

*The Diels–Alder Reaction with Certain o-Quinones.*

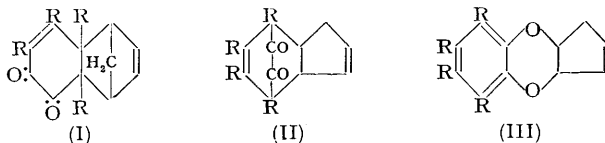
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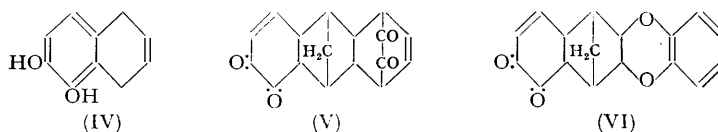
The addition of *cyclopentadiene* to *o*-benzoquinone is described, and the structure of the adduct discussed; butadiene and furan failed to add to the quinone. The addition of *cyclopentadiene* and butadiene to tetrabromo-*o*-benzoquinone is described, and the results compared with those of Horner and Merz (*Annalen*, 1950, **570**, 89). The addition of *cyclopentadiene* to 4-acetamido-*o*-benzoquinone is described; butadiene did not react with this quinone.

UNTIL recently there was only one description of the behaviour of an *o*-benzoquinone in the Diels–Alder reaction (Smith and Hac, *J. Amer. Chem. Soc.*, 1936, **58**, 229). These workers used tetramethyl-*o*-benzoquinone, and obtained a 1 : 1 adduct with *cyclopentadiene*, to which they ascribed structure (I; R = Me). This work was repeated by Horner and Spietschka (*Annalen*, 1953, **579**, 159), and the adduct is now known to be (II; R = Me). In addition, the behaviour of tetrachloro- and tetrabromo-*o*-benzoquinone has been described (Horner and Merz, *ibid.*, 1950, **570**, 89), and these quinones have been shown to react with *cyclopentadiene* to give two types of compound (II; R = Cl or Br), and (III; R = Cl or Br).

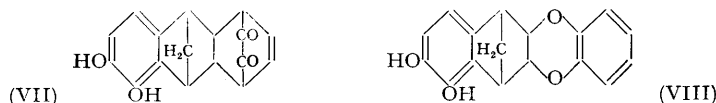
Intending to synthesise compounds of type (IV), the authors examined the behaviour of three *o*-benzoquinones in the Diels–Alder reaction. Although in one case a model experiment with *cyclopentadiene* succeeded, in no case was such a compound obtained from butadiene. This work was therefore broken off some years ago, but unforeseen circumstances have delayed publication. This paper is an amplification of results already described (Barltrop and Jeffreys, *Experientia*, 1951, 7, 290).



Initially, *o*-benzoquinone was treated in ethereal solution with a large excess of *cyclopentadiene*. However, the only product isolated contained two molecules of the quinone united with one of *cyclopentadiene*. This substance crystallised in pale yellow plates which gave no colour with ethanolic ferric chloride but, after being boiled for a short time with aqueous-ethanolic sodium acetate, gave the colour reactions characteristic of a catechol derivative. In view of this, and its ultra-violet absorption spectrum, the compound is believed to be either (V) or (VI).



In the Diels–Alder reaction, one molecule of *o*-benzoquinone could react with *cyclopentadiene* to give three systems: (II; R = H) and (III; R = H), by analogy with the corresponding tetrabromo-compound, and (I; R = H) by analogy with  $\beta$ -naphthaquinone (see also below). Of these three systems, (II; R = Me or Cl) has only very feeble absorption in the ultra-violet (Horner and Spietschka, *loc. cit.*), and veratrole, which system (III; R = H) would be expected to resemble, has only very weak absorption at wave-lengths longer than 3000 Å (Wolf and Herold, *Z. physikal. Chem.*, 1931, 13, B, 201), so that some other system must also be present. In addition, neither of the two systems (II; R = H) and (III; R = H) could be responsible for the production of a colour with ferric chloride, since system (III) contains no hydroxyl groups, and enolisation of system (II; R = H) would violate Bredt's rule. Thus, the first stage of the reaction would appear to be the addition of the diene to the quinone to give (I; R = H), followed by addition of a second molecule of the quinone to the isolated double bond in the diene residue; the boiling with sodium acetate rearranged this adduct to the phenolic isomer, either (VII) or (VIII). The small quantity of the adduct available prevented further examination. No adduct was obtained from *o*-benzoquinone, either with butadiene, or with furan.

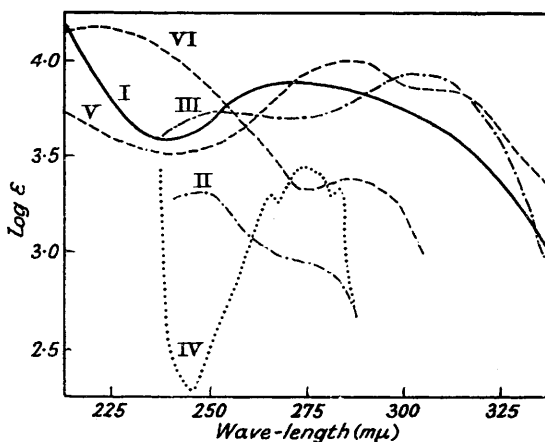


Attention was then turned to tetrabromo-*o*-benzoquinone, which was caused to react with *cyclopentadiene* under conditions slightly different from those used by Horner and Merz (*loc. cit.*). The reaction yielded three products: (i) the ether (III; R = Br), which was very inert, but could be reduced to a dihydro-derivative; (ii) the diketone (II; R = Br), which crystallised from the reaction mixture and was characterised by the preparation of a quinoxaline. The ether, and the hydrate of the diketone, were described by Horner and Merz. The third compound (iii), formed in less than 0.1% yield, was not found by these workers; it showed absorption in the ultra-violet which was much more intense than that of the bridged-ring diketone and occurred at longer wave-lengths, indicating

a higher degree of conjugation. Unlike the diketone (II; R = Br), this adduct did not form a hydrate, and possessed reactive bromine. In view of its absorption spectrum, and its reactivity, it is considered to be (I; R = Br). The addition of butadiene to this quinone in ethereal solution gave only one product. A compound of the same empirical formula, but of a different melting point, was obtained by Horner and Merz (*loc. cit.*). Because of the small yield of this adduct, experiments with tetrabromo-*o*-benzoquinone were discontinued.

Of the known *o*-quinones (see "Organic Reactions," John Wiley and Sons, Inc., New York, 1948, Vol. IV, p. 316), 4-acetamido-*o*-benzoquinone is fairly stable; further, adducts from it could, in principle, be converted into naphthalene derivatives of the required type by successive hydrolysis, diazotisation, and reduction.

The quinone had previously been prepared by Kehrmann and Hoehn (*Heiv. Chim. Acta*, 1925, 8, 218), but in view of the oxidation, and consequent loss of material accompanying the alkaline hydrolysis, of the intermediate 4-acetamidocatechol diacetate, an alternative synthesis was used. Catechol was converted into the isopropylidene ether of its 4-amino-derivative (Sloof, *Rec. Trav. chim.*, 1935, 54, 995), which was converted into the



I, Adduct from *o*-benzoquinone and cyclopentadiene. II, The diketone (II; R = Br). III, The diketone (I; R = Br). IV, *Veratrole* (Wolf and Herold, *loc. cit.*). V, The diketone (IX). VI, Alkali-rearranged product from (IX). Curves II and III were measured in chloroform, the others in methanol.

*N*-acetyl compound. Acid hydrolysis gave 4-acetamidocatechol, which was not isolated but was oxidised *in situ* to the required quinone. (The quinone, prepared either by Kehrmann and Hoehn's or by our method, gave analytical values for carbon which were *ca.* 1% low : in the original paper describing this quinone only a nitrogen analysis is given.) It was not possible to recrystallise it.



The quinone reacted very readily with *cyclopentadiene* to give a 40% yield of a yellow adduct, assumed to be (IX). Attempts to form either a quinoxaline or a phenylhydrazone from this compound gave only tars; similarly, an attempt to convert it into the corresponding catechol by treatment with hydrogen bromide in glacial acetic acid (Diels and Alder, *Ber.*, 1929, 62, 2337) caused complete decomposition. However, treatment with very dilute sodium hydroxide rearranged the initial adduct to a colourless material, which gave colour reactions characteristic of a catechol derivative. This is considered to be (X). Similar rearrangements of Diels-Alder adducts from *p*-benzoquinone have been carried out with concentrated alkali (*idem, loc. cit.*).

Although *cyclopentadiene* reacted very readily with this quinone, butadiene could not be induced to react, and the only products isolated were ill-defined materials derived only from the starting quinone.

## EXPERIMENTAL

*Reaction of o-Benzoquinone with cyclopentadiene.*—To a filtered solution of *o*-benzoquinone, prepared from catechol (2.5 g.) (Willstätter and Pfannenstiel, *Ber.*, 1904, **37**, 4744), a large excess of freshly distilled *cyclopentadiene* was added, and the mixture set aside at room temperature overnight. The initially deep red solution faded in about  $\frac{1}{2}$  hr. to yellow. Next day the solution was concentrated under reduced pressure, and ligroin (b. p. 40–60°) added until the initially granular precipitate began to appear gummy. After a few hours, the solid was collected and washed with ether to remove adhering tar. In each run the yield was only a few mg. The adduct was best recrystallised from acetonitrile or methyl propyl ketone. From the latter it formed pale yellow plates, m. p. 129–136°, unchanged by recrystallisation (Found: C, 72.3, 72.5; H, 4.7, 4.9.  $C_{17}H_{14}O_4$  requires C, 72.3; H, 5.0%).

In ethanolic solution, the initial adduct gave no colour with ferric chloride, and gave a pale yellow colour, after about 20 min., with a solution of ammonium molybdate in dilute acetic acid. After the adduct had been boiled for  $\frac{1}{2}$  min. with aqueous-ethanolic sodium acetate, the addition of ferric chloride solution gave a dark blue colour, which became pink on addition of ammonia and gave a transitory green colour on addition of acid; with an aqueous-acetic acid solution of ammonium molybdate it instantly gave a deep yellow colour. The last reaction is characteristic of phenols with *o*-hydroxyl groups (Quastel, *Analyst*, 1931, **56**, 311).

Attempts to add butadiene or furan to this quinone gave only tar.

*Addition of cyclopentadiene to Tetrabromo-o-benzoquinone.*—To the quinone (26 g.), in dry ether (350 c.c.), freshly distilled *cyclopentadiene* (5 c.c.) was added, and the mixture left at room temperature. The deep red solution faded to yellow in about  $\frac{1}{2}$  hr., and brown crystals (A) (8 g.) were deposited. The mother-liquor was decanted and concentrated to one-third of its volume. Pale yellow crystals (8 g.) were deposited, and a few mg. of lemon-yellow crystals (B) separated when the filtered solution was kept overnight in the refrigerator. The mother-liquor was again concentrated and, when kept overnight in the refrigerator, deposited a further quantity (2.5 g.) of orange crystals. The mother-liquor from this crystallisation contained tar.

Crop (A) was almost pure (II; R = Br), deposited quantitatively. Recrystallisation of this material from dry benzene gave deep yellow crystals of 4 : 5 : 6 : 7-tetrabromo-4 : 7-oxalylindene, m. p. 206° (decomp.; preheated bath) (Found: C, 27.6; H, 1.3; Br, 65.8%; *M*, 517.  $C_{11}H_6O_2Br_4$  requires C, 27.0; H, 1.2; Br, 65.3%; *M*, 490). This readily picked up water from any solvent to give a colourless hydrate which, unlike the parent material, was sparingly soluble in benzene. It was in this form that the adduct was isolated by Horner and Merz (*loc. cit.*), who did not describe the parent diketone. The hydrate began to lose water below 40°; its solution in ether was colourless at room temperature, but on being boiled under reflux it became yellow, the colour disappearing on cooling. The diketone failed to give a precipitate with ethanolic silver nitrate solution and did not liberate iodine from acidified potassium iodide solution.

Crop (B) was almost pure 3 : 4 : 9 : 10-tetrabromo-5 : 8 : 9 : 10-tetrahydro-5 : 8-methylene-1 : 2-naphthaquinone (I; R = Br); a further quantity was obtained by recrystallisation of the other fractions, the total yield being about 20 mg. Crystallised from ether, it forms lemon-yellow tablets, m. p. 140°, resolidifies and remelts at 187° (decomp.), undepressed on admixture with (II; R = Br) (Found: C, 27.3; H, 1.1; Br, 63.0.  $C_{11}H_6O_2Br_4$  requires C, 27.0; H, 1.2; Br, 65.3%). Owing to the small amount available, the molecular weight has not been determined. The substance did not form a hydrate. An ethanolic solution of this material gave an immediate precipitate with ethanolic silver nitrate and liberated iodine from acidified potassium iodide solution.

Recrystallisation of the residues, first from ether, then from ethanol, gave (III; R = Br) as needles (9 g.), m. p. 123°; crystallised from benzene, it formed massive rhombs, m. p. ca. 96°, which effloresced in air, losing benzene of crystallisation (Found: C, 27.1; H, 1.1; Br, 62.2%; *M*, 493. Calc. for  $C_{11}H_6O_2Br_4$ : C, 27.0; H, 1.2; Br, 65.3%; *M*, 490). The compound did not react with *o*-phenylenediamine in glacial acetic acid or with phenylhydrazine. It gave no colour with ferric chloride, either aqueous or ethanolic, and did not dissolve in alkali. Dissolved in methanol, the compound had absorption maxima at 2250 and 2800 Å (log  $\epsilon$  4.72 and 3.39 respectively).

*Preparation of the Quinoxaline from (II; R = Br).*—The diketone (1.95 g.) was dissolved in hot acetic acid (50 c.c.), a solution of *o*-phenylenediamine (0.25 g.) in acetic acid (5 c.c.) added, and the mixture kept for 30 min. at 100°. The crystalline deposit was recrystallised from glacial

acetic acid. The quinoxaline formed pale grey needles, m. p. 215° (decomp.) (Found: C, 36.8; H, 1.9; N, 4.6. Calc. for  $C_{17}H_{10}N_2Br_4$ : C, 36.3; H, 1.8; N, 5.0%).

*Reduction of (III; R = Br).*—The compound (2.5 g.), dissolved in ether (250 c.c.), was shaken with Raney nickel in presence of hydrogen at one atm. The rate of reduction slowed when one equiv. of hydrogen had been taken up, and the reduction was stopped when a slight excess had been absorbed. After filtration from the catalyst, the solution was concentrated to 15 c.c., and the solid (1.65 g.) was recrystallised from ethanol. 5 : 6 : 7 : 8-Tetrabromo-2 : 3-dihydrocyclopenta[b]-1 : 4-benzodioxan (nomenclature: Ring Index No. 1755) formed needles, m. p. 140° (Found: C, 27.0; H, 1.8; Br, 65.3.  $C_{11}H_8O_2Br_4$  requires C, 26.9; H, 1.6; Br, 65.0%).

*Addition of Butadiene to Tetrabromo-*o*-benzoquinone.*—Butadiene (0.9 c.c.; liquid) was added to a suspension of tetrabromo-*o*-benzoquinone (4.2 g.) in dry ether (25 c.c.), and the mixture kept at 100° in a sealed tube. After 1 hr. the quinone had disappeared, and the liquid had become yellow, depositing about 1 mg. of red needles. Evaporation of the filtered solution gave only amorphous material which, on chromatography in benzene over alumina, gave a trace of material crystallising in rhombic plates. Addition of methanol to the first runnings from the column caused the separation of colourless needles. After recrystallisation from methanol, the substance had m. p. 129–130° (Found: C, 31.7; H, 2.5; Br, 59.8. Calc. for  $C_{14}H_{12}O_2Br_4$ : C, 31.6; H, 2.3; Br, 60.1%). Horner and Merz (*loc. cit.*) describe a compound of the same formula, but with m. p. 138°. No ketonic material could be isolated from the products of this reaction.

*Preparation of 4-Acetamidocatechol isoPropylidene Ether.*—4-Aminocatechol *isopropylidene ether* (Sloof, *Rec. Trav. chim.*, 1935, 54, 995) (5 c.c.), suspended in water, was shaken with acetic anhydride (5 c.c.). The *amide* (8 g.) was collected, washed with water, and recrystallised, best from dibutyl ether, from which it separated as massive prisms, m. p. 107° (Found: C, 63.6; H, 6.2; N, 6.8.  $C_{11}H_{13}O_3N$  requires C, 63.7; H, 6.3; N, 6.8%). The compound was insoluble in ligroin, sparingly soluble in carbon tetrachloride and water, and very soluble in the other common solvents. From water and aqueous ethanol, it was deposited as an oil.

*Preparation of 4-Acetamido-*o*-benzoquinone.*—The foregoing *amide* (2 g.) was dissolved in concentrated sulphuric acid (3 c.c.), and the solution cooled and poured into water (40 c.c.). This clear solution was cooled in ice, and a solution of sodium dichromate (1 g.) in water (5 c.c.) added. The liquid instantly became dark red and soon deposited scarlet needles. After 2 min. the quinone (0.9 g., 55%) was collected, washed with a little ice-water, and dried *in vacuo* (Found: C, 57.1, 57.3; H, 4.2, 4.4; N, 8.3. Calc. for  $C_8H_7O_3N$ : C, 58.2; H, 4.2; N, 8.5. Found, for a sample of the quinone prepared by Kehrmann and Hoehn's method: C, 57.2; H, 4.3%).

*Addition of cyclopentadiene to 4-Acetamido-*o*-benzoquinone.*—To a suspension of the quinone (0.5 g.) in acetone (15 c.c.), freshly distilled *cyclopentadiene* (0.3 c.c.) in acetone (5 c.c.) was added. On warming to about 35° the quinone dissolved, and the solution became brown, depositing some tar. After 20 min. at room temperature, the mixture was kept overnight in the refrigerator. The 4-acetamido-5 : 8 : 9 : 10-tetrahydro-5 : 8-methylene-1 : 2-naphthaquinone (IX) (0.27 g., 40%) was collected and washed with acetone (5 c.c.). Concentration of the filtrate and washings gave a further 0.1 g. of crude product. The compound was purified by continuous extraction (Soxhlet) with acetone, the tar produced in the reaction being undissolved, and the diketone crystallising in the lower vessel. Two repetitions of the procedure gave a pure product.

From acetone, the adduct appeared as massive yellow rhombic prisms, m. p. *ca.* 145° with evolution of *cyclopentadiene* (Found: C, 67.6; H, 5.5; N, 6.0.  $C_{13}H_{13}O_3N$  requires C, 67.5; H, 5.7; N, 6.1%). The compound was also prepared by suspending the quinone in excess of *cyclopentadiene*; on addition of a few drops of ethanol, the mixture became hot and almost solid. The product was worked up as described above. Treatment of the diketone, dissolved in ethanol, with phenylhydrazine produced an intense yellow colour, but only a gum was isolated. Similarly, attempts to prepare a quinoxaline, either in glacial acetic acid, or by heating the reactants together, failed.

Attempts to add butadiene in ethanol at 56° gave only quinone decomposition products.

*Conversion of the Diketone (IX) into the Phenol (X).*—To the adduct (IX) (0.6 g.), dissolved in warm ethanol (40 c.c.), sodium hydroxide solution (2 drops of 10%) was added. The solution lost its yellow colour in a few seconds; warming was continued till a brown colour was just visible, then 2*N*-hydrochloric acid (4 drops) was added. The solution was concentrated almost to dryness and set aside. 4-Acetamido-5 : 8-dihydro-5 : 8-methylenenaphthalene-1 : 2-diol (X)

(0.4 g.) was collected, washed with ether, and recrystallised from ethyl acetate as rhombic prisms, m. p. 200° (decomp., but without evolution of *cyclopentadiene*) (Found: C, 67.1; H, 5.5; N, 5.8.  $C_{13}H_{13}O_3N$  requires C, 67.5; H, 5.7; N, 6.1%). In ethanol the compound gave a green colour with ferric chloride, rapidly becoming red; if alkali was present, the addition of ferric chloride gave a purple colour. In dilute acetic acid, the compound gave a deep yellow colour with ammonium molybdate.

Addition of a drop of concentrated hydrobromic acid to a solution of the diketone (IX) in glacial acetic acid (cf. Diels and Alder, *loc. cit.*) caused the solution to change from pale yellow to intense purple; only tar was isolated.

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