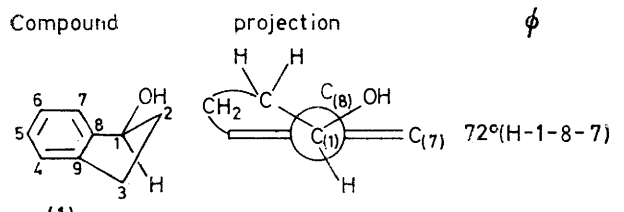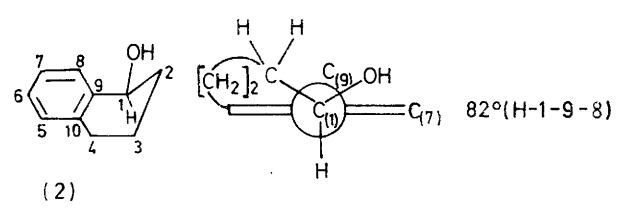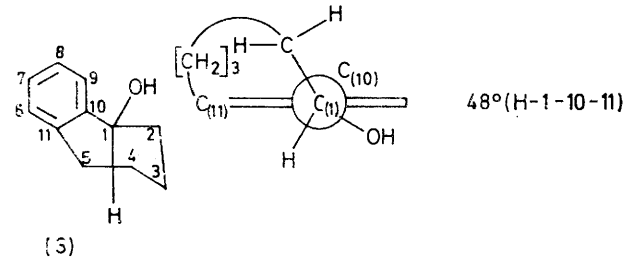# Applications of High Potential Quinones.   Part IX.[1]   A Stereoelectronic Effect in the Rates of Quinone Dehydrogenation of Benzocycloalkenols

By **David R. Brown** and **Alan B. Turner**,* Chemistry Department, University of Aberdeen, Aberdeen AB9 2UE

The reactivity sequence tetralin-1-ol > indan-1-ol ≫ tetrahydrobenzocyclohepten-1-ol is observed in the dehydrogenation of these benzyl alcohols to the corresponding ketones by dichlorodicyanobenzoquinone. There is a linear relationship between the angle of inclination of the tertiary benzylic C–H bond to the plane of the aromatic ring and log k, reflecting the degree of σ–π overlap in the transition state for the oxidation. Factors underlying the preferred pseudo-axial conformation of the benzylic hydroxy-groups in these benzocycloalkenols are discussed.

THE ease of oxidation of certain aromatic steroids by 2,3-dichloro-5,6-dicyanobenzoquinone (DDQ) has been ascribed to the reactivity of a tertiary benzylic C–H bond orthogonal to the plane of the adjacent aromatic ring.[2] In order to further evaluate the importance of this type of stereoelectronic effect, we have determined the rates of dehydrogenation of a series of benzocycloalkenols possessing a tertiary benzylic carbon atom. Benzyl alcohols are convenient substrates for this type of rate study since they are readily oxidised by DDQ under mild conditions,[3] and the resulting ketones require much more vigorous conditions for further dehydrogenation.

TABLE 1
Dihedral angles

In the alcohols chosen for study, indan-1-ol (1), tetralin-1-ol (2), and tetrahydrobenzocyclohepten-1-ol (3), progressive variation in ring size leads to alteration in the angle of inclination of the tertiary benzylic C–H bond to

the plane of the aromatic ring.   The relevant angles (ϕ) in these benzocycloalkenols, as measured from Dreiding models, are shown in Table 1.

Rates of reaction of DDQ with the three cycloalkenols, determined under pseudo first-order conditions, are collected in Table 2.   The second-order rate constants

TABLE 2
First- and second-order rate constants for the reaction of benzocycloalkenols with DDQ at 35.0°

Alcohol	[alcohol]/ M	10^4[DDQ]/ M	$10^4 k_1/s^{-1}$	$10^4 k_2/$ 1 mol^{-1} s^{-1}
	0.0662		0.419	6.32
(1)	0.132	6.25	1.24	9.38
	0.332		6.21	18.7
	0.000			3.21 *
	0.0133		0.352	26.5
	0.0332		1.03	31.3
(2)	0.0498	5.95	1.76	35.3
	0.0664		2.56	38.5
	0.330		33.2	101
	0.462		59.8	129
	0.000			23.5 *
	0.200		0.053	0.263
(3)	0.280	7.10	0.101	0.36
	0.360		0.162	0.45
	0.000			0.031 *

* Extrapolated.

are found to increase as the solvent (benzene) becomes more polar at higher benzocycloalkenol concentration for all three alcohols.   This indicates that the transition state is more polar than the reactants, in agreement with a mechanism involving abstraction of hydride ion in the rate-determining step (Scheme).[4]
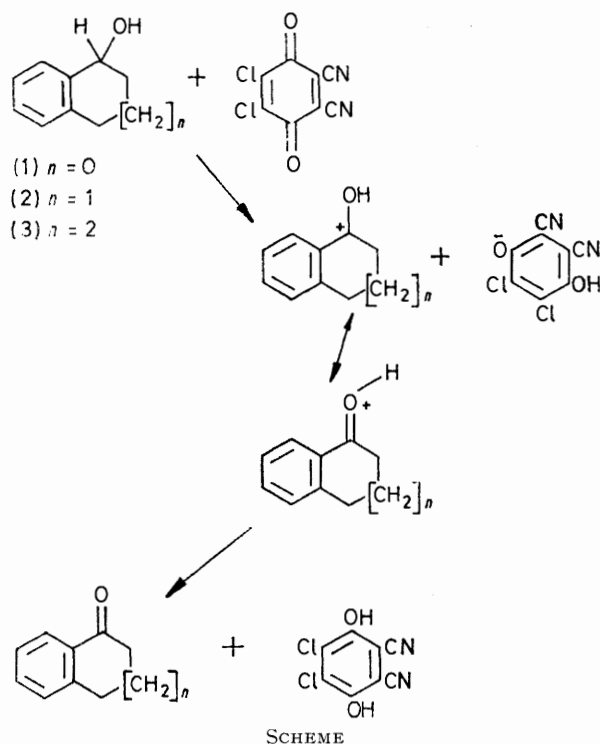
The observed differences (Table 3) in the rates of dehydrogenation of the benzocycloalkenols, particularly the low reactivity of the benzocycloheptenol (3), can be explained in terms of the dominant influence of the stereoelectronic effect referred to above.   As the axial benzylic C–H bond approaches an angle of 90° to the plane of the aromatic ring, the rate of dehydrogenation increases, owing to the progressive improvement in overlap of the developing carbonium ion with the π-system (optimal stabilisation being reached when the original C–H bond is orthogonal to the aromatic ring).

The relationship between ϕ and log k is approximately linear for the three compounds studied.   This relationship is also consistent with the predominance of the stereoelectronic effect over other factors such as steric

[1] Part VIII, J. M. Singh and A. B. Turner, *J.C.S. Perkin I*, 1972, 2294.

[2] W. Brown and A. B. Turner, *J. Chem. Soc. (C)*, 1971, 2566; cf. R. Mechoulam, B. Yagnitinsky, and Y. Gaoni, *J. Amer. Chem. Soc.*, 1968, **90**, 2418.

[3] H.-D. Becker and E. Alder, *Acta Chem. Scand.*, 1961, **15**, 218.

[4] E. A. Braude, L. M. Jackman, and R. P. Linstead, *J. Chem. Soc.*, 1954, 3548, 3564.

effects [5] involved in the approach of the quinone to the reaction site, and changes in torsional and angle strain due to alteration in geometry from tetrahedral to trigonal

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during the course of the reaction. (Relief of torsional strain due to this change in geometry is in fact much greater for five- and seven- than for six-membered rings.[6])

TABLE 3

Reaction rates and dihedral angles

Substrate	ϕ (°)	$\cos(90 - \phi)°$	$\log(100k)$
(1)	72	0.95	2.5
(2)	82	0.99	3.4
(3)	48	0.74	0.5

Effects of ring size upon rates of dehydrogenation of similar hydroaromatic compounds by high-potential quinones have been noted previously.[7] Since the substrate hydrocarbons used were capable of further (and probably faster) dehydrogenation beyond the styrene stage, the qualitative differences observed were difficult to evaluate. The advantage of the benzyl alcohols used in the present study is that they undergo only a single dehydrogenation, the product ketones being inert to DDQ under the conditions employed.

We have assumed in the above discussion that the Curtin–Hammett principle [8] applies, with the less stable

benzocycloalkenol conformers, having equatorial hydroxy-groups, reacting preferentially with DDQ, since Burstein and Ringold noted that equatorial allyl alcohols in the steroid series are oxidised 6.5 times faster than their axial epimers by DDQ.[9] A recent paper [10] assumes that the preferred conformation of tetralin-1-ol has a pseudo-equatorial hydroxy-group (4), although i.r. spectroscopic measurements [11] indicate a pseudo-axial hydroxy-group (5).
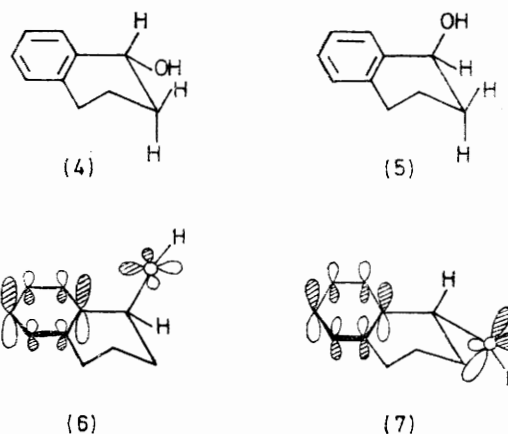
N.m.r. data for the benzylic $CH(OH)$ proton is given in Table 4 for the three benzocycloalkenols. Analogous

TABLE 4

N.m.r. data: $CH(OH)$ protons; 30°; CDCl$_3$ solution

Compound	δ	Unresolved multiplet width at half height (Hz)	Resolved coupling constants (Hz)
(2)	3.9	12	
(1)	4.3		6,6 (t)
(3)	4.9	12	

n.m.r. data have been reported [12] for the benzylic proton of 3-methyltetralin-1-ols: J 3 Hz (t) for the epimer with pseudo-axial hydroxy-group; J 6,11 Hz (dd) for the epimer with pseudo-equatorial hydroxy-group. Thus the narrow multiplet in the spectrum of tetralinol itself is consistent with the presence of a greater proportion of the conformer with the pseudo-axial hydroxy-group at room temperature.

The data for tetrahydrobenzocyclohepten-1-ol in Table 3 are also consistent with the presence of a greater proportion of the conformer having a pseudo-axial hydroxy-group,[13,14] but in the case of indanol it is

[5] J. Iwamura and N. Hirao, *Tetrahedron Letters*, 1973, 2447.
[6] H. C. Brown and M. Borkowski, *J. Amer. Chem. Soc.*, 1952, **84**, 1894; J. D. Roberts and V. C. Chambers, *ibid.*, 1951, **73**, 5034.
[7] L. M. Jackman, *Adv. Org. Chem.*, 1960, **2**, 329; *cf.* also N. L. Allinger and E. S. Jones, *J. Org. Chem.*, 1962, **27**, 70.
[8] *Cf.* J. McKenna, 'Conformational Analysis of Organic Compounds,' R.I.C. Lecture Series, 1966, No. 1, pp. 8—11; L. P. Hammett, 'Physical Organic Chemistry,' McGraw-Hill, New York, 2nd edn., 1970, pp. 119—120.

[9] S. H. Burstein and H. J. Ringold, *J. Amer. Chem. Soc.*, 1964, **86**, 4952.
[10] T. B. Patrick and P. H. Patrick, *J. Amer. Chem. Soc.*, 1973, **95**, 5192.
[11] N. Mori, M. Yoshifuji, Y. Asube, and Y. Tsuzuki, *Bull. Chem. Soc. Japan*, 1971, **44**, 1137.
[12] S. Mitsui, A. Kasahara, and K. Hanaya, *Bull. Chem. Soc. Japan*, 1968, **41**, 2526.
[13] M. St. Jaques and C. Vaziri, *Org. Magnetic Resonance*, 1972, **4**, 77.
[14] G. L. Buchanan and J. M. McCrae, *Tetrahedron*, 1967, **23**, 279.

difficult to decide which orientation is favoured since the degree of vicinal coupling in the five-membered rings of the two conformers are too similar.

The preferred conformation of cyclohex-2-enol, a very similar conformational system to tetralinol, is now thought to have a pseudo-axial hydroxy-group,[15] although there is some evidence to the contrary.[16] The pseudo-axial orientation is also favoured for the allylic acetoxy-group in the derived acetate. The preference for this orientation of the allylic substituent is ascribed to allylic strain,[15] although this type of strain is probably different in the benzocycloalkenol series, where the hydrogen on the adjacent vinylic carbon atom in cyclo-hexenol is replaced by the sp^2-carbon of the aromatic ring.[17] The increased relief of allylic strain may also be a factor in the relatively high reactivity of axial allyl alcohols[9] even though the equatorial allylic hydrogen and the π-bond are nearly orthogonal. It is also possible that the pseudo-axial hydroxy-group is stabilised by overlap of a lone pair with the aromatic LUMO (6).[18] Such overlap is not possible for a pseudo-equatorial hydroxy-group (7).

EXPERIMENTAL

Materials.—The alcohols were prepared from the ketones (Koch–Light pure grade) by lithium aluminium hydride reduction and purified by distillation (indanol, tetralinol) or recrystallisation from light petroleum (b.p. 60—80°) (tetrahydrobenzocyclohepten-1-ol). The alcohols all had satisfactory m.p.s and i.r. and n.m.r. spectra. DDQ was Koch–Light pure grade, and was recrystallised from benzene. Benzene was analytical reagent grade, stored over molecular sieves.

[15] Y. Senda and S. Imaizumi, *Tetrahedron*, 1974, **30**, 3813.
[16] R. J. Ferrier and N. Prasad, *J. Chem. Soc. (C)*, 1967, 1417.

Product Study.—The alcohols (20 mg) and DDQ (1 mol. equiv.) in benzene (3 ml) were reacted at room temperature (indanol and tetralinol) or heated under reflux under nitrogen cover (tetrahydrobenzocyclohepten-1-ol) for 7 h. The dichlorodicyanohydroquinone precipitate was centri-fuged and the benzene solution evaporated giving virtually quantitative yields of the ketones having n.m.r. spectra identical to those of the authentic materials.

Kinetic Determinations.—Dehydrogenations were carried out by established procedures[9] using a Unicam SP 800 spectrophotometer. Preliminary runs at a variety of concentrations established a first-order dependence of the rate on DDQ concentration. Dividing the first-order rate constants by benzocycloalkenol concentration gave the second-order rate constants which were extrapolated to zero benzocycloalkenol concentration. All slopes and inter-cepts were determined by least squares analysis. Good straight lines were obtained from the first-order integrated rate equation to *ca.* 2 half-lives where occasional deviations caused by hydroquinone crystallisation occurred. A typical set of points for tetralinol (6.64 × 10^{-2}M) and DDQ (5.95 × 10^{-4}M) is shown in Table 5.

TABLE 5

Readings of optical density during the reaction of tetralinol and DDQ

Time (min)	O.D.	Time (min)	O.D.
1.15	1.645	28.1	1.08
2.85	1.59	35.3	0.965
6.5	1.48	44.4	0.83
10.1	1.40	51.55	0.735
13.65	1.32	66.0	0.58
20.9	1.195	85.9	0.44

[17] N. L. Allinger and J. T. Sprague, *J. Amer. Chem. Soc.*, 1972, **94**, 5734.
[18] *Cf.* O. Eisenstein, N. T. Anh, Y. Jean, A. Devaquet, J. Cantacuzène, and L. Salem, *Tetrahedron*, 1974, **30**, 1717.