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# SOLVENT EFFECTS IN NMR SPECTROSCOPY—VI[1]

## CHEMICAL SHIFTS INDUCED BY BENZENE IN QUINONES

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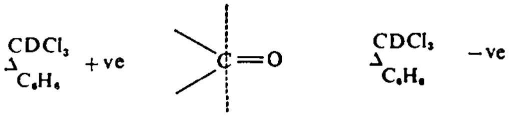
**Abstract**—Solvent shifts ($\Delta^{CDCl_3}_{C_6H_6} = \delta_{CDCl_3} - \delta_{C_6H_6}$ ppm) are reported for a number of methyl- and methoxy-substituted quinones. In the anthraquinones examined, a C-1 methyl group undergoes only a small upfield shift in benzene (0·06–0·17 ppm), whereas a C-2 or C-3 methyl group suffers a much larger upfield shift (0·52–0·60 ppm). These effects are only slightly modified by the presence of adjacent methyl groups. In contrast, the shifts observed for "isolated" C-1 or C-2 methoxy substituents in anthraquinones may be greatly modified in 1,2-dimethoxy or 1,3-dimethoxy-derivatives, reflecting the greater electronic interaction between the polar substituents. Solvent shifts support the previously assigned differences in stereochemistry and conformation between isoleutherin, eleutherin and a related system derived from the aphins.

It has recently been shown[2–5] for a large number of ketones, that the proton chemical shifts induced by benzene relative to deuterochloroform ($\Delta^{CDCl_3}_{C_6H_6} = \delta_{CDCl_3} - \delta_{C_6H_6}$) are positive for protons behind an isolated carbonyl group and negative for protons in front of an isolated carbonyl group (see I). We wished to extend our studies to other classes of conformationally rigid compounds containing carbonyl groups and the present paper records results for a number of quinones.



I

In Table 1, the deuterochloroform and benzene solution chemical shifts of the methyl resonances in some substituted benzoquinones (II–V), naphthaquinones (VI–IX) and anthraquinones (X–XIII) are summarized, together with the $\Delta^{CDCl_3}_{C_6H_6}$ values.

Considering first the results for the anthraquinones X–XIII, it is evident that a *peri*-methyl group (at C-1) only undergoes a small upfield shift (0·06–0·17 ppm) in benzene in these compounds, whereas a C-2 or C-3 methyl group suffers a much larger upfield shift (0·52–0·60 ppm). This difference in behaviour is understandable in terms of the shifts associated with isolated carbonyl functions,[2–5] since a C-1 methyl group will be influenced by a *peri*-carbonyl group which can exert a negative

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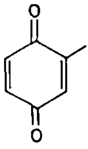
[1] Part V, D. H. Williams and D. A. Wilson, *J. Chem. Soc.* in press.

[2] J. D. Connelly and R. McCrindle, *Chem. & Ind.* 379 (1965).

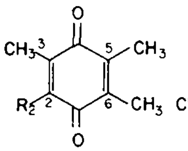
[3] D. H. Williams and N. S. Bhacca, *Tetrahedron* **21**, 1641 (1965).

[4] D. H. Williams and N. S. Bhacca, *Tetrahedron* **21**, 2021 (1965).

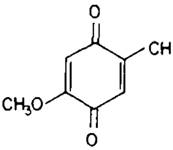
[5] D. H. Williams, *Tetrahedron Letters* 2305 (1965).



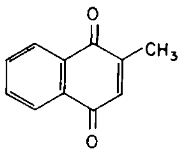
II



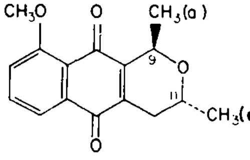
III, R = CH3
IV, R = Br



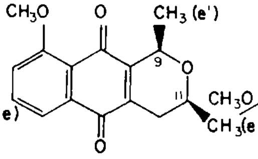
V



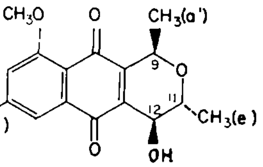
VI



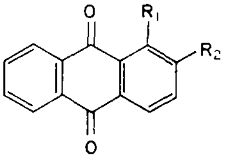
VII



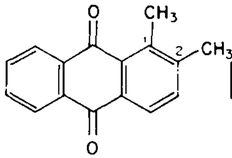
VIII



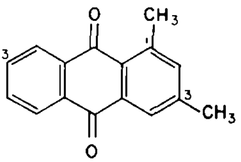
IX



X, R1 = CH3, R2 = H
XI, R1 = H, R2 = CH3



XII



XIII

Table 1. Chemical shifts ($\delta_{CDCl_3}$, $\delta_{C_6H_6}$) and solvent shifts ($\Delta^{CDCl_3}_{C_6H_6} = \delta_{CDCl_3} - \delta_{C_6H_6}$) of methyl resonances in some substituted quinones

| Compound (Methyl Resonance) | $\delta_{CDCl_3}$ | $\delta_{C_6H_6}$ | $\Delta^{CDCl_3}_{C_6H_6}$ | Compound (Methyl Resonance) | $\delta_{CDCl_3}$ | $\delta_{C_6H_6}$ | $\Delta^{CDCl_3}_{C_6H_6}$ |
|---|---|---|---|---|---|---|---|
| II | 2·08 | 1·59 | +0·49 | IX (9) | 1·58 | 1·50 | +0·08 |
| III | 2·00 | 1·71 | +0·29 | IX (11) | 1·38 | 1·43 | −0·05 |
| IV (3) | 2·21 | 1·92 | +0·29 | X | 2·83 | 2·70 | +0·13 |
| IV (5, 6) | 2·07 | 1·59 | +0·48 | XI | 2·52 | 1·92 | +0·60 |
| V | 2·05 | 1·63 | +0·42 | XII (1) | 2·75 | 2·58 | +0·17 |
| VI | 2·19 | 1·68 | +0·51 | XII (2) | 2·45 | 1·88 | +0·57 |
| VII (9) | 1·54 | 1·45 | +0·09 | XIII (1) | 2·78 | 2·72 | +0·06 |
| VII (11) | 1·35 | 1·11 | +0·24 | XIII (3) | 2·45 | 1·93 | +0·52 |
| VIII (9) | 1·52 | 1·61 | −0·09 | | | | |
| VIII (11) | 1·34 | 1·10 | +0·24 | | | | |

influence on $\Delta^{CDCl_3}_{C_6H_6}$. The methyl groups in II–VI, which are directly substituted on the quinonoid ring, all have intermediate positive $\Delta^{CDCl_3}_{C_6H_6}$ values (0·29–0·51 ppm), the magnitude of which varies appreciably with the nature of additional substituents.

The stereochemical[6,7] and conformational[8] features of isoeleutherin (VII), eleutherin (VIII) and the naphthaquinone dimethylether (IX) are known from previous studies. The methyl resonances of VII, VIII and IX have previously been specifically

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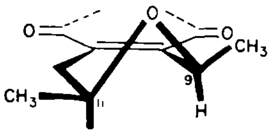
[6] H. Schmid and A. Eböthner, *Helv. Chim. Acta* **34**, 561 and 1041 (1951).

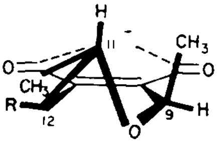
[7] W. Eisenhuth and H. Schmid, *Helv. Chim. Acta* **41**, 2021 (1958).

[8] D. W. Cameron, D. G. I. Kingston, N. Sheppard and Lord Todd, *J. Chem. Soc.* 98 (1964).

assigned to the C-9 or C-11 methyl groups in chloroform (or $CDCl_3$)[8] and the shifts in benzene solution are unambiguously available from the different coupling constants for the C-9 and C-11 methyl doublets of VII and IX. The benzene shifts for the methyl groups of VIII can be assigned since the $\Delta^{CDCl_3}_{C_6H_6}$ values for the C-11 methyl groups of VII and VIII can be predicted to be similar (the C-11 methyl groups of VII and VIII are both equatorial and in almost identical polar environments). It can be seen (Table 1) that the C-9 pseudo-axial methyl groups of VII and IX have small positive $\Delta^{CDCl_3}_{C_6H_6}$ values (+0·09 and +0·08 ppm, respectively), whereas the C-9 pseudoequatorial methyl group of VIII has a negative $\Delta^{CDCl_3}_{C_6H_6}$ value (−0·09 ppm). Dreiding models of eleutherin (see VIIIa) indicate that the pseudoequatorial C-9 methyl group is held only slightly above the plane of the *peri*-carbonyl function, whereas the corresponding models of VII and IX (see VIIa and IXa) contain the pseudo-axial C-9 methyl group much further removed from the influence of the *peri*-carbonyl function. Thus it is apparent that the solvent shifts follow the trends anticipated from the studies on compounds containing isolated keto-groups.[2-5] It should be noted that the solvent shifts of the C-11 methyl groups of VII and VIII are, as predicted, the same (0·24 ppm), but the value is changed in sign (to −0·05 ppm) by the C-12 hydroxyl group of IX.

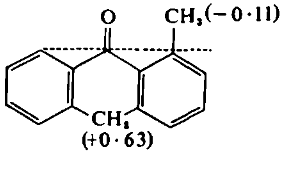


VIII a

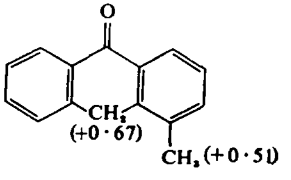


VII a, R=H
IX a, R=OH

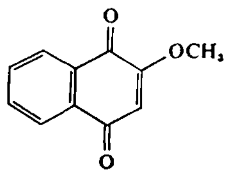
The utility of solvent shifts in determining the composition of a reduction product from an anthraquinone may be illustrated by reference to the reduction of 1-methylanthraquinone (X) by stannous chloride and concentrated hydrochloric acid.[9] The resulting mixture contained two anthrones in the ratio 4:6. The minor component gave resonances at $\delta$ = 4·27 (—$CH_2$—) and $\delta$ = 2·83 (—$CH_3$) in deuterochloroform and $\delta$ = 3·64 (—$CH_2$—) and $\delta$ = 2·94 (—$CH_3$) in benzene; the solvent shifts define this product as 1-methylanthrone (see XIV for the $\Delta^{CDCl_3}_{C_6H_6}$ values) and similarly the major component from chemical and solvent shift considerations [$\delta_{CDCl_3}$ = 4·09 (—$CH_2$—) and $\delta_{CDCl_3}$ = 2·39 (—$CH_3$); $\delta_{C_6H_6}$ = 3·42 (—$CH_2$—) and $\delta_{C_6H_6}$ = 1·88 (—$CH_3$)] is 4-methylanthrone (XV).



XIV



XV



XVI

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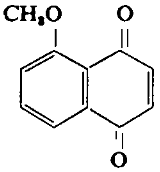
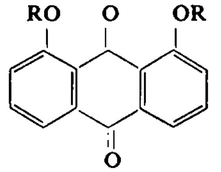
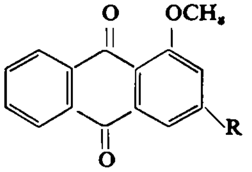
[9] D. W. Cameron, R. I. T. Cromartie, D. G. I. Kingston and G. B. V. Subramanian, *J. Chem. Soc.* 4565 (1965).



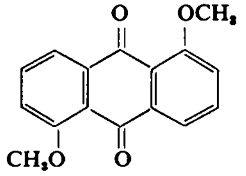
XVII



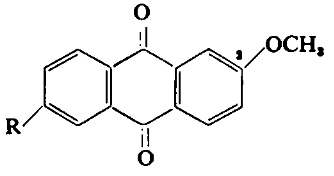
XVIII, R = $CH_2CH_3$
XIX, R = $CH_3$



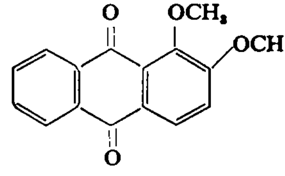
XX, R = H
XXI, R = $OCH_3$



XXII



XXIII, R = H
XXIV, R = $OCH_3$



XXV

Solvent shifts have also been determined for the methoxyl resonances of a number of methoxynaphthaquinones (XVI–XVII) and methoxyanthraquinones (XIX–XXV) and the data are summarized in Table 2, together with data for the methoxyl resonances of the previously discussed compounds V, VII, VIII, IX and the diethyl ether XVIII.

TABLE 2. CHEMICAL SHIFTS ($\delta_{CDCl_3}$, $\delta_{C_6H_6}$) AND SOLVENT SHIFTS ($\Delta^{CDCl_3}_{C_6H_6} = \delta_{CDCl_3} - \delta_{C_6H_6}$) OF METHOXYL RESONANCES IN SOME SUBSTITUTED QUINONES

| Compound (Methoxyl Resonance) | $\delta_{CDCl_3}$ | $\delta_{C_6H_6}$ | $\Delta^{CDCl_3}_{C_6H_6}$ | Compound (Methoxyl Resonance) | $\delta_{CDCl_3}$ | $\delta_{C_6H_6}$ | $\Delta^{CDCl_3}_{C_6H_6}$ |
|---|---|---|---|---|---|---|---|
| V | 3·81 | 2·86 | +0·95 | XX | 4·00 | 3·34 | +0·66 |
| VII | 3·99 | 3·32 | +0·67 | XXI (1 or 3) | 4·00<br>and 3·95 | 3·33<br>and 3·24 | +6·67,<br>+0·71<br>or +0·62,<br>+0·76 |
| VIII | 3·97 | 3·28 | +0·69 | | | | |
| IX (6, 8) | 3·96 | 3·24 | +0·72 | | | | |
| XVI | 3·92 | 2·88 | +1·04 | XXII | 4·02 | 3·34 | +0·68 |
| XVII | 4·00 | 3·26 | +0·74 | XXIII | 3·97 | 3·16 | +0·81 |
| XVIII(—$CH_2$—) | 4·22 | 3·64 | +0·58 | XXIV | 4·00 | 3·20 | +0·80 |
| XVIII(—$CH_3$) | 1·53 | 1·18 | +0·35 | XXV (1) | 4·01 | 3·90 | +0·11 |
| XIX | 4·00 | 3·35 | +0·65 | XXV (2) | 4·01 | 3·10 | +0·91 |

It is evident from the data in Table 2 that all the methoxyl resonances undergo upfield shifts in benzene solution and that the shifts are as large as approximately 1 ppm in V and XVI, which contain methoxyl groups directly attached to the quinonoid ring. The results are consistent with the observation[10] that aromatic methoxyl resonances usually suffer high-field shifts in benzene, irrespective of the presence of neighbouring carbonyl groups. The $\Delta^{CDCl_3}_{C_6H_6}$ values for *peri*-methoxyl groups are approximately the same (0·67, 0·69, 0·74, 0·65, 0·66, 0·68 ppm) in VII, VIII, XVII, XIX, XX and XXII, as might be expected since all those methoxyl groups have

[10] Unpublished results obtained at the University Chemical Laboratory, Cambridge.

similar steric and polar environments. Likewise, the C-2 methoxyl groups of XXIII and XXIV have very similar shifts (0·81 and 0·80 ppm respectively). However in the naphthaquinone dimethylether IX, containing *meta*-methoxyl functions, the methoxyl shifts are identical (0·72 ppm), and do not correspond with those obtained above for isolated methoxyl groups; the modified solvent shifts probably reflect the electronic interaction which can take place between the methoxyl substituents. Similarly, the methoxyl groups of 1,3-dimethoxyanthraquinone (XXI) cannot be securely differentiated. The methoxyl resonances of XXV have been specifically assigned in both solvents from the spectra of 1,2-dimethoxyanthraquinone partially deuterated in the C-1 methoxyl group; the deuterated material was prepared by methylation of 1-hydroxy-3-methoxyanthraquinone with diazomethane in the presence of deuterium oxide.[11] The difference between the solvent shifts for the C-1 and C- 2 methoxyl groups of XXV is very large (0·11 ppm vs. 0·91 ppm) and the shifts bear no relation to those induced by the isolated functions since the groups are now capable of interacting by both through-bonds and through-space mechanisms. This behaviour should be contrasted with that of adjacent methyl groups (in XII) where the mutual electronic interactions are insufficient to modify the characteristic shift values to any extent.

## EXPERIMENTAL

All spectra were determined using a Perkin–Elmer 60 Mc spectrometer; tetramethylsilane was employed as an internal reference standard and the temperature of the probe was 33·3°.

*Acknowledgements*—The authors wish to thank I.C.I. Ltd., Dyestuffs Division for samples of 2-hydroxy-, 2,6-dihydroxy- and 1,3-dihydroxy-anthraquinones, Professor H. Schmid for samples of eleutherin and isoeleutherin, and record their gratitude to Miss Pat Grist for skilful technical assistance in obtaining some of the spectra. One of us (P. E. S.) is grateful to Ciba Ltd. for a research studentship.

[11] K. J. Van Der Merwe, P. S. Steyn and S. H. Eggers, *Tetrahedron Letters* 3923 (1964).