Synthetic 1,2-Quinones: Synthesis and Thermal Reactions

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In recent years major advances have been made in the study of 1,2-quinones. A few specific reviews are available* but no single article has been published about the broad spectrum of quinone chemistry. The present Review, covering the years 1946—1967, does not include a discussion of naturally occurring 1,2-quinones but an attempt has been made to describe the most important advances in the chemistry of the synthetic quinones.

1 Synthesis

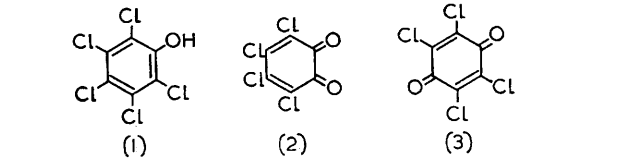
Two main approaches are used to synthesise 1,2-quinones, either by the introduction of oxygen into a suitably substituted phenol, or by the oxidation of catechol derivatives.[1]

A. Introduction of Oxygen.—The low-temperature oxidation of pentachlorophenol (1) to the corresponding 1,2-quinone (2) is typical[2] of the use of nitric acid in phenol oxidation. The product (2) is subject to contamination since at slightly higher temperatures the 1,4-quinone (3) is formed. Electrophilic attack *ortho* to the hydroxyl substituent gives rise to the intermediate chloronitro-ketone which thermally rearranges eliminating nitrosyl chloride[3] (Scheme 1).

Similar phenol oxidations have been studied by Bell and Buck[4] who also studied the conversion of alkyl ethers of 1-halogeno-2-naphthols into 1,2-naphthaquinones.[3,5] The product results from nitration at position 1 with concomitant dealkylation to produce the intermediate (4), isolable in some cases, which rearranges with elimination of nitrosyl chloride to give the quinone (5). In certain cases Wilson[5] and Bell[6] found examples of bromine migration, *e.g.*, in the

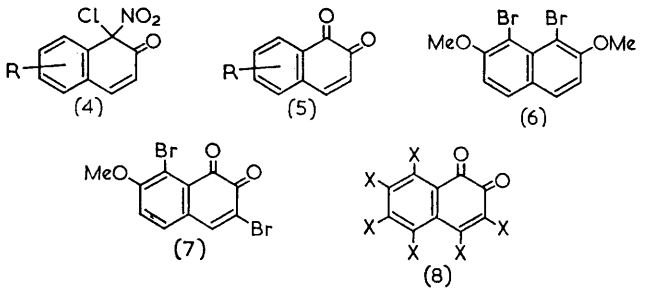
* Reviews of various aspects of 1,2-quinone chemistry are as follows: Synthesis, J. Cason, *Org. Reactions*, 1948, **4**, 305; Nascent Quinones in Synthesis, H. W. Wanzlich, *Angew. Chem. Internat. Edn.*, 1964, **3**, 401; Cycloaddition Reactions, G. Pfundt and G. O. Schenck in '1,4-Cycloaddition Reactions', ed. J. Hamer, Academic Press, New York, 1967; Photochemistry, J. M. Bruce, *Quart. Rev.*, 1967, **21**, 405; Diels–Alder Reactions, L. W. Butz and A. W. Rytina, *Org. Reactions*, 1949, **5**, 136; A. Onischenko, 'Diene Reactions', Oldbourne Press, 1965.

[1] J. Cason, *Org. Reactions*, 1948, **4**, 305.
[2] A. L. Rocklin, U.S. Pat. 2920082, 1960 (*Chem. Abs.*, 1960, **54**, 10959i); W.-H. Chang, *J. Org. Chem.*, 1962, **27**, 2921.
[3] F. Bell and K. R. Buck, *J. Chem. Soc.*, 1963, 6069.
[4] F. Bell and R. D. Wilson, *J. Chem. Soc.*, 1956, 2340.
[5] R. D. Wilson, *Tetrahedron*, 1958, **3**, 236; 1960, **11**, 256.
[6] F. Bell, *J. Chem. Soc.*, 1961, 5293.



Scheme 1

oxidation of (6)—(7). In a like manner hexafluoro-[7] and hexachloro-1,2-naphthaquinones[8] (8; X = Cl or F) can be prepared by the oxidation of the corresponding heptahalogeno-2-naphthols. (The analogous tetrafluoro-1,2-benzoquinone has not been prepared in this manner and indeed is only referred to once in the literature as being prepared by oxidation of catechol with H_2O_2–HF.*)

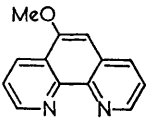


Similar oxidations have been used in the preparation of 1,10-phenanthroline-5,6-quinone (10) by the oxidation of (9).[9]

Lead tetra-acetate has also been used in the conversion of 1,2-dihydro-6-hydroxyquinoline (11) into the quinone (12).[10] Similar results can be obtained by the use of chromium trioxide in glacial acetic acid. Lead tetra-acetate has been used by Wessely and his co-workers[11] for the synthesis of 2,2-diacetoxycyclohexa-3,5-dienone (13) but this is beyond the scope of this Review.

* P. P. T. Sah and S. A. Peoples, *Arzneimittel-Forsch.*, 1961, **11**, 27 (*Chem. Abs.*, 1962, **57**, 16466g), report that tetrafluoro-1,2-benzoquinone is unstable melting at 125—155°. Since this Review was completed the synthesis of tetrafluoro-1,2-benzoquinone, m.p. 55—62°, has been reported (V. D. Shteingarts and A. C. Buduck, *Chem. Abs.*, 1968, **68**, 114218m).

[7] G. C. Yakobson, V. D. Shteingarts, and N. V. Vorozhtsov, *Chem. Abs.*, 1965, **62**, 9078b.
[8] J. G. E. Feynes, *J. Chem. Soc.*, 1968, 5.
[9] J. Druey and P. Schmid, *Helv. Chim. Acta*, 1950, **33**, 1080.
[10] R. R. Holmes, J. Conrady, J. Guthrie, and R. McKay, *J. Amer. Chem. Soc.*, 1954, **76**, 2400.
[11] G. Billek, J. Swoboda, and F. Wessely, *Tetrahedron*, 1962, **18**, 909.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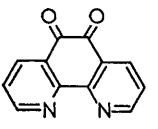
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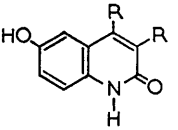
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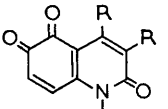
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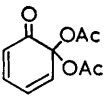
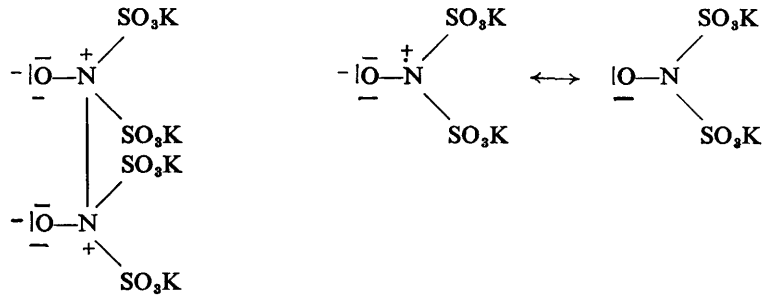
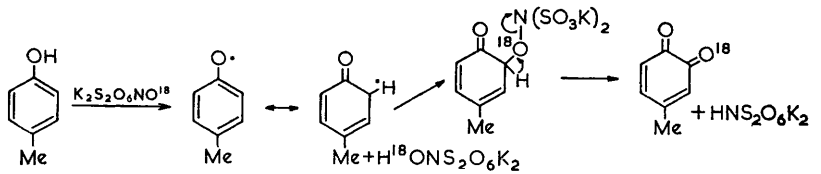

(13)

Potassium nitrosodisulphonate, Fremy's salt, has been developed as a versatile oxidant of phenols. The salt, described as an unstable orange dimer (14), dissociates into a more stable purple radical (15) on solution in aqueous phosphate buffer (pH 8—11). Its usefulness for hydroxylation of phenols has been reviewed.[12] Quinone formation, by use of the salt, has been shown to be a two-step process involving two moles of oxidant per mole of phenol. Labelling studies[13] have shown that the incorporated oxygen comes from the salt and not the solvent (Scheme 2). For the synthesis of 1,2-quinones it is essential that a *para*-blocked phenol be used as shown.



Earlier studies on the mechanism of the oxidation had shown that a three-step

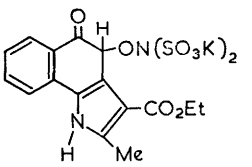


Scheme 2

[12] J. D. Loudon, *Progr. Org. Chem.*, 1961, **5**, 46.
[13] H. J. Teuber and H. H. Dietz, *Angew. Chem. Internat. Edn.*, 1965, **4**, 871.

process was involved,[14] as suggested in Scheme 2, and intermediate (16) was isolated from the oxidation of (16a).[14b]

The scope of the reaction is vast,[15] a large number of *p*-substituted phenols having been oxidised to the corresponding 1,2-quinones.[16–18] Unsaturated



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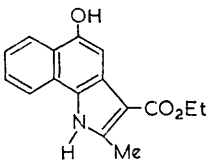

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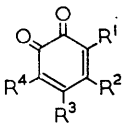
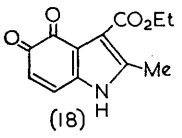


(17)

sidechains are unaffected by the procedure (17; R^1 = OMe, R^2 = R^4 = H, R^3 = allyl)[16] and (17, R^1 = R^3 = Me, R^2 = H, R^4 = C≡CH)[19] being readily obtained from the corresponding phenols. 2-Naphthols[20] and 4-substituted 1-naphthols,[21] studied as models for the dehydrase enzyme system, give the 1,2-naphthaquinones.

Heterocyclic compounds can be oxidised similarly. Thus 3-ethoxycarbonyl-5-hydroxy-2-methylindole, 2-hydroxycarbazole, 4,8-disubstituted-5-hydroxyquinoline and 7-hydroxyquinoline can be oxidised to the corresponding 1,2-quinones (18—21).[22–25]



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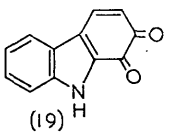

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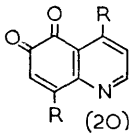

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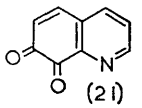
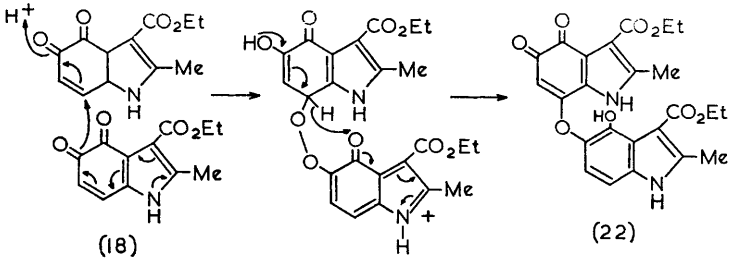


(21)

Fremy's salt oxidations are generally carried out in the presence of sodium acetate or phosphate buffer and under these conditions the reactions are usually uncomplicated. At lower pH anomalous products are encountered. An example

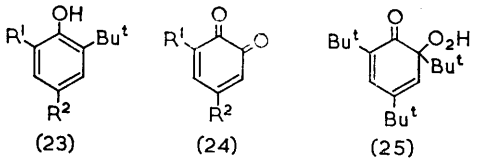
[14] H. J. Teuber and N. Götz, *Chem. Ber.*, 1956, **89**, 2654; H. J. Teuber and G. Thaler, *ibid.*, 1959, **92**, 667.
[15] H. J. Teuber and W. Rau, *Chem. Ber.*, 1953, **86**, 1036; H. J. Teuber and N. Götz, *ibid.* 1954, **87**, 1236.
[16] H. J. Teuber and G. Staiger, *Chem. Ber.*, 1955, **88**, 802.
[17] A. V. El'tsov, *Chem. Abs.*, 1963, **59**, 11463d.
[18] E. Mueller, F. Guenterand, and A. Rieker, *Z. Naturforsch.*, 1963, **18**b, 1002.
[19] F. Wessely, E. Zbiral, and E. Lahrmann, *Chem. Ber.*, 1959, **92**, 2141.
[20] R. G. Cooke and W. R. Owen, *Austral. J. Chem.*, 1962, **15**, 486; W. A. Remers, P. N. James, and M. J. Weiss, *J. Org. Chem.*, 1963, **28**, 1169; L. Horner, K. H. Teichmann, K. H. Weber, and E. Geyer, *Chem. Ber.*, 1965, **98**, 1233; L. Horner and K. H. Weber, *ibid.*, p. 1246.
[21] H. Cassebaum and H. Hofferek, *Chem Ber.*, 1959, **92**, 1643; H. Cassebaum, *ibid.*, 1957, **90**, 2876.
[22] H. J. Teuber and G. Staiger, *Chem. Ber.*, 1954, **87**, 1251.
[23] H. J. Teuber and G. Thaler, *Chem. Ber.*, 1958, **91**, 2253.
[24] H. J. Teuber and S. Benz, *Chem. Ber.*, 1967, **100**, 2918.
[25] H. J. Teuber and S. Benz, *Chem. Ber.*, 1967, **100**, 2077.

of this is the dimerisation[23] of quinone (18) in the presence of acid to give a new quinone (22). Scheme 3 is a probable mechanism for this process. In other cases,

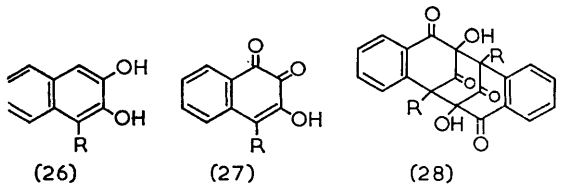


Scheme 3

e.g., the oxidation of phenol (23; R^1 = Bu^t, $CH_2{\cdot}COCH_3$; R^2=Ph), dealkylation accompanies introduction of oxygen.[18,26] In both cases elimination of a t-butyl substituent takes place giving quinone (24, R^1 = Bu^t, $CH_2{\cdot}COCH_3$; R^2 = Ph, Bu^t) the process being similar to the thermolysis of hydroperoxide (25) which yields (24; R^1 = R^2 = Bu^t) as the radical anion.[27]

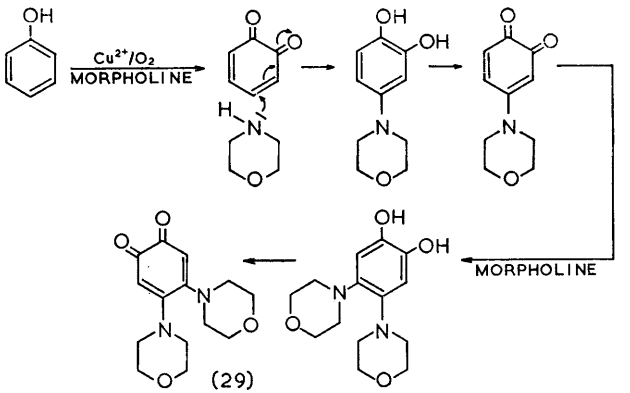


Oxidation of 2,3-dihydroxynaphthalenes (26) produces the hydroxy-1,2-quinones (27) which form dimers (28)[28,29] in low yield. The alkyl derivative (26; R = alkyl) gives, on oxidation, the monomeric quinone (27; R = CH_3)[29] although dimerisation can be brought about by treatment with base.

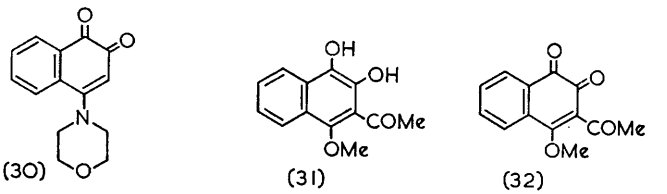


[26] R. Magnusson, *Acta Chem. Scand.*, 1960, **14**, 1643; 1964, **18**, 759.
[27] H. R. Gersmann and A. F. Bickel, *J. Chem. Soc.*, 1959, 2711; J. J. Conradi and G. A. McLaren, *J. Amer. Chem. Soc.*, 1960, **82**, 4745.
[28] H. J. Teuber, *Angew. Chem. Internat. Edn.*, 1967, **6**, 471.
[29] H. J. Teuber and G. Steinmetz, *Chem. Ber.*, 1965, **98**, 666.

One of the more interesting 1,2-quinone syntheses is that described by Brackman and Havinga.[30] The synthesis was discovered in an attempt to simulate tyrosinase oxidation. The process involves the oxidation of a phenol in the presence of Cu^{2+} complexes of secondary amines and oxygen. The mechanism is obviously complex and involves a series of steps. The product incorporates the secondary amine, this presumably being the result of a Michael addition (see later). The reaction sequence is summed up in Scheme 4. The reaction does not terminate after the first addition of amine but further oxidation and addition takes place to produce the 1,2-quinone (29). Similar oxidation of 2-naphthol produces the 1,2-naphthaquinone (30).



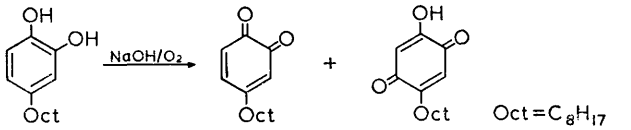
Scheme 4



B. Oxidation of Catechol Derivatives.—The classical method of catechol oxidation is the use of silver oxide[1] in dry ether, a method which produces reasonable yields of product. Some modern applications of this are the oxidation of (31) → (32)[31] or the oxidation of substituted catechols.[18,32–35] Potassium

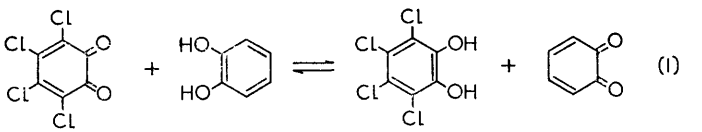
[30] W. Brackman and E. Havinga, *Rec. Trav. chim.*, 1955, **74**, 937, 1021, 1070, 1100, 1107.
[31] D. J. Cram, *J. Amer. Chem. Soc.*, 1949, **71**, 3953.
[32] K. Sturm and L. Horner, *Annalen*, 1955, 597, 1.
[33] L. Horner and W. Spietschka, *Annalen*, 1953 **579**, 159.
[34] W. Flaig, T. Ploetz, and H. Biergans, *Annalen*, 1955, **597**, 196.
[35] J. M. Bruce and F. K. Sutcliffe, *J. Chem. Soc.*, 1955, 4435; 1956, 3820, 3824.

ferrocyanide can also be used for such oxidations.[36] 2-Amino-1-naphthols[37] or 1-amino-2-naphthols[38,39] are oxidised by ferric chloride but usually amines give poor yields of quinone. The use of oxygen or alkaline peroxide gives mixtures of 1,2- and 1,4-quinones[40,41] (Scheme 5).



Scheme 5

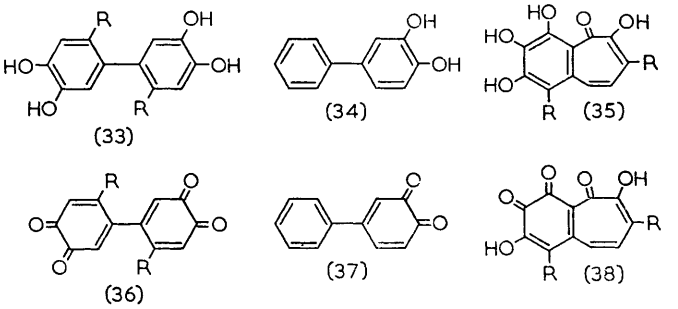
Of particular interest in catechol oxidations is the method developed by Horner and Duerckheimer[42] using tetrachloro- or tetrabromo-1,2-benzoquinones in anhydrous ether. This method, which uses the high redox potential of 1,2-benzoquinones, supersedes the process using 1,4-benzoquinones. The restriction in its use is the redox potential of the catechol being oxidised which must be lower than that of the oxidising quinone so that the equilibrium (1) lies toward the products. Polarographic information is available on many catechols.[43]



The mode of action of tetrahalogeno-1,2-benzoquinones as dehydrogenating agents has been the subject of a recent investigation.[44] The major mechanistic study, however, was made by Linstead *et al.*[45] and the subject has been reviewed.[46] The method is straightforward and few complications have been reported. Several examples of the method's utility are the oxidations of catechols or

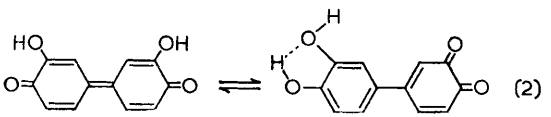
[36] J. Iwao and M. Kawazu, *J. Pharm. Soc. Japan*, 1956, **76**, 811.
[37] J. W. McLeod and R. H. Thomson, *J. Org. Chem.*, 1960, **25**, 36.
[38] M. Gates, *J. Amer. Chem. Soc.*, 1950, **72**, 228.
[39] H. E. French and K. Sears, *J. Amer. Chem. Soc.*, 1948, **70**, 1279.
[40] J. Posspisil and V. Ettel, *Chem. listy.*, 1958, **52**, 939.
[41] I. Buben and J. Posspisil, *Tetrahedron Letters*, 1967, 5123.
[42] L. Horner and W. Duerckheimer, *Z. Naturforsch.*, 1959, **14b**, 741 (Ger. Pat. 1126852, *Chem. Abs.*, 1962, **57**, 8504g).
[43] L. Horner and E. Geyer, *Chem. Ber.*, 1965, **98**, 2009, 2016.
[44] B. M. Trost, *J. Amer. Chem. Soc.*, 1967, **89**, 847.
[45] E. A. Braude, L. M. Jackman, and R. P. Linstead, *J. Chem. Soc.*, 1954, 3548.
[46] L. M. Jackman, *Adv. Org. Chem.*, 1960, **2**, 329.

naphthols,[42,47] dihydroxybiphenyls (33, 34),[48] and benzotropolones (35)[49] to the quinones (36—38) respectively. Other biphenyl-1,2-quinones (substituted



3-phenyl-1,2-benzoquinones) have been synthesised by oxidation of the corresponding catechols with silver oxide.[35]

Of importance with respect to the biphenyl-1,2-quinones is the position of the equilibrium (2) (Scheme 6) on introduction of an *ortho*-hydroxy-substituent. Musso and Pietsch[50] showed that there was a solvent-dependence in the equilibrium position and that in dioxan the diphenoquinone is favoured but in methanol the tautomeric 1,2-quinone is present.

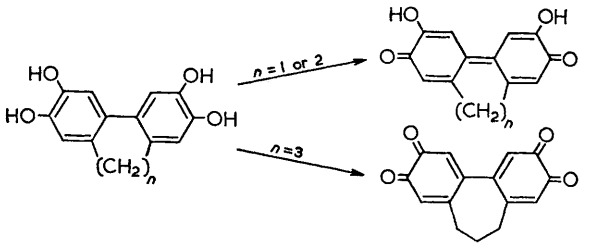


Scheme 6

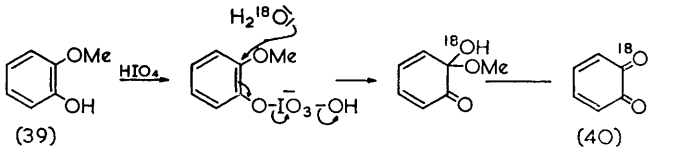
Horner and Weber[51] have studied the oxidation of a series of bridged tetrahydroxybiphenyls. They showed that oxidation of the biphenyl (n = 1 or 2) gives rise to diphenoquinones but when n = 3 a bis-1,2-quinone is isolated (Scheme 7).

Periodate, the subject of a recent Review,[52] can also be used for the oxidation of catechol derivatives including monoethers in which demethylation takes place. Thus guaiacol (39) is readily converted into 1,2-benzoquinone (40).[53]

[47] L. Horner, K. H. Teichmann, K. H. Weber, and E. Geyer, *Chem. Ber.*, 1965, **98**, 1233.
[48] L. Horner and K. H. Weber, *Chem. Ber.*, 1963, **96**, 1568; 1967, **100**, 2842.
[49] L. Horner, S. Gowecke, and W. Duerckheimer, *Chem. Ber.*, 1961, **94**, 1276; L. Horner and K. H. Weber, *ibid.*, 1962, **95**, 1227.
[50] H. Musso and H. Pietsch, *Chem. Ber.*, 1967, **100**, 2854.
[51] L. Horner and K. H. Weber, *Chem. Ber.*, 1967, **100**, 2842.
[52] B. Sklarz, *Quart. Rev.*, 1967, **21**, 3.
[53] E. Adler and R. Magnusson, *Acta Chem. Scand.*, 1959, **13**, 505.



Scheme 7

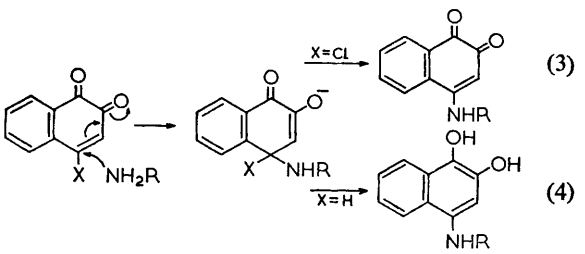


The mechanism shown above is supported by the observation that when $H_2{}^{18}O$ is used, labelled quinone is obtained.[54] The oxidation of catechol was shown to be different, no labelled 1,2-quinone being obtained with $H_2{}^{18}O$. This can be explained by attack of labelled water at hydrogen rather than at carbon.

2 General Reaction Processes

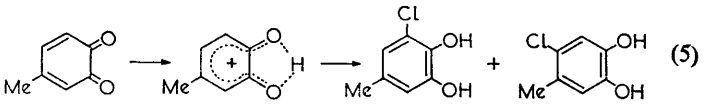
A. Carbonyl and Conjugate (Michael) Addition.—The presence of a conjugated carbonyl system allows conjugate addition to take place. This can be of two types, either nucleophilic on the neutral molecule or acid-catalysed involving nucleophilic attack on the conjugate acid. Products derived from nucleophilic 1,4-addition depend on the nature of the substituent at the 4-position of the quinone. If this is a good leaving group a new 1,2-quinone is produced (reaction 3) while if the substituent is hydrogen, a dihydroxy-derivative is obtained (reaction 4). Various nucleophilic reagents can be used.

Acid-catalysed processes are the result of nucleophilic attack of an anion on



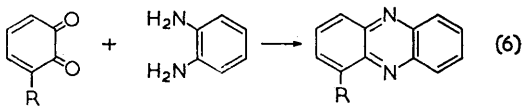
[54] E. Adler, I. Falkenberg, and B. Smith, *Acta Chem. Scand.*, 1962, **16**, 529.

the conjugate acid of the 1,2-quinone and are either 1,4- or 1,6-additions, *e.g.*, addition (5) of HCl.



(5)

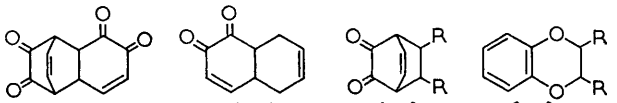
The dicarbonyl system of the quinone can show reactions typical of this class of compound. Thus they can react (6) which 1,2-diamines to produce phenazine derivatives or with substituted hydrazine to give hydrazones.



(6)

Alcohol condensations are also possible as is simple cleavage of the 1,2-dicarbonyl group by peracids.

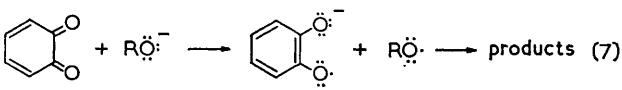
B. Cycloaddition Reactions.—In cycloadditions 1,2-benzoquinones can react in various ways: (*a*) with themselves to yield dimers (41), (*b*) as a dienophile with dienes to yield bicyclo[4,4,0]decadienes (42), (*c*) as homo-dienes using the C–C system giving bicyclo[2,2,2]octenes (43), or (*d*) as hetero-dienes using the C–O system to give 1,4-dioxens (44).



(41) (42) (43) (44)

3 Redox Reactions

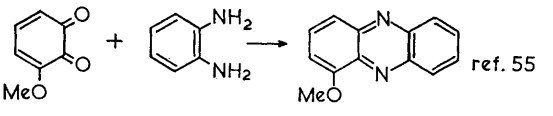
Like 1,4-benzoquinone the 1,2-analogues can act as oxidising agents. The 1,2-benzoquinones are much more reactive and are better oxidising agents except for special cases (such as dichlorodicyano-1,4-benzoquinone which is an extremely good oxidising agent; $E_0 = ca.$ 1 v) ($E_0 = 0{\cdot}792$ for 1,2-benzoquinone compared with 0·699 v for 1,4-benzoquinone). The 1,2-quinones can accept one electron from a suitable donor to produce a radical anion. Such intermediates can also complicate reaction mechanistic schemes, *e.g.*, reaction (7).

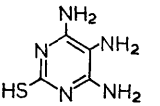


(7)

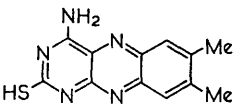
4 Carbonyl and Conjugate (Michael) Addition

A. Amines.—Nucleophilic attack at the carbonyl functions is best exemplified by the formation of phenazines[48a,55] from the reaction of 1,2-quinones with 1,2-phenylenediamine. Similarly a pyrimidine (45), a 1,2-diamine, reacts with



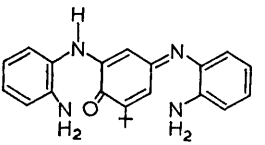


(45)

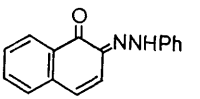


(46)

4,5-dimethyl-1,2-benzoquinone dimer, used because of its low redox potential, to give the diazaphenazine (46) in excellent yields.[56] This type of reaction is usually useful for the preparation of derivatives of 1,2-quinones although occasionally abnormal products, *e.g.*, (47) from 3-t-butyl-5-methoxy-1,2-benzoquinone,[57] are isolated.



(47)



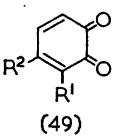
(48)

Substituted hydrazines react at the carbonyl function of 1,2-quinones of low redox potential to give hydrazones, phenylhydrazine giving (48) on reaction with 1,2-naphthaquinone.[58] Reaction of toluene-*p*-sulphonylhydrazine with 1,2-quinones has been utilised for the synthesis of diazo-oxides (49; X = N_2) by the reaction of base upon the hydrazones (49; X = $NNHSO_2$-tolyl).[59] Reduction of these gives a mixture of isomeric phenols showing which carbonyl was preferentially attacked (see Table). Horner and Weber[49] used this method of diazo-oxide formation for an elegant synthesis (8), *via* precursor (50),[60] of azulene. The 1,2-quinones having higher redox potentials are reduced on reaction with arylsulphonylhydrazines producing the catechol, nitrogen, and the

[55] A. R. Surrey, *Org. Synth.*, 1946, **26**, 86.
[56] T. J. Bardos, D. B. Olsen, and T. Enkoji, *J. Amer. Chem. Soc.*, 1957, **79**, 4704.
[57] F. R. Hewgill, D. G. Hewitt, and P. B. Langley, *Austral. J. Chem.*, 1965, **18**, 1241.
[58] H. E. Fierz-David, L. Blangey, and H. Kaul, *Helv. Chim. Acta*, 1946, **19**, 1765; D. S. Dearka and S. Mukergi, *J. Indian Chem. Soc.*, 1963, **40**, 899.
[59] L. Horner and W. Duerckheimer, *Chem. Ber.*, 1962, **95**, 1206.
[60] See also P. A. S. Smith and W. L. Berry, *J. Org. Chem.*, 1961, **26**, 27.

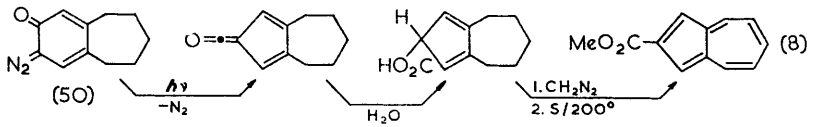
arylsulphinic acid.[59] Akita[61] has also shown that 1,2-quinones are readily reduced by the use of hydrazine.

Table



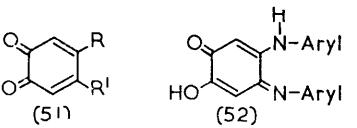
(49)

	Reduction product
R^1 = MeO, R^2 = H	67% 2-MeO, 32% 3-MeO
R^1 = H, R^2 = MeO	98% 3-MeO, 2% 4-MeO
R^1 = H, R^2 = Cl	91% 3-Cl, 8% 4-Cl
R^1 = H, R^2 = Me	88% 3-Me, 12% 4-Me



(50) (8)

In the reactions reported in the literature simple amines react differently from the processes described above, and undergo conjugate addition. 1,2-Benzoquinone has been shown to react with various amines to produce 4,5-disubstituted 1,2-quinones. This process is carried out in the presence of excess of oxidant and involves addition, aromatisation, oxidation, addition, and oxidation and is typical of the process previously described for Michael addition with a poor leaving group. Generally secondary amines have been used, there being no possibility of tautomerisation to the 1,4-quinoneimine. Quinones (51) are obtained by reaction with dimethylamine (51; $R^1 = R^2 = NMe_2$) and ethyleneimine (51; $R^1 = R^2 = N$).[62a] Mono-adducts (51; R^2 = NMePh, NMe_2,[62a] $N(CH_2{\cdot}OH)_2$[62b]; R^1 = H; R^2 = N, R^1 = Me)[62a] have also been reported.

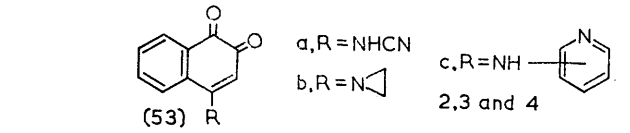


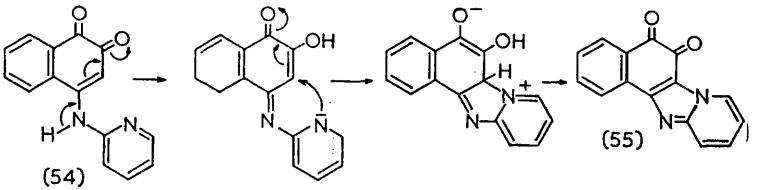
(51) (52)

Aniline and several arylamines also yield similar products; $R^1 = R^2 = NHAr$[63] which could exist as the tautomers (52). Similar studies have been carried out in the naphthalene series although leaving groups (sulphonic acid groups) are usually incorporated which eliminates the need for a reoxidation step. Thus sodium or potassium 1,2-naphthoquinone-4-sulphonate gives 4-substituted quinones (53a, b, and c) on reaction with calcium cyanamide[64] ethyleneimine and

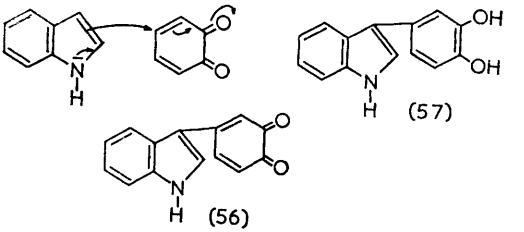
[61] T. Akita, *Chem. Abs.*, 1962, **57**, 9711a.
[62] (*a*) L. Horner and H. Lang, *Chem. Ber.*, 1956, **89**, 2768; (*b*) K. H. Konig and G. Letsch, *ibid.*, 1959, **92**, 1789.
[63] V. C. Barry, J. G. Belton, J. F. O'Sullivan, and D. Twomey, *J. Chem. Soc.*, 1958, 859; U.S. Pat. 2943089, 28/6/1960 (*Chem. Abs.*, 1961, **55**, 588i).
[64] L. F. Fieser *et al.*, *J. Amer. Chem. Soc.*, 1948, **70**, 3213.

aminopyridines.[65–67] The 2-aminopyridine substituted naphthaquinone (54) reacts further by intramolecular cyclisation and oxidation to give (55) which can also be prepared by the reaction of 2-aminopyridine with 3,4-dichloro-1,2-naphthaquinone.[68] 3,4-Dichloro-1,2-naphthaquinone also yields 4-amino-3-chloronaphthaquinones by reaction with aniline, acylhydrazones, and various amides.[69]





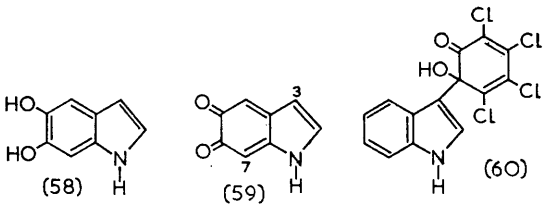
Indole and substituted indoles are reported to react with 1,2-benzoquinones also by a 1,4-mechanism[70] to produce indolylquinones (56) *via* the catechol (57).



The reaction is carried out in the presence of excess of oxidant so that the quinone is the final product. While the structures may have been thought to be suspect, proof was obtained from the independent synthesis of the 2- and 3-isomers.[71] This study was carried out in an attempt to verify the postulate that melanin, a polymer resulting from the oxidation of (58), was formed by addition

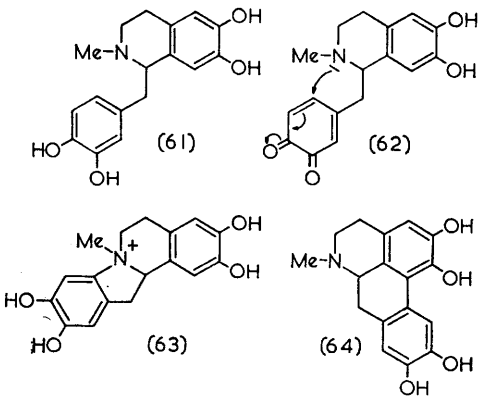
[65] Brit. Pat. 806079, 1958 (*Chem. Abs.*, 1959, **53**, 12301f).
[66] W. Gauss, S. Petersen, and G. Domagk, *Chem. Abs.*, 1960, **54**, 2356h.
[67] W. L. Mosby and M. L. Silva, *J. Chem. Soc.*, 1964, 3990.
[68] W. L. Mosby, *J. Org. Chem.*, 1961, **26**, 1316.
[69] M. Akatsuka, *Chem. Abs.*, 1963, **59**, 7443a.
[70] J. D. Bu'Lock and J. Harley-Mason, *J. Chem. Soc.*, 1951, 703.
[71] J. M. Bruce, *J. Chem. Soc.*, 1959, 2366; 1960, 360.

via the 3- and 7-position of the quinone (59).[72] (The chemistry of a closely related system, the adrenochromes, has also been reviewed.[73])



Indole attacks the carbonyl group of tetrachloro-1,2-benzoquinone.[74] The product (60) was shown to have a hydroxyl function from the i.r. spectrum and the possibility of N–C bond formation was excluded by the similar reaction with *N*-methylindole. Final proof was acquired by aromatisation of the adduct (60), by reaction with zinc and acetic acid, to 2-(3-indolyl)-3,4,5,6-tetrachlorophenol.

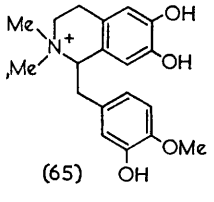
Interesting work on the reactions of amines with 1,2-quinones has been carried out by Franck and Tietze in a study of alkaloid biosynthesis.[75] Laudanosoline (61) can be oxidised by ferric chloride to the 1,2-quinone (62) which then cyclises to the quaternary salt (63) with formation of an N–C bond.[75] However, the



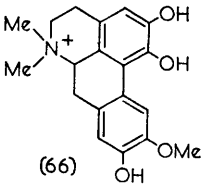
reaction pathway can be diverted if high concentrations of oxidant ($FeCl_3$) are employed so that the catechols become co-ordinated to the iron and 1,2-quinone formation is inhibited. Thus (61) can be converted into the aporphine (64) presumably by free-radical coupling. Prevention of N–C bond formation can also be effected by quaternisation of the nitrogen. The usual mechanism for *in*

[72] R. J. S. Beer, K. Clarke, H. G. Khorana, and A. Robertson, *J. Chem. Soc.*, 1948, 2223; H. S. Mason, *J. Biol. Chem.*, 1948, **172**, 83.
[73] R. A. Heacock, *Chem. Rev.*, 1959, **59**, 181.
[74] L. Horner and W. Spietschka, *Annalen*, 1955, **591**, 1.
[75] B. Franck and L. F. Tietze, *Angew. Chem. Internat. Edn.*, 1967, **6**, 799.

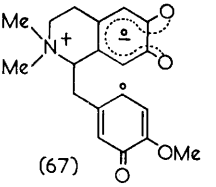
vitro alkaloid biosynthetic pathways is a phenoxy-free-radical process[76] and as such is outside the scope of this Review. Other investigators[77] have considered the intermediacy of 1,2-quinones in the oxidation of (65) to the aporphine (66). Formation of N–C bonds is not favoured owing to the quaternised nitrogen and only one of the catechol substituents can be oxidised to a quinone. Thus the process can be considered to be 1,6-addition of a phenolate anion to the



(65)



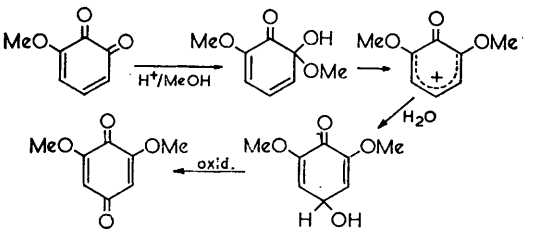
(66)



(67)

1,2-quinone. Nevertheless, attractive as this suggestion may be, electron transfer to the quinone from the phenolate anion producing (67) is also possible thus making the cyclisation a free-radical process.

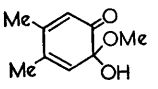
B. Phenols and Alcohols.—The processes involving amines are mostly all nucleophilic and do not require any catalysis. Alcohols, which are much poorer nucleophiles, do not normally add to 1,2-quinones and usually require the presence of acid (see page 213). Thus several 1,2-quinones have been shown to react with aliphatic alcohols in the presence of mineral acids as catalyst[78,79] to produce a 1,4-quinone. The suggested mechanism is shown in Scheme 8. The



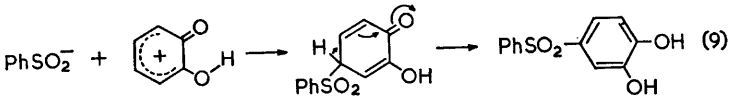
Scheme 8

possibility of hemiketals as intermediates is substantiated by the reaction of 4,5-dimethyl-1,2-benzoquinone with methanol to yield the hemiketal (68). The formation of sulphur carbon bonds can also be considered to be acid-catalysed particularly in the efficient addition (9) of benzenesulphinic acid. Similar addition

[76] B. Franck, G. Blaschke, and G. Schlinghoff, *Angew. Chem. Internat. Edn.*, 1964, **3**, 192; *ibid.*, p. 1101.
[77] A. H. Jackson and J. A. Martin, *J. Chem. Soc.*, 1966, 2061.
[78] L. Horner and S. Gowecke, *Chem. Ber.*, 1961, **94**, 1291.
[79] L. Horner and T. Burger, *Annalen*, 1967, **708**, 105.

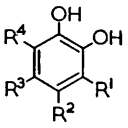


(68)



(9)

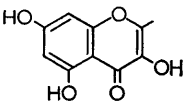
of benzenesulphinic acid has been reported to 4,5-dimethyl-,[80] 3-hydroxy-,[81] 3-methoxy-,[82] and 4-flavanyl-substituted[83] 1,2-quinones giving catechols (69).

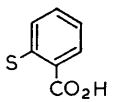


(69)

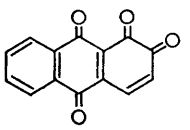
a, $R^2 = R^3 = Me$, $R^1 = H$, $R^4 = PhSO_2$

b, $R^1 = OH$ or Me, R^3 or $R^4 = PhSO_2$

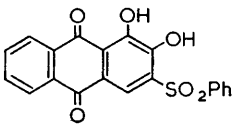
c, $R^1 = R^4 = H$, $R^2 = PhSO_2$, $R^3 =$ 

d, $R^2 = R^3 = Me$, $R^4 = H$, $R^1 = SCH_2CO_2H$ or 

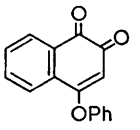
Salicyclic and thioglycollic acids behave in an analogous manner[80] with 4,5-dimethyl-1,2-benzoquinone. Similar additions take place to the diquinone (70) to give the catechol (71). In this reaction the addition is 1,6 rather than 1,4, the difference being attributed to the influence of the *p*-quinone moiety in the molecule.[84]



(70)



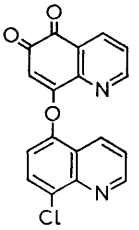
(71)



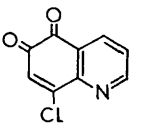
(72)

[80] L. Horner and K. Sturm, *Annalen*, 1959, **597**, 1.
[81] L. Horner and W. Duerckheimer, *Z. Naturforsch.*, 1959, **14b**, 744.
[82] L. Horner, K. H. Weber, and W. Duerckheimer, *Chem. Ber.*, 1961, **94**, 2881; L. Horner, K. Dolling, and E. Geyer, *Monatsh.*, 1967, **98**, 852.
[83] H. Loth and H. Diedrich, *Tetrahedron Letters*, 1968, 715.
[84] H. W. Wanzlich, *Angew. Chem.*, 1960, **72**, 581.

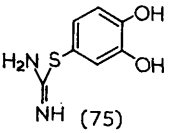
Phenols and thiophenol also add to 1,2-quinones. 4-Phenoxy-1,2-naphthaquinone (72) is readily formed[85] by reaction of phenol with 4-chloronaphtha-1,2-quinone. This is typical of Michael additions with a good leaving group as is the product (73) obtained from the *in situ* oxidation of 7-chloro-5-hydroxyquinoline with Fremy's salt[24] which arises from addition of the hydroxyquinol to the 1,2-quinone (74). Thiophenol yields 3-methoxy-5-thiophenoxy-[86] and



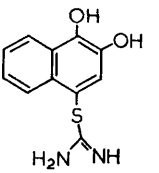
(73)



(74)



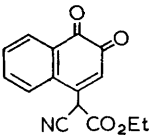
(75)



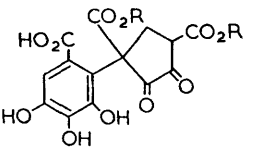
(76)

3-thiophenoxy-4,5-dimethyl-catechol[80] on reaction with 3-methoxy- and 4,5-dimethyl-1,2-benzoquinone respectively. Thiourea is also reported to add in this manner giving (75) with 1,2-benzoquinone[84] and (76) with 1,2-naphthaquinone.[87]

C. Stabilised Anions and Ketones.—Typical of the nucleophilic addition of stabilised anions to 1,2-quinones is that of ethyl cyanoacetate anion to 1,2-naphthaquinone producing (77). In this example no leaving group is incorporated thus requiring additional oxidation to produce the quinone.[88,89] (Glycine ethyl ester also reacts[90] readily with 1,2-naphthaquinone to give a 4-amino-1,2-quinone.) Similarly, stabilised anions add to oxidised gallic acid producing a substituted pyrogallol without further oxidation [formation of (78) is a typical example[91]].



(77)

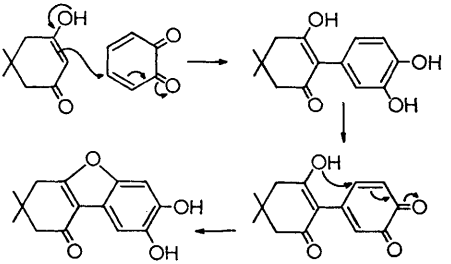


(78)

Ketones or their enols can also be utilised for this type of addition. 1,2-Benzoquinone reacts with dimedone to yield (79).[92] The process is executed in the

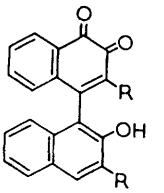
[85] W. I. Awad and M. S. Hafez, *J. Amer. Chem. Soc.*, 1958, **80**, 6057.
[86] L. Horner and S. Gowecke, *Chem. Ber.*, 1961, **94**, 1267.
[87] H. Burton and S. B. David, *J. Chem. Soc.*, 1952, 2193.
[88] M. Gates, *J. Amer. Chem. Soc.*, 1950, **72**, 228.
[89] M. Gates and W. G. Webb, *J. Amer. Chem. Soc.*, 1958, **80**, 1186.
[90] H. Cassebaum, *Chem. Ber.*, 1957, **90**, 2876.
[91] H. W. Wanzlich, *Chem. Ber.*, 1959, **92**, 3006.
[92] H. W. Wanzlich, R. Gritzky, and H. Heidepriem, *Chem. Ber.*, 1963, **96**, 305.

presence of excess of oxidant and involves addition, aromatisation, oxidation, addition, and aromatisation. A similar process can be used to account for dimers



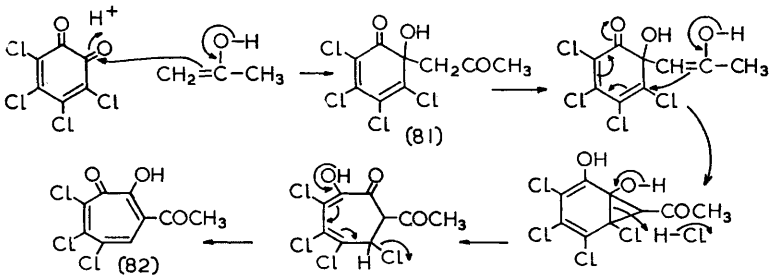
(79)

formed during the oxidation of 2-naphthol with peroxide–molybdate[93] giving quinone (80; R = H) or of the oxidation of 3-substituted 2-naphthols with Fremy's salt to give (80; R = CO_2H[94] or R = OH[95]).



(80)

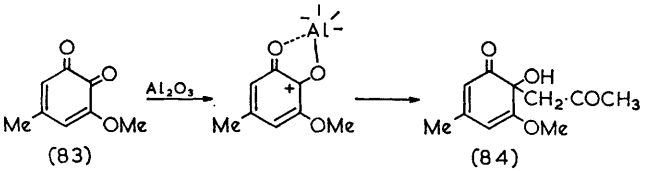
Acetone is reported to react[96] with tetrachloro-1,2-benzoquinone in the presence of hydrochloric acid. Careful working-up yields the intermediate (81) which if allowed to react further produces the tropolone (82). A probable mechanism is shown in Scheme 9.



Scheme 9

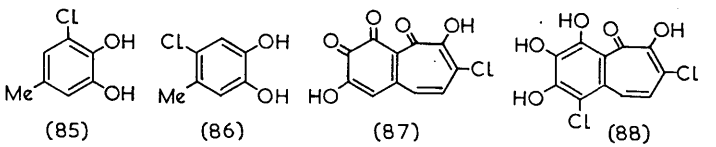
[93] I. D. Raacke-Fels, C. H. Wang, R. K. Robins, and B. E. Christensen, *J. Org. Chem.*, 1950, **15**, 627; A. R. Bader, *J. Amer. Chem. Soc.*, 1951, **73**, 3731.
[94] H. Pracejus, *Annalen*, 1956, **601**, 61.
[95] H. J. Teuber and G. Steinmetz, *Chem. Ber.*, 1965, **98**, 666.
[96] G. O. Schenck, B. Brahler, and M. Cziesla *Angew. Chem.*, 1956, **68**, 247.

Magnusson extended the scope of this reaction to 1,2-naphthaquinones[97] and alkyl-1,2-benzoquinones[98] using alumina as catalyst. No rearrangements like the one above was encountered. In unsymmetrically substituted quinones he established that C–C bond formation took place at the more electrophilic carbonyl group, *i.e.*, the one which gave the less stable carbonium ion. In Scheme 10, 3-methoxy-5-methyl-1,2-benzoquinone (83) reacts with acetone to give quinol (84).



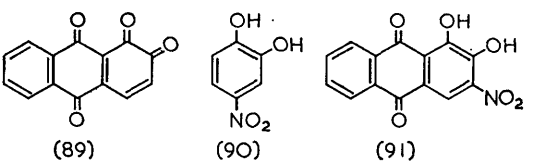
Scheme 10

D. Inorganic Acids.—Hydrogen chloride and bromide add to 1,2-quinones producing a mixture of 1,4- and 1,6-addition products depending on the solvent employed.[79] 4-Methyl-1,2-benzoquinone produces both (85) and (86) on reaction with hydrogen chloride. Several reports appear in the earlier literature of



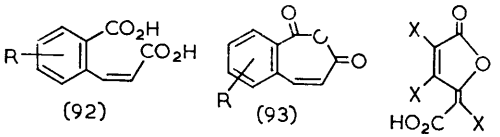
addition of both acids (HBr and HCl) being made to several quinones, *e.g.*, 4,5-dimethyl-[80] and 3-methoxy-benzoquinone and the benzotroponequinone[49] (87) producing 3-chloro-4,5-dimethyl- and 5-chloro-3-methoxy-catechol and the tropolone (88) respectively.

Sodium nitrite reacts with 1,2-benzoquinone[99] and the diquinone (89)[100] giving nitrocatechols (90) and (91) respectively. Subsequent oxidation of (90) in the presence of nitrite gives further addition to produce 3,4-dinitrocatechol, the position of addition being influenced by the initial nitro-substituent.



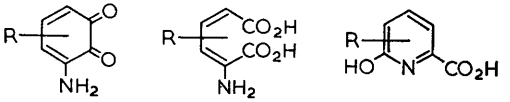
[97] R. Magnusson, *Acta Chem. Scand.*, 1958, **12**, 791.
[98] R. Magnusson, *Acta Chem. Scand.*, 1960, **14**, 1643; 1964, **18**, 421.
[99] D. H. Rosenblatt, J. Epstein, and M. Levitch, *J. Amer. Chem. Soc.*, 1953, **75**, 3277.
[100] See ref. 76*b*.

E. Peracids.—1,2-Benzoquinones react by nucleophilic attack of the peracid at carbonyl carbon, the result being the formation of an anhydride typical of a Baeyer–Villiger oxidation. 1,2-Naphthaquinones[101,102] are converted into the diacid (92) or anhydride (93) and in the case of 1,2-naphthaquinone a peroxide is reported.[101] 4-Methyl-,[103] tetrachloro-,[104] and tetrabromo-1,2-benzoquinones[101] give rise to similar products although the tetrahalogeno-compounds produce



(92) (93) (94)

γ-lactones (94) by ring-opening, and recyclisation with loss of halogen. Boyer and Morgan[105] investigated the oxidation of 3-aminocatechols as an *in vitro* study of the enzymic conversion of 3-hydroxyanthranilic acid, *via* α-amino-β-carboxymuconic acid semialdehyde, to quinolinic and picolinic acids. Conversion of the aminocatechols into the 1,2-quinones (95) and peracid oxidation gave muconic acids (96) which cyclised readily to pyridine derivatives (97).



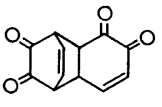
(95) (96) (97)

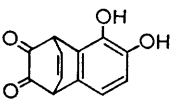
5 Cycloaddition Reactions

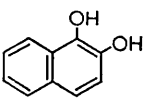
The normal modes in which 1,2-quinones can react in cycloaddition reactions have already been outlined.

A. Dimerisation.—1,2-Benzoquinone dimerises readily to give an adduct in which one quinone molecule behaves as a diene and the other as a dienophile. The dimer of the parent has been shown to have the structure (98).[106–108] The dimer, on being warmed in water isomerises[107,108] to the phenol (99) and on pyrolysis forms 1,2-dihydroxynaphthalene (100)[108] by a loss of two molecules of carbon monoxide. Various other 1,2-quinones have been shown to dimerise,[16,18,109] the process being independent of the redox potential of the quinone.[109] The dimers

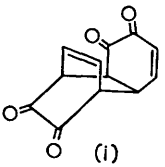
[101] P. Karrar and L. Schneider, *Helv. Chim. Acta*, 1947, **30**, 859.
[102] H. E. French and K. Sears, *J. Amer. Chem. Soc.*, 1948, **70**, 1279; see also Boeseken *et al.*, *Rec. Trav. chim.*, 1930, **49**, 92; 1935, **54**, 315.
[103] P. Karrar, R. Schwyzer, and A. Neuwirth, *Helv. Chim. Acta*, 1948, **31**, 1210.
[104] P. Karrar and Th. Hohl, *Helv. Chim Acta*, 1949, **32**, 1028.
[105] J. H. Boyer and L. R. Morgan, *J. Amer. Chem. Soc.*, 1960, **82**, 4748.
[106] A. A. Patchett and B. Witkop, *J. Org. Chem.*, 1957, **22**, 1477.
[107] J. Harley-Mason and A. H. Laird, *J. Chem. Soc.*, 1958, 1718.
[108] L. Horner and W. Duerckheimer, *Chem. Ber.*, 1958, **91**, 5232.
[109] L. Horner and W. Duerckheimer, *Z. Naturforsch.*, 1959, **14b**, 742; L. Horner and T. Burger, *Annalen*, 1967, **710**, 102; H. J. Teuber, *Angew. Chem.* 1956, **68**, 420; E. Adler, *ibid.*, 1957, **69**, 272.


(98)

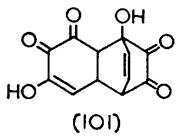

(99)

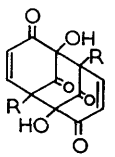

(100)

are assumed to have an *endo–cis*-configuration (i) based on the observed dipole of 4·7 D, for the dimer of 4-t-butyl-1,2-benzoquinone which is in good agreement with the theoretical value.[110]


(i)

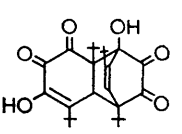
While the alkyl-1,2-quinones behave in the above manner 3-hydroxy-1,2-benzoquinones dimerise in a different way. Originally it was suggested[111] that 3-hydroxy-1,2-benzoquinone gave similar dimers (101) to 1,2-benzoquinone but this has been shown to be incorrect[112] and the structure is now believed to be the symmetric dimer (101a; R = H) arising from a type of aldol condensation between two moles of quinone.


(101)

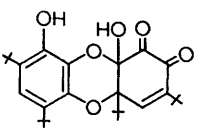

(101a)

Alkyl-substituted 3-hydroxyquinones (101a; R = Et) behave similarly[113] as do 3-hydroxynaphthaquinones (28).[28,29] One result which does not fit into this scheme is the dimerisation of 3-hydroxy-4,6-di-t-butyl-1,2-benzoquinone which was reported[81] to give (102) as the dimeric product. However structure (102) has since been shown to be incorrect[114] and the structure suggested is either (103a) or (103b), the latter being favoured on steric grounds. Treatment of this dimer with a catalytic amount of base or by heating it to its m.p. yields a new colourless compound originally formulated as (104a).[111b] An identical product has been

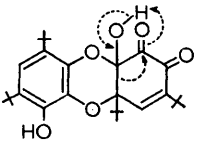
[110] L. Horner and W. Duerckheimer, *Chem. Ber.*, 1962, **95**, 1219.
[111] (*a*) J. C. Salfeld, *Chem. Ber.*, 1960, **93**, 737; (*b*) J. C. Salfeld and E. Baume, *ibid.*, p. 745.
[112] H. J. Teuber and M. Dietrich, *Chem. Ber.*, 1967, **100**, 2908.
[113] H. J. Teuber, P. Heinrich, and M. Dietrich, *Annalen*, 1966, **696**, 64.
[114] A. Critchlow, R. D. Haworth, and P. L. Pauson, *J. Chem. Soc.*, 1951, 1318; A. Critchlow, E. Haslam, R. D. Haworth, P. B. Tinker, and N. M. Waldron, *Tetrahedron*, 1967, **23**, 2829.



(102)

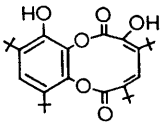


(103a)

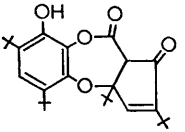


(103b)

isolated by other workers[113,114] but the structure has now been revised to (104b) derived from (103b) by an α-ketal rearrangement. Such a structure readily

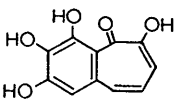


(104a)

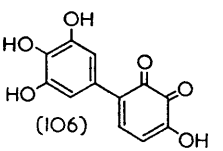


(104b)

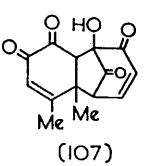
accounts for the formation of 4,6-di-t-butylpyrogallol and 3,5-di-t-butylcyclopentendione.[113,114] Also of interest at this point is the oxidation of pyrogallol to produce purpurogallin (105) *via* 3-hydroxy-1,2-benzoquinone.[114] It was suggested[114] that dimerisation of the 1,2-quinone to give (106), a diphenoquinone, followed by ring opening and oxidative cyclisation and decarboxylation produced purpurogallin. Doubt was cast by Horner *et al.*[109] on this mechanism by the isolation of a mixed dimer (107) from 3-hydroxy-1,2-benzoquinone and 4,5-dimethyl-1,2-benzoquinone and also by the isolation of (108) during purpurogallin formation in ethanol.[82,115,116] The isolation of this ester does not necessarily eliminate the Haworth suggestions[114] since bond rupture in (106) in the presence of ethanol could produce (109) which conceivably could cyclise oxidatively. However on the evidence available the Horner suggestions of prior dimerisation of the 1,2-quinone (*e.g.*, 107) are more acceptable.



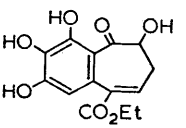
(105)



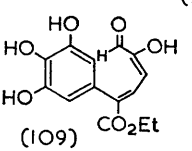
(106)



(107)



(108)

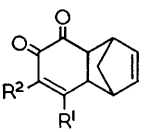


(109)

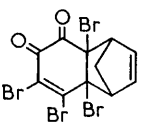
[115] L. Horner and W. Duerckheimer, *Z. Naturforsch.*, 1959, **14b**, 743, 744.
[116] J. C. Salfeld, *Angew. Chem.*, 1957, **69**, 723.

Horner *et al.*[115] demonstrated the use of 1,2-benzoquinones as oxidants of substituted pyrogallols to produce benzotropolones with the pyrogallol making up the seven-membered ring. If substituted pyrogallols are employed the substituents at positions 4, 5, or 6 appear at 3, 4, or 5 in the tropolone. Typically 1,2-benzoquinone and pyrogallol give benzotropolone (105). By use of this process or by direct oxidation many benzotropolones have been synthesised.[82,114–116]

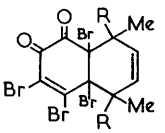
B. Reaction as a Dienophile; Bicyclo[4,4,0]decadienes (Decalins).—A reinvestigation[117–119] in the benzenoid series showed that the product of reaction between 1,2-benzoquinone and cyclopentadiene was a 1:1 adduct (110; $R^1 = R^2 = H$) and not a 2:1 adduct as originally suggested.[120] Similar adducts (110; $R^2 = H$, $R^1 = Ph$,[117] Me,[117] Cl,[118]: $R^1 = H$; $R^2 = MeO, Ph, Cl, Pr^i$ [121]) have been reported from the reaction of various 1,2-quinones with cyclopentadiene. Occasionally the product isolated is a mixture of decalin and bicyclo[2,2,2]octane-type adducts. This is exemplified by the reaction of 3-chloro-1,2-benzoquinone with cyclopentadiene where both adducts are obtained in equal amounts[121] but this may be fortuitous since the decalin-type adducts thermally rearrange (see page 228).



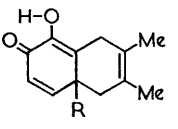
(110)



(111)



(112)



R=CO_2Me,CN
(113)

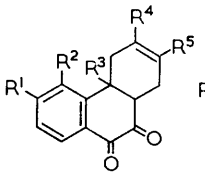
Tetrabromo-1,2-benzoquinone yields a similar product (111) isolated in trace amounts.[120]

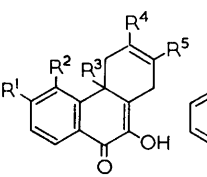
Simple 1,2-benzoquinones are only reported to react with cyclic dienes although tetrabromo-1,2-benzoquinone yields (112; R = H or Me) on reaction with hexa-2,4-diene or 2,5-dimethylhexa-2,4-diene.[122] A similar adduct isolated as the enol (113) is also reported from the reaction of 4-methoxycarbonyl- and 4-cyano-1,2-benzoquinone with 2,3-dimethylbutadiene.[123] The ease with which these compounds enolise is to be contrasted with compound (110; $R^1 = R^2 = H$) where no enolisation is detected.

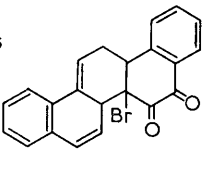
1,2-Naphthaquinones react as dienophiles with acyclic dienes and were

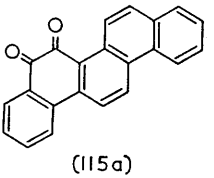
[117] F. J. Evans, H. S. Wilgus, and J. W. Gates, *J. Org. Chem.*, 1965, **30**, 1655.
[118] W. M. Horspool, J. M. Tedder, and Z. U. Din, *Chem. Comm.*, 1965, 775; *J. Chem. Soc.*, 1968, 1597.
[119] D. O. Chapman, H. S. Wilgus, and J. W. Gates, *Tetrahedron Letters*, 1965, 6175.
[120] J. A. Barltrop and J. A. D. Jeffreys, *Experientia*, 1951, VII, 290; *J. Chem. Soc.*, 1954, 154.
[121] M. F. Ansell and A. F. Gosden, *Tetrahedron Letters*, 1967, 4537.
[122] H. Euler and H. Hasselquist, *Arkiv Chem.*, 1963, **6**, 139; H. Hasselquist, H. Euler, G. Hauskopf, and G. Glaser, *Chem. Ber.*, 1953, **86**, 969.
[123] M. F. Ansell and A. F. Gosden, *Chem. Comm.*, 1965, 520.

originally studied by Fieser and his co-workers.[124–127] 4-Alkyl-1,2-naphthaquinones and 2,3-dimethylbutadiene[124] react to give [114; $R^1 = R^2 = H$, $R^3 =$ $PhCH_2$ or $CH(CO_2Et)_2$, $R^4 = R^5 = Me$]. Gates *et al.*[88,89,128–131] have also studied this reaction as a possible route to the synthesis of the morphine ring system. Typical examples are the reactions of 4-cyanomethyl-1,2-naphthaquinone with various dienes producing 1:1 adducts (114; $R^3 = CH_2CN$, $R^1 =$ OMe, OH, or H, $R^2 = H$, $R^4 = R^5 =$ Me or H). While the structure was originally thought to be the diketone (114)[128] it is more probable to suggest that it exists as the enol (114a).


(114)

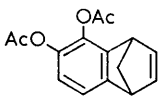

(114a)

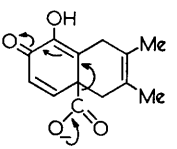

(115)

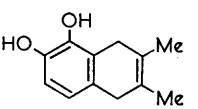

(115a)

Elimination of HBr is reported[132] from the non-isolated intermediate (115) of the condensation of 3-bromo-1,2-naphthaquinone and 1-vinylnaphthalene to give, after oxidation, a new quinone (115a). 1,2-Phenanthraquinones behave in a similar manner to the naphthaquinones with dimethylbutadiene yielding 1:1 adducts.

The aromatisation of 1,2-quinonediene adducts has been used as evidence for the bicyclo[4,4,0]decadiene structure. Thus (110; $R^1 = R^2 = H$) forms the diacetate (116) on treatment with acetic anhydride–pyridine.[118] Adduct (113; $R = CO_2Me$) also aromatises[123] on treatment with base by decarboxylation of the vinylogous carboxylate anion (117) to yield the catechol (118).

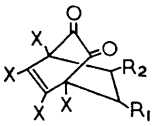

(116)

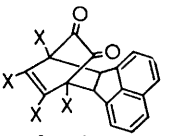

(117)

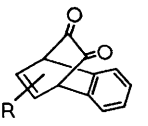

(118)

[124] L. F. Fieser and C. K. Bradsher, *J. Amer. Chem. Soc.*, 1939, **61**, 417.
[125] L. F. Fieser and J. T. Dunn, *J. Amer. Chem. Soc* , 1937, **59**, 1016.
[126] L. F. Fieser and J. T. Dunn, *J. Amer. Chem. Soc.*, 1937, **59**, 1021.
[127] L. F. Fieser and J. T. Dunn, *J. Amer. Chem. Soc.*, 1937, **59**, 1024.
[128] M. Gates and W. F. Newhall, *J. Amer. Chem. Soc.*, 1948, **70**, 2261.
[129] M. Gates and W. F. Newhall, *Experientia*, 1949, V, 285.
[130] M. Gates, R. B. Woodward, W. F. Newhall, and R. Kunzli, *J. Amer. Chem. Soc.*, 1950, **72**, 1141.
[131] M. Gates and G. Tschudi, *J. Amer. Chem. Soc.*, 1956, **78**, 1380.
[132] W. Davies and B. C. Ennis, *J. Chem. Soc.*, 1959, 915.

C. Reactions as 1,3-Dienes; Bicyclo[2,2,2]octadienes. — Polysubstituted 1,2-benzoquinones generally form adducts of this type. Tetramethyl-1,2-benzoquinone reacts with styrene and cyclopentadiene[133a] giving adducts (119; X = CH_3; R^1 = Ph, R^2 = H or R^1 R^2 = $CH_2{\cdot}CH{=}CH_2$) respectively, the latter being a correction of the earlier literature.[133b] Similar adducts are obtained with 3,5-dimethyl-1,2-benzoquinone.[134] The study of the tetrahalogeno-1,2-benzo-

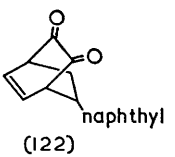

(119)


(120)

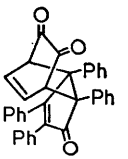

(121)

quinones has been favoured because of their remarkable shelf stability. These quinones show a marked tendency to react in this manner with mono- or disubstituted olefins giving adducts (119), in addition to 1,4-dioxenes (see next section), with styrene,[135] indene,[135] and cyclopentadiene.[120,135] Acenaphthylene is also reported[135–137] to give a similar product (120) with tetrahalogeno-1,2-benzoquinones. Latif *et al.*[136] showed that acenaphthene also gave the same product and they suggested that low hydrocarbon recovery in dehydrogenation experiments with the tetrahalogeno-1,2-benzoquinones[138] and acenaphthene could be due to such an adduct. However, high hydrocarbon recovery is possible,[44] a result which casts doubt on the suggestion of Latif *et al.* Dehydrobenzene is also known to react[139] with several 1,2-benzoquinones, particularly alkyl-substituted derivatives giving benzo-adducts (121).

There are few examples of reactions between 1,2-benzoquinone with olefins which yield this type of adduct as the primary product. 1-Vinylnaphthalene is reported[140] to give adduct (122) in good yield and tetracyclone yields[141] traces of (123) on reaction with 1,2-benzoquinone. However, while simple 1,2-benzo-



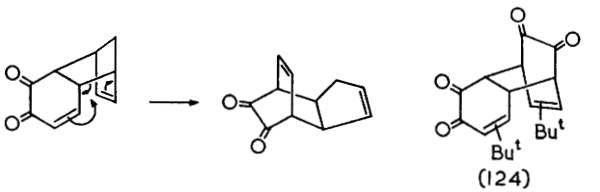
(122)



(123)

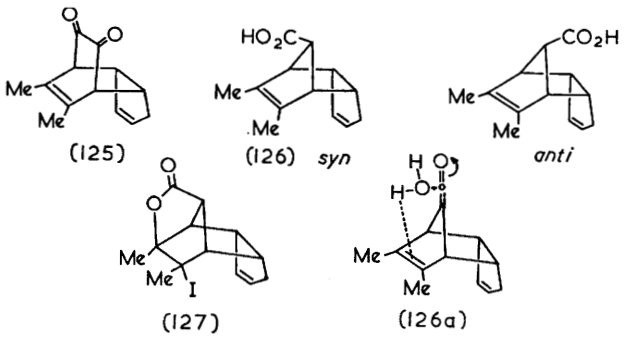
[133] (*a*) L. Horner and W. Spietschka, *Annalen*, 1952, **579**, 159; (*b*) L. I. Smith and L. R. Hac, *J. Amer. Chem. Soc.*, 1936, **58**, 229.
[134] F. Wessely, H. Budzikiewicz, and W. Metlesics, *Monatsh.*, 1959, **90**, 121.
[135] L. Horner and H. Merz, *Annalen*, 1950, **570**, 89; L. Horner, *ibid.*, 1952, **579**, 170.
[136] N. Latif, I. Fathy, M. Mishriky, and A. Attallah, *J. Org. Chem.*, 1960, **25**, 1618.
[137] A. Schonberg and N. Latif, *J. Chem. Soc.*, 1952, 446.
[138] E. A. Braude, A. G. Brook, and R. P. Linstead, *J. Chem. Soc.*, 1954, 3569.
[139] C. W. Rees and R. Atkin, personal communication.
[140] Q. N. Porter, T. G. Corbett, and W. Davies, *Austral. J. Chem.*, 1965, **18**, 1775.
[141] W. M. Horspool, J. M. Tedder, and Z. U. Din, unpublished observations.

quinones do not give this type of adduct as the primary product the cyclopentadiene–1,2-benzoquinone adducts (decalins) are thermally labile and have been shown, in several cases,[118,121] to rearrange to bicyclo[2,2,2]octadienes. While the stereochemistry of the initial adduct is unknown[118] it is not unreasonable to accept the suggestion[118,123] that rearrangement is possible *via* a Cope rearrangement (Scheme 11) owing to the proximity of the double bonds in the



Scheme 11

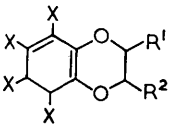
endo–cis-configuration. The suggestion of the *endo–cis*-configuration was first made by Horner and Duerckheimer[142] who measured the dipole moment of the dimer of 4-t-butyl-1,2-benzoquinone and found that the measured value was in good agreement with that calculated for the form shown in (124). Further studies on these stereochemical problems are implied[143] in a study on adduct (125) which was converted into (126), a mixture of acids [the *syn*:*anti* ratio was 10:1, thought to be due to the assistance given by the double bond in the addition of water to the keten (126a)]. It was then shown that the *syn*-acid could form a γ-lactone (127) a result in agreement with the suggested configuration, *i.e.*, *endo–cis*-addition of the diene to the benzoquinone.



D. Reaction of the Heterodiene System.—*Dioxen formation.* Dioxens are formed readily by thermal[144] and photochemical[145] reactions. Typical of the products

[142] L. Horner and W. Duerckheimer, *Chem. Ber.*, 1962, **95**, 1219.
[143] L. Horner and D. W. Baston, *Chem. Ber.*, 1965, **98**, 1252.
[144] G. Pfundt and G. O. Schenck, in '1,4-Cycloaddition Reactions', ed. J. Hamer, Academic Press, New York, 1967, p. 345.
[145] J. M. Bruce, *Quart. Rev.*, 1967, **21**, 405.

encountered are those formed by the thermal reactions of tetrahalogeno-1,2-benzoquinones with various olefins (styrene,[135] stilbenes,[146] β-ethoxystyrene,[135] cyclopentadiene,[120] and benzofuran[135]) to give (128) in addition to the bicyclo[2,2,2]octadienes already discussed.



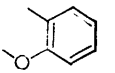
(128)

$R^1 = Ph$, $R^2 = H$

$R^1 = R^2 = Ph$ or *p*-tolyl

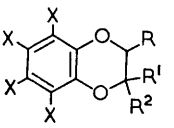
$R^1 = Ph$, $R^2 = OEt$

X = Cl or Br

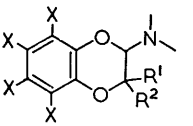
$R^1 R^2 =$ 

$R^1 R^2 =$ 

Similar reactions occur with ketenes, ketenimines, sulphinates, and enamines giving lactones (129, R = O),[147,148] iminolactones (129, R = NR),[149–151] sulphones (129, R = S = O),[152] and aminodioxenes (130).[153] The examples above



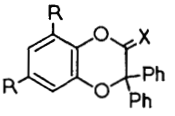
(129)



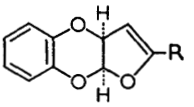
(130)

above involve the higher potential tetrahalogeno-1,2-quinones which show a preference to produce this type of product, but some alkyl-substituted 1,2-quinones yield similar compounds, *e.g.*, 3,5-di-t-butyl-1,2-benzoquinone reacts with diphenylketen giving lactone (131; R = Bu^t, X = O)[148] or with enamines yielding aminodioxens (131; R = Bu^t, X = H, NR_2).[153] A product (131; R = H, X = O) is also reported from the reaction of 1,2-benzoquinone with diphenylketen.[154] Products (132; R = H or Me) can also be isolated from the reaction of

[146] A. Schonberg and N. Latif, *J. Amer. Chem. Soc.*, 1950, **72**, 4828.
[147] L. Horner, W. Spietschka, and A. Gross, *Annalen*, 1951, **573**, 17.
[148] W. Ried and W. Radt, *Annalen*, 1964, **676**, 110; 1965, **688**, 170; *Angew. Chem.*, 1963, **75**, 368 (*Internat. Edn.*, 1963, **2**, 397).
[149] W. Ried and W. Radt, *Naturwiss.*, 1965, **52**, 130.
[150] W. Ried and W. Radt, *Annalen*, 1965, **688**, 174.
[151] W. Ried and P. Junker, *Annalen*, 1967, **700**, 32.
[152] J. Strating, L. Thijs, and B. Zwanenburg, *Rec. Trav. chim.*, 1967, **86**, 641.
[153] W. Ried and E. Torok, *Naturwiss.*, 1964, **51**, 265; *Annalen*, 1965, **687**, 187.
[154] J. L. E. Erickson and J. M. Dechary, *J. Amer. Chem. Soc.*, 1952, **74**, 2644.

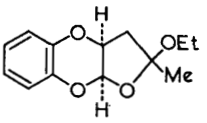


(131)



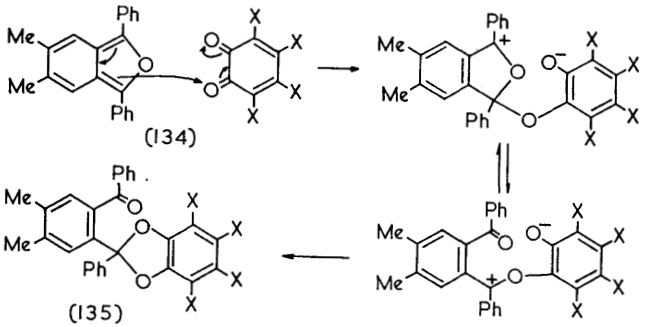
(132)

this quinone with furans.[155] The reaction of 1,2-benzoquinone with 2-methylfuran can be complicated by carrying out the addition in commercial chloroform (ethanol added as stabiliser) when the product isolated is (133),[155] presumably the result of ethanol addition to (132). This addition must take place during the initial complex formation since it is unlikely that addition to the double bond could take place under the conditions employed.



(133)

Isobenzofuran (134) also produces unusual products (135; X = H or Cl) with tetrachloro-1,2-benzoquinone or 1,2-benzoquinone (under a nitrogen atmosphere). A possible two-step mechanism is shown in Scheme 12 which pictures the addition as electrophilic but a free-radical mechanism is equally plausible.[155]

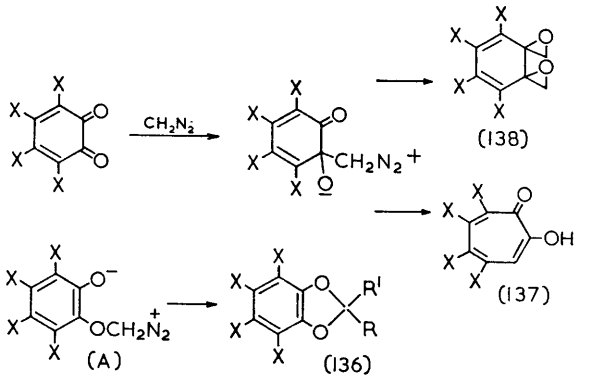


Scheme 12

Dioxole formation. The simplest representation of the reaction with diazoalkanes is shown in Scheme 13. With the polyhalogeno-1,2-quinones the most abundant product is the dioxole (136) but consideration of the complex mechanistic possibilities shows that other products are feasible and have, in some cases, been isolated. Two major possibilities are loss of nitrogen to produce a carbene, discounted by Horner and Lingau,[156] or else nucleophilic attack by the diazo-

[155] W. M. Horspool, J. M. Tedder, and Z. U. Din, unpublished observations.
[156] L. Horner and E. Lingnau, *Annalen*, 1951, **573**, 30.

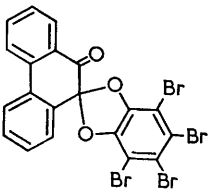
alkane. The latter process is certainly well established in the case of monoketones and can be used to account for ring expansion (137) or oxiran (138) products. This mechanism does not, however, account for dioxole formation and it is necessary, if a heterolytic process is operating, to suggest[157] nucleophilic attack on oxygen producing (A) which loses nitrogen to give the dioxole (136). The original structures put forward for many of the compounds were necessarily uncertain but the use of modern spectroscopic techniques has made product identification more simple. Various diazoalkanes have been used although most



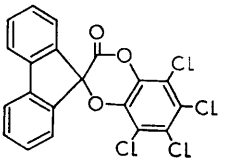
often the tetrahalogenoquinones are employed because of their shelf stability. Examples of the diazo-compounds used in this reaction are diazomethane,[156,158,159] diaryl-[156,159,160] and monoaryl-diazomethanes,[158,161] ethyl diazoacetate,[162] 9-diazofluorene,[156,158,162–165] and 9-diazoxanthene[166] all reacting readily with tetrahalogeno-1,2-benzoquinones to give dioxoles (136) with R^1 and R^2 the substituents of the original diazo-compound. A difference in the rate of reaction of tetrachloro- and tetrabromo-1,2-benzoquinone is suggested[148] as an explanation for the different products isolated from their reaction with 9-diazophenanthra-9,10-quinone. The tetrabromoquinone traps the keto-carbene to yield ketal (139) whereas with the tetrachloroquinone Wolff rearrangement takes place before formation of lactone (140).[148]

Phenanthraquinone forms the usual dioxole products on reaction with diphenyl-, phenyl-, and phenylmethyl-diazomethane.[156,161] This reaction has been shown to be solvent-dependent and, with diazomethane, phenanthra-

[157] A. Schonberg, A. Mustafa, W. I. Awad, and G. E. M. Moussa, *J. Amer. Chem. Soc.*, 1954 **76**, 2273.
[158] A. Schonberg and G. Schutz, *Chem. Ber.*, 1962, **95**, 2386.
[159] A. Schonberg, W. I. Awad, and N. Latif, *J. Chem. Soc.*, 1951, 1368.
[160] N. Latif, I. Fathy, and N. Mishriky, *J. Org. Chem.*, 1959, **24**, 1883.
[161] A. Schonberg and A. Mustafa, *J. Chem. Soc.*, 1946, **746**.
[162] L. Horner and K. Sturm, *Annalen*, 1955, **597**, 1.
[163] A. Schonberg and N. Latif, *J. Chem. Soc.*, 1952, 446.
[164] N. Latif and N. Mishriky, *J. Org. Chem.*, 1962, **27**, 846.
[165] N. Latif and N. Mishriky, *Canad. J. Chem.*, 1964, **42**, 2893.
[166] N. Latif and I. Fathy, *Canad. J. Chem.*, 1959, **37**, 863.

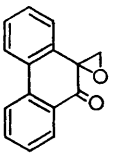


(139)

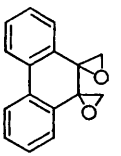


(140)

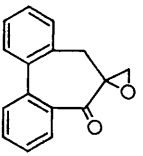
quinone and 1,8-diazaphenanthraquinone gives oxiran products (141) and (142) in tetrahydrofuran or dioxan.[167] Methanol produces a ring-expanded product (143) from phenanthraquinone and diazomethane. With ethyl diazoacetate in



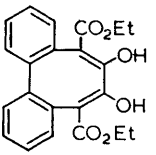
(141)



(142)

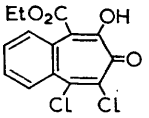


(143)



(144)

tetrahydrofuran–aluminium chloride phenanthraquinone yields a cyclo-octatetraene (144)[167] and tropolone (145) from 3,4-dichloro-1,2-naphtha-quinone.[168]



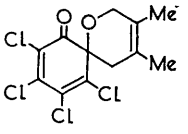
(145)

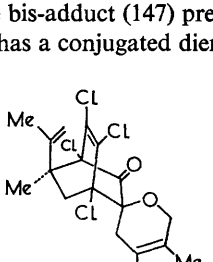
Dioxoles can also be obtained from the reaction of diazo-precursors with two moles of high-redox-potential quinone. The reaction is presumably a dehydrogenation to give the diazo-compound which then reacts with the 1,2-quinone. Examples of this are restricted to the polyhalogeno-1,2-quinones and fluorene- and xanthen-hydrazones.[161] Dioxoles are also isolated from the reaction of the same quinones with thioketones.[164,169] but the reaction is much slower than the dehydrogenation of hydrazones described above.

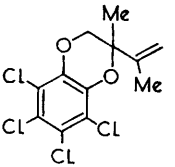
Other cycloaddition reactions. Acyclic dienes exhibit different reactions with tetrahalogeno-1,2-quinones from cyclic dienes. Tetrachloro-1,2-benzoquinone forms a mono- (146) and a bis-adduct (147) with 2,3-dimethylbutadiene,[170] con-

[167] B. Eistert and G. Fink, *Chem. Ber.*, 1962, **95**, 2395; B. Eistert, R. Wolheim, G. Fink, H. Minas, and L. Klein, *Chem. Ber.*, 1968, **101**, 84.
[168] B. Eistert and L. Klein, *Chem. Ber.*, 1968, **101**, 391.
[169] A. Schonberg and E. Singer, *Chem. Ber.*, 1963, **96**, 1256.
[170] M. F. Ansell and V. J. Leslie, *Chem. Comm.*, 1967, 949.

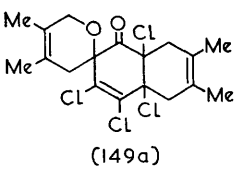
trary to initial reports[135] where only a bis-adduct was obtained. The formation of (146) is unusual but it is pointed out that certain polyhalogenocyclic ketones behave in a similar manner. The bis-adduct (147) presumably arises by addition of the diene to (146) which still has a conjugated diene in the molecule. Both of

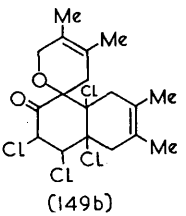

(146)

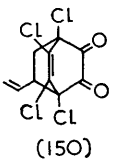

(147)


(148)

these adducts are thermally labile, (146) a Claisen ether rearrangement intermediate, readily rearranging to the dioxen (148) in refluxing benzene. The bis-adduct (147), represented as one of the four possible isomers, rearranges by a Cope reaction to give either (149a) or (149b).[171] The latter (149b) has been shown to be the structure of the rearranged product on the basis of spectral evidence. The high yields from this process suggest that only one isomer is formed in the initial Diels–Alder reaction and this has the stereochemistry shown in (147). Butadiene behaves differently and yields the bicyclo[2,2,2]octadiene (150)[135,170] as the mono-product and an analogue of (147) as the bis-adduct.


(149a)


(149b)


(150)

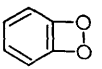
6 Colourless 1,2-Benzoquinone, an Enigma

Finally an interesting problem still exists in the chemistry of the simplest 1,2-quinone. One of the major texts in organic chemistry[172] relates a problem encountered by Wilstätter[173] in the synthesis of 1,2-benzoquinone by oxidation of catechol with silver oxide. Two isomeric forms are reported; the usual red form (151) and a colourless unstable 'isomer' formulated as (152). This, in the light of modern concepts, is surprising. No work has been reported on attempts to verify this although Kuhn and Hammer[174] report a similar colourless form at low temperatures reverting to the red form at room temperature. Results from our laboratory[155] indicate that the formation of the colourless quinone is independent of the oxidant used. Crystalline 1,2-benzoquinone, from tetra-

[171] M. F. Ansell, personal communication.
[172] Rodd, 'Chemistry of Carbon Compounds', vol. IIIb, Elsevier, Amsterdam, 1956, p. 689.
[173] R. Wilstätter and A. Pfannenstiel, *Ber.*, 1908, **41**, 2508.
[174] R. Kuhn and I. Hammer, *Chem. Ber.*, 1950, **83**, 413.

chloro-1,2-benzoquinone oxidation of catechol, also gives a colourless form on cooling a saturated ether solution. Indeed the cycle, red to colourless (on cooling) and back to red on warming can be repeated many times. However the solution to this problem still remains to be found.

(151)



(152)

I thank Professor Lord Tedder, with whom I collaborate on 1,2-benzoquinone research, and my colleagues at Dundee for discussions and comment.