87. *The Oxidation of Phenols with Benzoyl Peroxide. Part II.*

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In contrast to *m*-4- and *m*-5-xylenols (*J.*, 1949, 3189), *m*-2-xylenol reacts with benzoyl peroxide in boiling chloroform, to give mainly 3 : 5 : 3′ : 5′-tetramethyldiphenoquinone (V). This involves the coupling of two phenolic radicals in the 4-position.

Mesitol yields 4-benzoyloxy-2 : 4 : 6-trimethyl*cyclo*hexa-2 : 5-dienone (VIII; R = Me, X = ·O·COPh) by the addition of a benzoate group in the 4-position to a phenolic radical, together with a trace of 3 : 5 : 3′ : 5′-tetramethylstilbenequinone (IX; R = Me), whilst a product of the latter type was the only substance that could be isolated after oxidation of 2 : 6-di-*tert.*-butyl-4-methylphenol.

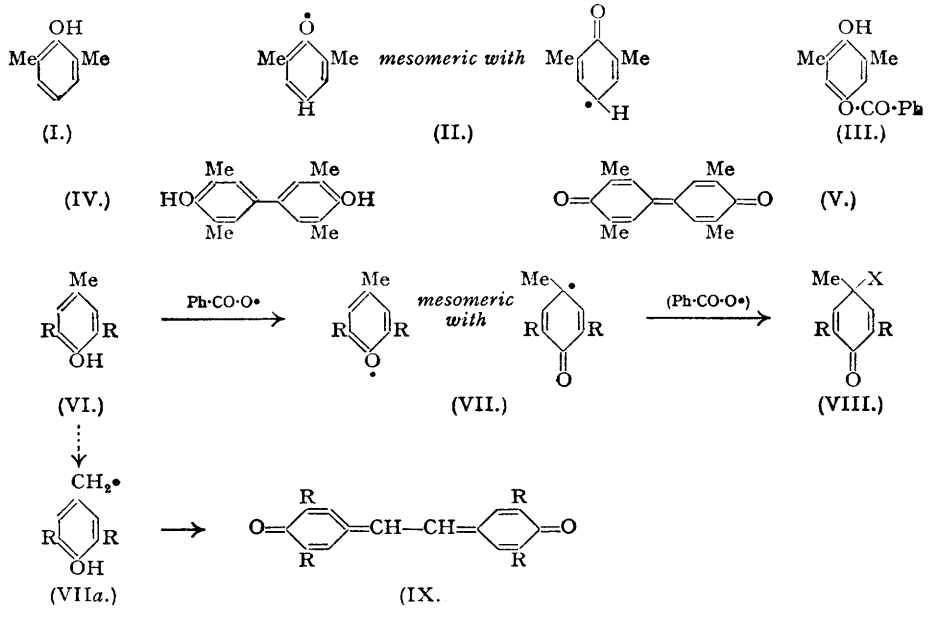
These oxidations are reviewed in connection with the rôles of phenols as inhibitors of autoxidation processes.

In a previous paper (*J.*, 1949, 3189 *) we reported that on treatment with benzoyl peroxide in boiling chloroform solution phenol, the isomeric cresols, and *m*-4- and *m*-5-xylenol were oxidised to give the monobenzoates of pyrocatechol derivatives. We have now extended our study to *m*-2-xylenol (I), mesitol, and 2 : 6-di-*tert.*-butyl-4-methylphenol, in all of which both positions *ortho* to the hydroxy-group have been blocked by alkyl substituents.

Unlike the compounds previously studied, *m*-2-xylenol (I) gave 50% of the red 3 : 5 : 3′ : 5′-tetramethyl-4 : 4′-diphenoquinone (V), 10% of the corresponding 4 : 4′-dihydroxy-3 : 5 : 3′ : 5′-tetramethyldiphenyl (IV), and only 10% of the expected 5-benzoyloxy-*m*-2-xylenol (III). The formation of about 60% of the dimeric products (IV) and (V) substantiates our surmise of Part I

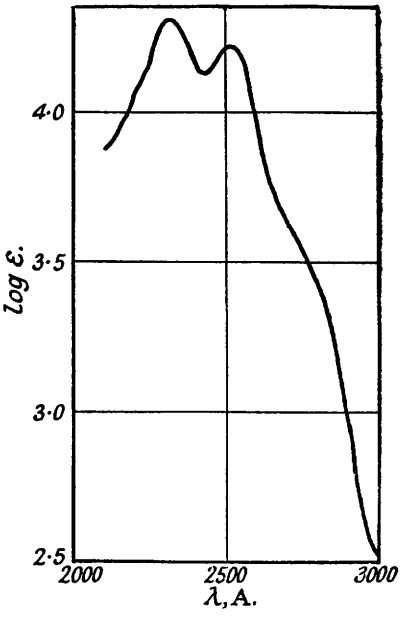
* Regarded as Part I of this series.

(*loc. cit.*) that oxidation by means of benzoyl peroxide proceeds by abstraction of a hydrogen atom by benzoate radicals and the transient formation of mesomeric phenol radicals such as (II).



Mesitol (VI; R = Me), after 12 hours' refluxing with benzoyl peroxide in chloroform, gave over 90% of 4-benzoyloxy-2 : 4 : 6-trimethyl*cyclo*hexa-2 : 5-dienone (VIII; R = Me, X = O·CO·Ph), with a trace of the red insoluble 3 : 5 : 3′ : 5′-tetramethylstilbenequinone (IX; R = Me) which had previously been prepared by Porter and Thurber (*J. Amer. Chem. Soc.*, 1921, **43**, 1194; cf. Goldschmidt and Bernard, *Ber.*, 1923, **56**, 1965) by oxidising mesitol with moist silver oxide. The production of (IX) may indicate that there can also be some slight side-chain attack at the *p*-methyl group to give the radical (VII*a*).

The "quinole" (VIII; R = Me, X = O·CO·Ph) has possibly been made by Bamberger and Rising (*Ber.*, 1900, **33**, 3636) by oxidation of mesitylhydroxylamine and benzoylation of the product, and perhaps by the oxidation of mesitol with Caro's acid (Bamberger, *Ber.*, 1903, **36**, 2028), but we have not been successful in repeating either of these preparations. In view of the great instability to water of the corresponding bromo-compound (VIII; R = Me, X = Br) (Fries and Brandes, *Annalen*, 1939, **542**, 48) the interpretation of Bamberger's work is open to doubt, and we have therefore substantiated the structural formula of our reaction product. Our material gives a red 2 : 4-dinitrophenylhydrazone, and its ultra-violet absorption spectrum (see figure), with absorption maxima at 2310 and 2510 A., has some similarities with that of an αβ-unsaturated ketone. Moreover, catalytic reduction converted our compound into mesitol and benzoic acid, whilst acid hydrolysis, followed by oxidation with ferric chloride and final sulphite reduction of the volatile quinone so formed, led to the isolation of both benzoic acid and 2 : 6-dimethylquinol, thus establishing the 4-position of the benzoate group (X in VIII). We failed to isolate any direct hydrolysis product corresponding to Bamberger's "mesityl-quinole" (VIII; R = Me, X = OH).



Maxima: 2310 *and* 2510 A.; ε = 20,400 *and* 16,600.

4-Methyl-2 : 6-di-*tert.*-butylphenol (VI; R = Bu^t) was attacked exceedingly slowly by benzoyl peroxide, and after 70 hours the only oxidation product isolated was 3 : 5 : 3′ : 5′-tetra-*tert.*-butylstilbene-4 : 4′-quinone (IX; R = Bu^t).

These results are of interest in connection with the use of alkylphenols as antioxidants (cf. Rosenwald, Hoatson, and Chenicek, *Ind. Eng. Chem.*, 1950, **42**, 162) since mesitol and 4-methyl-2 : 6-di-*tert.*-butylphenol are amongst the most potent antioxidants known. If chain-growth in an autoxidation process ceases because an active radical is destroyed by a reaction (*A*) which leads to a chemically inert aryl radical, •O–Aryl, of type (II) or (VII) (cf. Bolland, *Quart. Reviews*, 1949, **3**, 9; Bolland and Ten Have, *Trans. Faraday Soc.*, 1947, **43**, 201), then it would be expected that the first stage at least in the oxidation of mesitol or of 4-methyl-2 : 6-di-*tert.*-butylphenol would be easier than in less hindered phenols such as *p*-cresol, which is a relatively poor antioxidant. However, it now appears that the oxidation of *p*-cresol by benzoyl peroxide is the faster process.

We would therefore suggest that the reaction between *p*-cresol and benzoyl peroxide is not simply due to free benzoate radicals, though it must be started by a reaction of type (*A*). It may also include a chain-continuing reaction (*B*) between the *p*-tolyl radical and benzoyl peroxide molecules. This view accords with the findings of Nozaki and Bartlett (*J. Amer. Chem. Soc.*, 1946, **68**, 1686) and subsequent workers, who have shown conclusively that the decomposition of benzoyl peroxide in many solvents is, in no small part, a chain reaction and that typical "inhibiting agents" act, with varying degrees of efficacy, by reducing the chain length.

(*A*) $\mathrm{Rad\bullet + H\text{-}O\text{-}Aryl \longrightarrow Rad\text{-}H + \bullet O\text{-}Aryl}$

(*B*) $\mathrm{CH_3{\cdot}\dot{C}_6H_3{\cdot}OH}$ (tautomeric with $\mathrm{CH_3{\cdot}C_6H_4O\bullet}$) $\mathrm{+ Ph{\cdot}CO{\cdot}O\text{-}O{\cdot}COPh \longrightarrow Ph{\cdot}CO{\cdot}O\bullet + CH_3{\cdot}C_6H_3(OH){\cdot}O{\cdot}COPh}$

We therefore suggest, tentatively, that the less effective phenolic inhibitors (chiefly the monohydric phenols rather than derivatives of quinol or pyrocatechol) may yield aryloxy-radicals of an appreciable degree of chemical reactivity, and consequently that in autoxidation systems they may to some extent be able to act not only as chain-stopping agents but also as chain-transfer agents, by effecting dehydrogenations of the type of (*C*) :

(*C*) $\mathrm{Aryl\text{-}O\bullet + H\text{-}R \longrightarrow Aryl\text{-}O\text{-}H + \bullet R}$

Experimental.

Oxidation of m-2-*Xylenol* (I).—The xylenol (12·2 g., 0·1 mol.) and benzoyl peroxide (24·2 g., 0·1 mol.) were refluxed in purified chloroform (300 ml.) for 4 hours. The solution was then washed with aqueous sodium hydrogen carbonate, the extracts were acidified, and benzoic acid (20·8 g., 0·17 mol.) was collected. Evaporation of the dried chloroform layer yielded a deep red gummy solid, which, when rubbed with ether (30 ml.), left 3 : 5 : 3′ : 5′-tetramethyl-4 : 4′-diphenoquinone (V) (6·1 g.) as a red insoluble powder. This crystallised from acetic acid in deep red needles, m. p. 210—215° (decomp.) (Found : C, 79·7; H, 6·3. Calc. for $C_{16}H_{16}O_2$: C, 80·0; H, 6·7%). Auwers and Markovits (*Ber.*, 1905, **38**, 226) have recorded the decomposition range as 207—217°. Evaporation of the ethereal solution gave a red gum (10·1 g.) which was distilled at 160—200° (oil-bath)/0·05 mm. The distillate, a mixture of *5-benzoyloxy*-m-2-*xylenol* (III) (1·5 g.) and 4 : 4′-dihydroxy-3 : 5 : 3′ : 5′-tetramethyldiphenyl (IV) (1·0 g.), was fractionally crystallised from light petroleum (b. p. 80—100°). The 5-benzoate crystallised in colourless plates, m. p. 140° (Found : C, 74·8; H, 5·9. $C_{15}H_{14}O_3$ requires C, 74·3; H, 5·8%). It was benzoylated in boiling pyridine solution and yielded 2 : 6-dimethylquinol dibenzoate, which crystallised from methanol in colourless needles, m. p. 116° unchanged on admixture with an authentic specimen prepared from 2 : 6-dimethylbenzoquinone by reduction and benzoylation. The 4 : 4′-dihydroxy-3 : 5 : 3′ : 5′-tetramethyldiphenyl proved to be identical with the substance obtained by reducing the diphenoquinone (V) with zinc dust in boiling acetic acid; it crystallised from methanol in colourless needles, m. p. 221° (Found : C, 79·1; H, 7·6. Calc. for $C_{16}H_{18}O_2$: C, 79·3; H, 7·45%) [diacetate, m. p. 172° (Found : C, 73·5; H, 6·8. Calc. for $C_{20}H_{22}O_4$: C, 73·6; H, 6·8%)]. Auwers and Markovits give the m. p.s as 220—221° and 174° respectively.

Oxidation of Mesitol.—Mesitol (13·6 g., 0·1 mol.) and benzoyl peroxide (24·2 g., 0·1 mol.) were refluxed in chloroform (250 ml.) for 12 hours. The bright red solution, worked up as above, gave benzoic acid (13·0 g., 0·11 mol.) and a 0·3 g. of deep-red, insoluble 3 : 5 : 3′ : 5′-tetramethylstilbene-4 : 4′-quinone (IX; R = Me). The latter was identical with the quinone obtained by oxidising mesitol in benzene solution with moist silver oxide (Porter and Thurber, *J. Amer. Chem. Soc.*, 1921, **43**, 1194) since samples prepared by both methods were readily reduced by zinc dust in boiling acetic acid to 4 : 4′-dihydroxy-3 : 5 : 3′ : 5′-tetramethylstilbene which crystallises from glacial acetic acid in colourless needles of m. p. and mixed m. p. 238°. Goldschmidt and Bernard (*Ber.*, 1923, **56**, 1963) give m. p. 225—235° and have verified the structure by synthesis. The dihydroxystilbene (1·2 g.) was hydrogenated at room temperature and atmospheric pressure in alcohol (50 ml.) over palladised charcoal (0·2 g.) to 4 : 4′-dihydroxy-3 : 5 : 3′ : 5′-tetramethyldibenzyl, colourless needles (from benzene), m. p. 168° (Found : C, 79·9; H, 8·1. Calc. for $C_{18}H_{22}O_2$: C, 80·0; H, 8·1%). Fries and Brandes (*Annalen*, 1939, **542**, 48) give m. p. 167°.

An ether-soluble neutral fraction from the oxidation of mesitol was a pale yellow oil (23·2 g.) which solidified on storage. It was purified by distillation at 0·02 mm. or, more simply, by treatment with half its weight of benzoyl chloride in boiling pyridine, and crystallised from methanol in colourless needles, m. p. 126—127° (Found: C, 74·8; H, 6·1. Calc. for $C_{16}H_{16}O_3$: C, 75·0; H, 6·2%). Its structure was established as 4-benzoyloxy-2 : 4 : 6-trimethyl*cyclo*hexa-2 : 5-dienone (VIII; R = Me, X = O·CO·Ph) thus: (i) it formed a red, very insoluble 2 : 4-dinitrophenylhydrazone, m. p. 270° (decomp.); (ii) on its thermal decomposition at 175°/30 mm., benzoic acid, m. p. and mixed m. p. 122, separated; (iii) on its oxidation (2·0 g.) with powdered potassium permanganate (3·7 g., *ca.* 4 O per mol.) in pure acetone (200 ml.) containing magnesium sulphate (6 g.), benzoic acid was again obtained; (iv) hydrogenation in alcohol at room temperature and pressure (palladised charcoal) gave benzoic acid, m. p. and mixed m. p. 122°, and mesitol, m. p. and mixed m. p. 71—72°, in equal amounts; (v) hydrolysis (of 2·0 g.) in a mixture of alcohol (30 ml.) and concentrated hydrochloric acid (20 ml.) for 3 hours under reflux gave a mixture from which ethyl benzoate (0·95 g.) was separated by steam distillation; the residue was treated with ferric chloride (2·0 g.) and again steam-distilled, and this distillate was treated with a little potassium iodide and then saturated with sulphur dioxide; after 24 hours the excess of sulphur dioxide was removed by boiling and the cooled solution was then extracted with ether; the extract yielded 2 : 6-dimethylquinol (0·15 g.), colourless needles (from xylene), m. p. 150° alone or mixed with an authentic specimen. Attempts, following Bamberger (*locc. cit.*), to synthesise the 4-benzoyloxy-2 : 4 : 6-trimethyl*cyclo*hexa-2 : 5-dienone (*a*) *via* its hydrolysis product (VIII; R = Me, X = OH) by the oxidation of mesitol with Caro's acid, or (*b*) by way of the reduction of nitromesitylene to mesitylhydroxylamine were unsuccessful.

*Oxidation of 4-Methyl-2 : 6-di-*tert.*-butylphenol.*—The phenol (11 g., 0·05 mol.) and benzoyl peroxide (12·1 g.) were refluxed in purified chloroform (150 ml.) for 70 hours. The bright red solution was then extracted with aqueous sodium hydrogen carbonate, the extracts were acidified, and benzoic acid (8·2 g., 0·67 mol.) was collected. Evaporation of the dried chloroform layer gave a bright red gum from which, by rubbing with ether (30 ml.), insoluble 3 : 5 : 3′ : 5′-*tetra*-tert.-*butylstilbene*-4 : 4′-*quinone* (IX; R = Bu^t) (1·0 g.) was removed by filtration. This crystallised from glacial acetic acid in crimson rods, m. p. 300° (decomp.) (Found: C, 82·7; H, 9·7. $C_{30}H_{42}O_2$ requires C, 82·9; H, 9·7%). Its reduction product, m. p. 230°, reoxidised rapidly on exposure to the air. The ethereal filtrate contained traces of unchanged reactants, but no other alkali-insoluble material could be isolated.

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