two plumbagin moieties. A comparison of the chemical shifts and relative intensities of the eleven lines of plumbagin and the 22 lines of 3,8′-biplumbagin revealed that a pair of lines assignable to C-3 and C-8 of plumbagin (C-3, δ135.67; C-8, δ118.71) in the $^{13}C\{^1H\}$NMR spectrum of the latter are displaced downfield to δ142.54 and 126.55, respectively, with a reduced intensity due to substitution and the remaining lines are closely spaced doublets near the corresponding chemical shifts of plumbagin with the exception of the lines at δ119.20 (C-8) and 137.86 (C-3′) (Table 1). Thus, a 3,8′-linkage between the two plumbagin moieties is confirmed. ^{13}C chemical shift assignments of 7-methyljuglone methyl ether (**7**) and plumbagin methyl ether (**8**) have also been made in comparison with juglone methyl ether [9], 7-methyljuglone (**5**) and plumbagin (**6**) (Table 1).

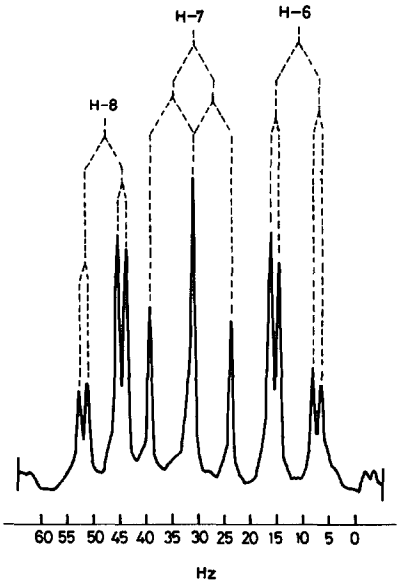


Fig. 4. ^1H NMR spectrum of plumbagin ($CDCl_3 + C_6D_6$ after D_2O exchange, H-6, H-7 and H-8 region).

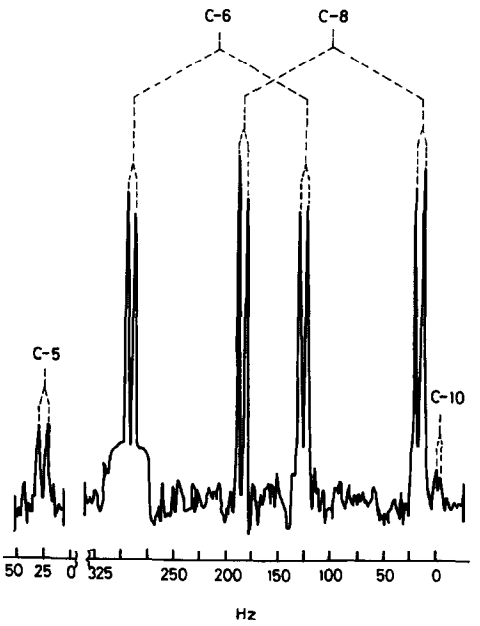


Fig. 5. ^{13}C NMR spectrum of plumbagin ($CDCl_3 + C_6D_6$ after D_2O exchange, C-5, C-6 and C-8 regions).

EXPERIMENTAL

The $^{13}C\{^1H\}$NMR spectra of **1–5** and **8** were recorded in $CDCl_3$ with TMS as internal standard at RT in the Fourier transform mode on a Brüker WH 270 spectrometer operating at 67.89 MHz (pulse width: 15 μsec, Repetition time: 3 sec, data points: 8k, quadrature detection) controlled by Nicolet BNC-12 (20 bits work, 16k memory). The ^1H coupled ^{13}C NMR spectra of **6** and **7** (pulse width: 9 μsec, Repetition time: 5 sec) were recorded in $CDCl_3$ at room temp. with TMS as int. standard on a Jeol Fx 90Q FT NMR spectrometer (data points 8k, quadrature detection) controlled by a J.E.C. 980B computer.

Isodiospyrin (**1**) [1, 3] and rotundiquinone (**2**) [4, 5] were isolated from the root bark and roots (stripped of the bark) respectively of *Diospyros chloroxylon* Roxb. Their identities were established by comparison of their physical properties and spectral data with those reported earlier for these compounds. Compound **1** was accompanied by diosindigo A [13], 7-methyljuglone, 2-methylnaphthazarin [14], diospyrin and 3,6-dihydroxy-4,5-dimethoxynaphthalene [1]. Compound **2** was found to co-occur with 7-methyljuglone, mamegakinone, diospyrin and 2′,3′-epoxydiospyrin [8].

Identification of plumbagin (**6**), 3,3′-biplumbagin (**4**) [7] and 3,8′-biplumbagin (**2**) [6] used in the ^{13}C NMR study has been described earlier. 7-Methyljuglone methyl ether (**7**) and

plumbagin methyl ether (**8**) were prepared by methylation of **5** and **6**, respectively, using MeI and Ag_2O at room temp. Their identities were established by ^{1}H NMR and MS.

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