

Periodate Oxidation of Phenols

I. Monoethers of Pyrocatechol and Hydroquinone

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Treatment of monoalkyl, monobenzyl, and monophenyl ethers of pyrocatechol or hydroquinone with sodium metaperiodate leads mainly to oxidative removal of the ether substituent, with the formation of *o*- or *p*-quinone and the corresponding alcohol (or phenol). In the same way, 1- and 4-hydroxy-dibenzofuran undergo oxidative cleavage at the ring oxygen. These reactions presumably proceed *via* a quinol-like hemiketal intermediate.

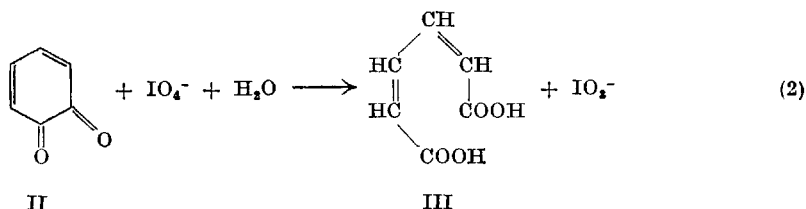
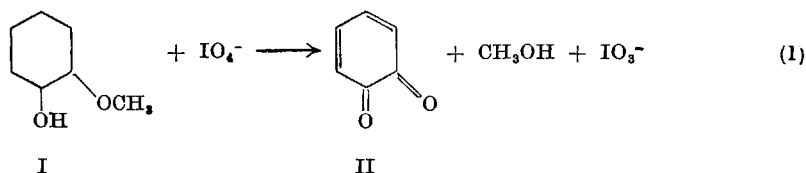
The monophenyl ether of hydroquinone gave the cleavage products (*p*-quinone and phenol), and in addition a compound, (2-hydroxyphenyl)-*p*-benzoquinone, obviously formed as a result of rearrangement and further oxidation of the intermediate.

The action of periodate on pyrocatechol and hydroquinone monoethers is discussed in comparison with that of some other specific oxidants, *e.g.*, sodium bismuthate, lead tetraacetate, and potassium nitrosodisulphonate.

PYROCATECHOL MONOETHERS

In a previous communication¹ it was reported that the treatment of guaiacol (I) with sodium metaperiodate in aqueous or dilute acetic acid solution resulted in the rapid liberation of nearly one mole of methanol per mole of phenol. A method of estimation of the number of guaiacyl residues with a free phenolic hydroxyl group in lignin was based on this result².

The formation of methanol was found to be complete in a few minutes. During this time about one mole of periodate per mole of guaiacol was consumed, and the solution acquired a dark-red colour indicating the formation of *o*-benzoquinone (II). This initial reaction was followed by further periodate consumption at a lower rate and *cis, cis*-muconic acid (III) was isolated¹ from the brownish solution finally obtained. These observations indicated the following as the main reactions in the rapid initial step (1) and the subsequent slower phase (2):



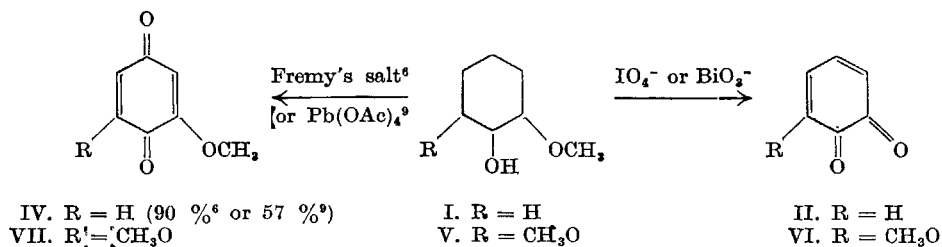
In the aqueous solvents used the oxidative cleavage by reaction (2) is accompanied by a competitive decomposition (polymerisation) of the *o*-benzoquinone primarily formed. It has been possible, however, to isolate *o*-benzoquinone in good yield by rapidly extracting the freshly prepared, dark-red aqueous mixture of guaiacol and periodate with methylene chloride. This proves the correctness of eqn. (1) for the initial step of the periodate oxidation of guaiacol.

Since oxidative demethoxylation with periodate proceeds readily with a great variety of guaiacol compounds¹, it appears to open a new way for the preparation of *o*-quinones. 4-Methyl-*o*-benzoquinone³ was obtained in 70 % yield after short treatment of 4-methylguaiacol (creosol) with periodate in aqueous solution. This periodate method can be considered complementary to the method of Teuber^{4,5}, which involves *ortho*-oxidation of *p*-substituted phenols by Fremy's salt (potassium nitrosodisulphonate, ON(SO₃K)₂). Unlike periodate, Fremy's salt attacks the free *o*-position rather than the methoxyl group of *p*-substituted guaiacols, 4-methylguaiacol, for instance, being converted into 3-methoxy-5-methyl-*o*-benzoquinone⁵.

The two oxidants mentioned also differ with respect to their behaviour towards guaiacols with a free *p*-position. The action of Fremy's salt on such phenols gives the corresponding *p*-quinones⁶; guaiacol, for instance, gives methoxy-*p*-benzoquinone (IV) in 90 % yield. In the reaction between guaiacol and periodate, however, the oxidation takes place almost exclusively at the 2-position, that is, at the ring carbon atom carrying the methoxyl group, with the formation of *o*-benzoquinone. As indicated by the formation of about 90 % of the calculated quantity of methanol, only about 10 % of the guaiacol is oxidised at the 4- and 6-positions.

The periodate method can therefore also be expected to be suitable for the preparation of *o*-quinones carrying a substituent in the 3-position and unsubstituted in the 5-position (II, R = substituent), from 6-substituted guaiacols (I, R = substituent). As yet, the action of periodate upon pyrogallol-1,3-dimethyl ether (V) has been examined and found to yield, under certain conditions, 3-methoxy-*o*-quinone (VI) as a major product.

Potassium bismuthate (KBiO_3), which was introduced by Rigby ⁷ as a glycol-splitting agent similar to periodate and lead tetraacetate, was found ⁸ to oxidise guaiacol in the same way as periodate, as shown in the reaction scheme below:



On the other hand, lead tetraacetate, although being largely equivalent to both periodate and bismuthate as a glycol-splitting agent, differs from the two latter oxidants but resembles Fremy's salt with regard to its action on guaiacols. Thus, similar to Fremy's salt ⁶, lead tetraacetate oxidises guaiacol and 2,6-dimethoxyphenol to give methoxy-*p*-quinone (IV) and 2,6-dimethoxy-*p*-quinone (VII) ⁹, respectively, without attacking the methoxyl groups.

In polar solvents such as acetone and methylene chloride, 3-methoxy-*o*-benzoquinone (VI) gave the hitherto unknown dimer, m.p. 139–140°. By the action of periodate this dimeric *o*-quinone was readily converted into 3,8-dimethoxy-1,2-naphthoquinone. Similarly, periodate oxidation of the recently described dimeric *o*-benzoquinone ²⁰ yielded 1,2-naphthoquinone. These reactions, as well as the periodate oxidation of V, will be further discussed in following communications.

Pyrocatechol and its homologues are also rapidly oxidised by periodate, giving the corresponding *o*-quinones. The action of periodate on 4-methylpyrocatechol, for instance, produced 4-methyl-*o*-quinone in high yield.

The oxidative cleavage of pyrocatechol monoethers is a general reaction. An investigation was made of its application to the following ethers: 1) guaethol (VIII) (the monoethyl ether of pyrocatechol); 2) 2-hydroxydiphenyl ether (IX) (as an example of pyrocatechol monoaryl ethers); 3) 4-hydroxy-dibenzofuran (X) (as an example of a cyclic monoaryl ether of pyrocatechol).

Guaethol (VIII), in aqueous solution or in 80% acetic acid, consumed about the same amount of periodate at about the same rate as guaiacol (Fig. 1). Ethanol was detected by gas phase chromatography in the distillate obtained from an aqueous guaethol-periodate reaction mixture after removal of excess periodate and iodate by precipitation with lead nitrate.

The initial attack of periodate on 2-hydroxydiphenyl ether (IX) in 80% acetic acid solution was appreciably slower than on the pyrocatechol monoalkyl ethers, and there was no distinct break in the periodate consumption curve after the consumption of one mole of periodate per mole of substance (Fig. 1). As shown by the formation of phenol, the reaction was, however, similar to that with the monoalkyl ethers.

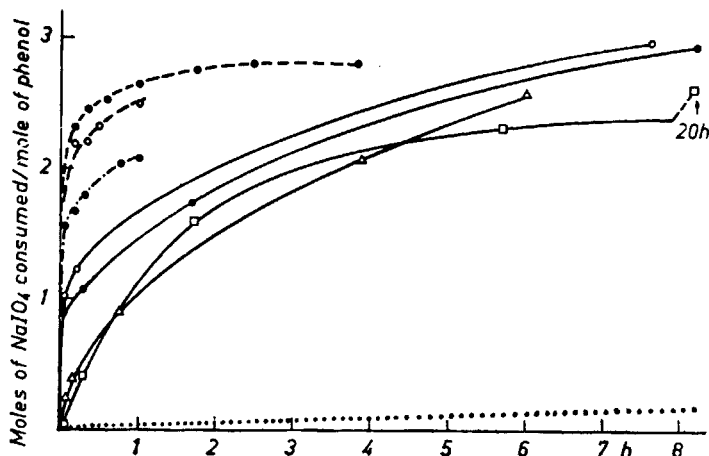
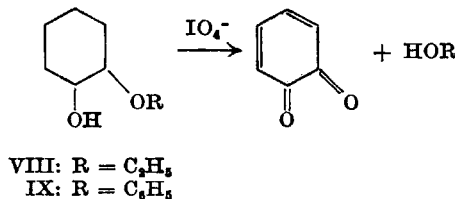


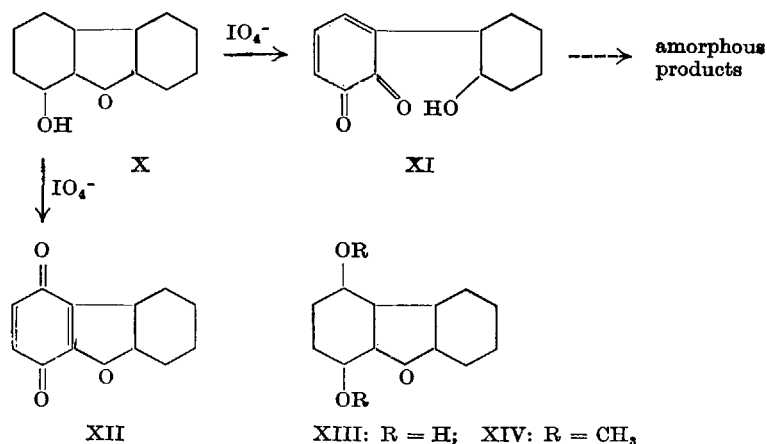
Fig. 1. Consumption of periodate by pyrocatechol monoethers. The reaction mixtures contained 10 mmole of the phenol and 70 mmole of NaIO_4 per litre.

● - - - -● Guaicol in water, 4°; ● - - - -● 25°; ● - - - -● in 80 % acetic acid, 25°. ○ - - - -○ Guaethol (VIII) in water, 25°; ○ - - - -○ in 80 % acetic acid, 25°. △ - - - -△ 2-Hydroxydiphenyl ether (IX); □ - - - -□ 4-Hydroxydibenzofuran (X); Phenol; in 80 % acetic acid, 25°.



Although excess periodate was present, phenol could be detected even after a reaction time of 48 h. Phenol, unlike pyrocatechol and its monoethers, thus reacts only very slowly with periodate (*cf.* Fig. 1). In this respect periodate differs from Fremy's salt which readily oxidises phenol to *p*-benzoquinone⁹. As will be described in a forthcoming communication, the homologues of phenol, with alkyl substituents at the *o*- or *p*-positions or at both, exhibit strongly enhanced reactivity towards periodate.

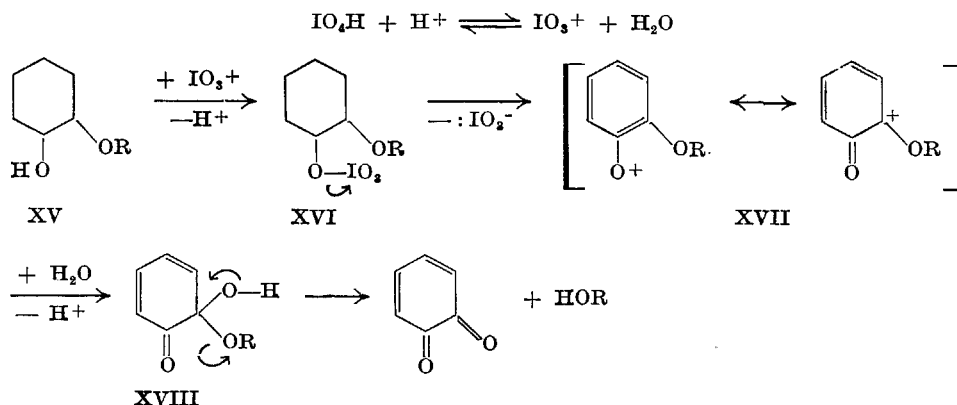
The periodate consumption curve of 4-hydroxydibenzofuran (X) (Fig. 1) was similar to that of IX, and the bulk of the material was converted into a brown, amorphous product. This may indicate that the reaction proceeded mainly in the normal way, *i.e.*, by *o*-oxidation, with the opening of the furan ring and the intermediate formation of the *o*-quinone XI, followed by polymerisation or by further periodate oxidation. A side-reaction, with *p*-oxidation of X to dibenzofuran-1,4-quinone (XII), m.p. 187—188°, occurred to an extent of about 15 %.



The structure of XII was demonstrated by reduction to the previously known 1,4-dihydroxy-dibenzofuran (XIII), m.p. 217—218^{°10}, and methylation of this compound to the dimethyl ether (XIV), m.p. 76—78^{°10}.

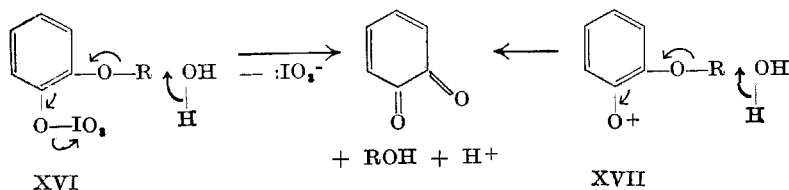
The quinone XII was regenerated in quantitative yield from the hydroquinone XIII when the latter was treated with periodate. Obviously, in compound XIII the dehydrogenation of the hydroquinone structure is more favoured than the oxidative ether cleavage (*cf.* also p. 515).

It was tentatively suggested in a previous communication¹ that the oxidative cleavage of pyrocatechol monoethers by periodate followed a radical mechanism involving two successive one-electron transfers. However, according to Levitt¹¹ a great variety of oxidants used in organic chemistry, including periodic acid, probably react by a two-electron transfer, thus giving rise to ionic mechanisms. Criegee¹² has adopted the views of Levitt for the mechanism of lead tetraacetate oxidation. Analogously, the main reaction between pyrocatechol monoethers and periodate can be represented as follows.



According to Levitt, the active species in periodate oxidation is the periodonium cation, IO_3^+ , (or its hydrates), formed in a reversible reaction from periodic acid by the loss of OH^- . The cation would attack the pyrocatechol monoether (XV) at the site of the greatest electron density, *i.e.* at the phenolic hydroxyl group, yielding the periodic acid aryl ester XVI, the phenolic hydrogen atom being released as a proton. The ester XVI can then decompose forming an iodate anion ("two-electron transfer") and the mesomeric aroxy cation XVII. Addition of a molecule of water to XVII would then give the *o*-quinol-like hemiketal XVIII and a proton and, finally, spontaneous decomposition of the hemiketal would yield the *o*-quinone and the alcohol HOR.

Alternatively, the ester XVI or the cation XVII may decompose directly, without the intermediate formation of the hemiketal XVIII, in a concerted reaction with a molecule of water as an electron donor:



The remarkable ease of oxidative cleavage of the pyrocatechol monoethers could suggest some specific relationship between the periodate molecule and the two *ortho* oxygen atoms of the pyrocatechol component, possibly involving the initial formation of a highly reactive periodic acid *di*ester-like complex. Such an assumption, however, seems superfluous, since, as described in the following section, hydroquinone monoethers, where such a complex is not possible, are split by periodate as readily as the pyrocatechol analogues.

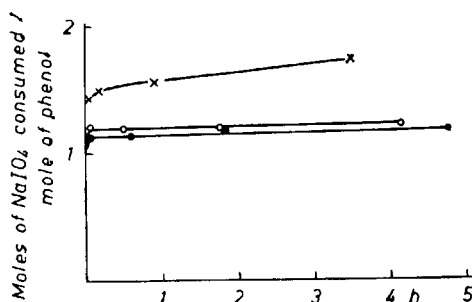


Fig. 2. Consumption of periodate by hydroquinone monoethers in 80 % acetic acid at 25°. Concentrations, same as given in Fig. 1.

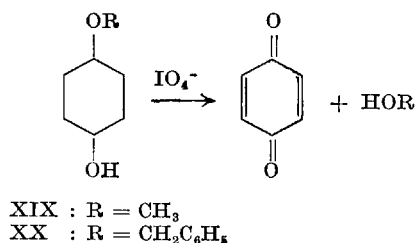
- Hydroquinone monomethyl ether (XIX).
- Hydroquinone monobenzyl ether (XX).
- ×—× Hydroquinone monophenyl ether (XXI).

HYDROQUINONE MONOETHERS

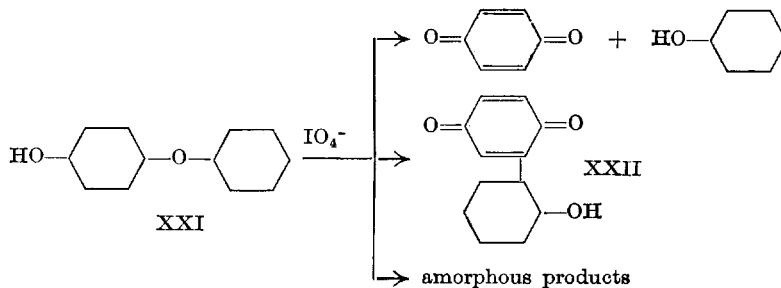
Hydroquinone itself is instantaneously oxidised by periodate (*cf.* also Ref.¹³) giving *p*-benzoquinone which, unlike *o*-benzoquinone, is stable in the presence of periodate. Four different monoethers of hydroquinone (XIX, XX, XXI, and XXIV) were examined.

Hydroquinone monomethyl ether (XIX), when treated with excess periodate in aqueous or aqueous acetic acid solution (80 % HOAc), consumed very rapidly slightly more than one mole of periodate (Fig. 2), yielding *p*-benzoquinone and 93—94 % of the calculated amount of methanol.

Hydroquinone monobenzyl ether (XX), in 80 % acetic acid, behaved similarly (Fig. 2). Benzyl alcohol was isolated as the 3,5-dinitrobenzoate.



The oxidation of hydroquinone monophenyl ether (XXI) was more complicated. In 80 % acetic acid it rapidly consumed about 1.4 mole of periodate. Dilution of the reaction mixture (after a reaction time of 30 min) yielded a brown, amorphous precipitate (about 14 % of the weight of compound XXI used). The expected reaction products, *p*-benzoquinone and phenol, were found in the reaction mixture; the yields of these products indicated that about 60 % of the starting material had undergone the "normal" ether cleavage reaction.



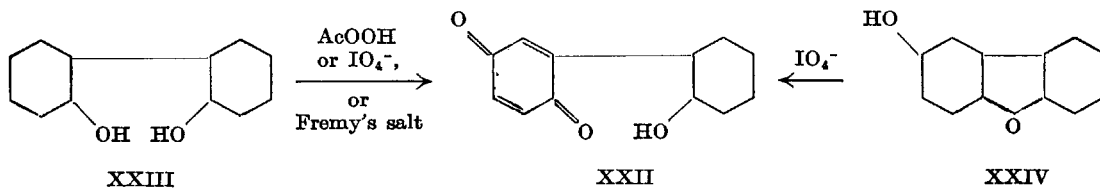
A brick-red crystalline substance, C₁₂H₈O₃, m.p. 196°, was also isolated from the solution in about 15 % yield. It was found to be identical with a product obtained by Grundmann¹⁴ by the oxidation of 2,2'-dihydroxydiphenyl (XXIII) with peracetic acid. On the basis of the analytical composition and the chemical properties of the red product Grundmann considered it to be (2-hydroxyphenyl)-*p*-benzoquinone (XXII). This structure has now been



Fig. 3. Light absorption of (2-hydroxyphenyl)-*p*-benzoquinone (XXII). Solvent: 95 % ethanol.

confirmed by the following observations. The red substance (light absorption curve, Fig. 3) was readily reduced by zinc dust in acetic acid to the hitherto unknown 2,2',5'-trihydroxydiphenyl (XXVII, see p. 513), obtained as a distillable colourless glass (b.p. 150°/0.001 mm Hg). Treatment of the latter product with periodate regenerated substance XXII. In harmony with the view that XXII is a *p*-quinone, it could be titrated with sodium thiosulphate¹⁵. The result of the titration indicated a molecular weight of 199 (calc. for C₁₂H₈O₃: 200). Oxidative degradation of XXII with hydrogen peroxide yielded salicylic acid, clearly indicating the presence of the 2-hydroxyphenyl residue.

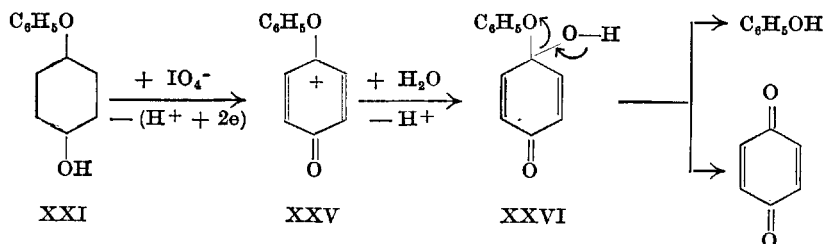
The quinone XXII was formed from 2,2'-dihydroxydiphenyl (XXIII) not only by peracetic acid according to Grundmann but also — although in a lower yield — on treatment with sodium periodate. The formation of a red compound was also observed by Teuber and Rau⁶ when XXIII was oxidised with Fremy's salt. The latter authors, however, could not decide whether the reaction product was XXII or an addition product of di-*p*-quinone and



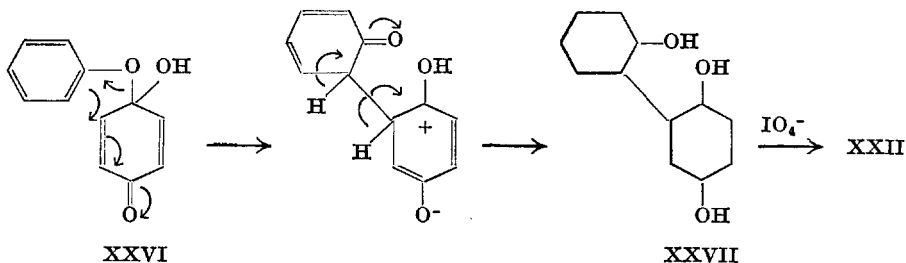
XXIII. It has now been established that the product prepared according to Teuber and Rau is identical with XXII, obtained by one of the methods mentioned above.

Treatment of a ring-closed analogue of XXI, 2-hydroxydibenzofuran (XXIV), with periodate resulted in cleavage of the cyclic ether bond and gave the (2-hydroxyphenyl)-*p*-benzoquinone XXII in good yield.

The mechanism of the oxidative cleavage of hydroquinone monoethers should be similar to that discussed above for the corresponding reaction of pyrocatechol monoethers. The oxidation of hydroquinone monophenyl ether (XXI), for instance, would then involve the intermediate steps of the mesomeric cation XXV and the *p*-quinol-like hemiketal XXVI, which would decompose to yield the major reaction products, phenol and *p*-quinone. The same result would be obtained by assuming concerted reactions similar to those given for the pyrocatechol series (p. 510).



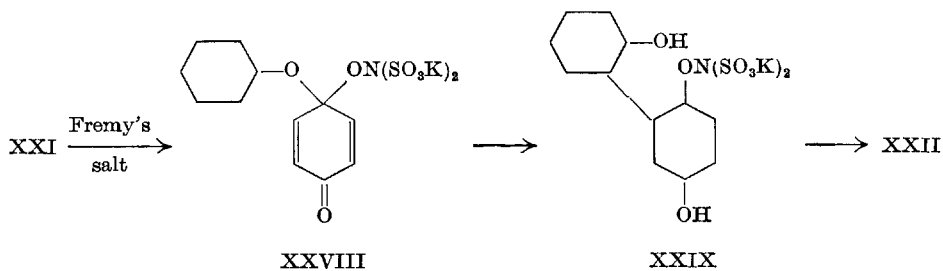
The side-reaction giving XXII that occurs in the oxidation of XXI, can be easily understood as the result of the rearrangement of the hypothetical *o*-quinol-like intermediate XXVI. This would yield the aromatic 2,2',5'-trihydroxydiphenyl (XXVII) which, in the presence of periodate, would be oxidised to XXII, as described above (p. 512). The rearrangement $\text{XXVI} \rightarrow \text{XXVII}$ is comparable to that undergone



by ordinary *p*-quinols, although here this reaction requires the presence of a strong acid (*cf.* Bamberger¹⁶, Witkop¹⁷).

No systematic comparison has yet been made of the action of periodate and other specific oxidants on hydroquinone monoethers, but some preliminary conclusions can be drawn from the experimental material available. As in the case of the pyrocatechol monoethers, the action of sodium bismuthate is

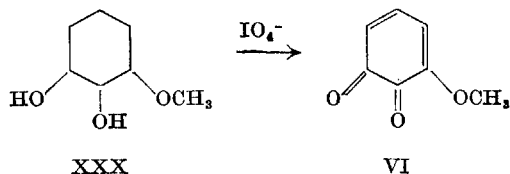
quite similar to that of periodate, the oxidative cleavage of the hydroquinone monoethers into *p*-quinone and the corresponding alcohol being the main reaction⁸. It has been reported that lead tetraacetate reacts with hydroquinone monomethyl ether; however, the reaction products have not been isolated⁹. Fremy's radical does not affect the ether groupings of the monomethyl and monobenzyl ethers of hydroquinone (XIX, XX), but gives high yields of 4-methoxy and 4-benzyloxy-*o*-quinone, respectively⁵. This is analogous to the reaction between Fremy's salt and 4-alkylphenols, and is also in accordance with the production of methoxy-*p*-quinone (IV) from guaiacol⁶ by the same oxidant. Surprisingly enough, it has now been found that hydroquinone monophenyl ether (XXI), when treated with Fremy's salt, is converted into (2-hydroxyphenyl)-*p*-quinone (XXII), which is also obtained as a by-product in the reaction between periodate and XXI. Since *p*-benzoquinone and phenol are not formed in the reaction between Fremy's salt and XXI it seems that the latter reaction does not proceed *via* the quinol-like intermediate XXVI, which has been assumed to be the precursor, in the periodate reaction, of the cleavage products (*p*-quinone and phenol) as well as of the rearrangement product XXII. The result of the oxidation of XXI by Fremy's salt suggests, that the primary intermediate could be the quinitol-like substance XXVIII, which would undergo direct rearrangement to XXIX, followed by conversion of the latter into XXII.



Quinitol-like substances of type XXVIII have been obtained by Teuber and Götze¹⁸, by the oxidation of phenanthrols and naphthols with Fremy's salt.

At the same time as the investigations described in the preceding sections, an examination was also made of the periodate oxidation of pyrogallol-1-methyl ether (XXX), methoxyhydroquinone (XXXI), 2,5-dimethoxyhydroquinone (XXXII), and 2,4-dimethoxyphenol (XXXIII).

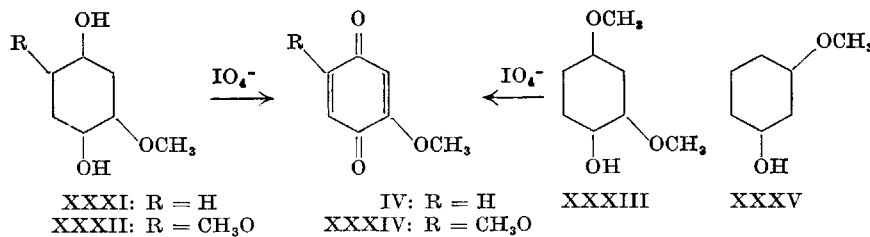
Oxidation of XXX with an equimolar amount of periodate yielded 3-methoxy-*o*-quinone (VI) in a yield of 57%. As XXX contains a free "pyro-



catechol" as well as a "pyrocatechol monoether" grouping, the result indicates that the former grouping is more easily attacked than the latter one.

When XXX was treated with excess periodate, a 58 % yield of VI could be isolated after 2 min. About 1.5 mole of periodate was consumed in this time; on more prolonged oxidation there was further consumption of periodate. The quinone VI also consumed appreciable amounts of the oxidant (about 2 mole of periodate after 20 h). In both cases, almost one mole of methanol was liberated. This periodate degradation of 3-methoxy-*o*-quinone (VI) is being further investigated.

The hydroquinone groupings in methoxyhydroquinone (XXXI) and in 2,5-dimethoxyhydroquinone (XXXII) were so rapidly oxidised that the methoxyl groups of the "pyrocatechol monoether" groupings also present in these compounds remained unaffected (*cf.* also the oxidation of XIII, p. 509). The corresponding *p*-quinones (IV and XXXIV) were produced in practically quantitative yields; unlike the 3-methoxy-*o*-quinone (VI), they were not further attacked by periodate.



The preparation of *p*-quinones from the corresponding hydroquinones, by periodate oxidation, seems to be widely applicable. In addition to the examples reported above, a quantitative conversion of tetrabromohydroquinone into bromanil has also been made.

2,4-Dimethoxyphenol (XXXIII), when treated with an excess of periodate, yielded one mole of methanol and methoxy-*p*-quinone (IV). Thus, of the "pyrocatechol monoether" and the "hydroquinone monoether" groupings, both of which are present in XXXIII, the latter grouping was attacked preferentially.

A few experiments with resorcinol monomethyl ether (XXXV) confirmed the expectation that the rapid ether cleavage reaction is confined to the monoethers of the pyrocatechol and hydroquinone series. The resorcinol ether consumed periodate comparatively slowly, although appreciably faster than phenol (*cf.* Fig. 1). After a reaction time of 16 h, 0.11 mole of methanol had been liberated and a small quantity of methoxy-*p*-quinone (IV) could be isolated. Obviously, there was a slow oxidation in the positions *ortho* and *para* to the phenolic hydroxyl group, giving methoxy-*p*-quinone and methoxy-*o*-quinone. The latter appears to be the source of the methanol formed (*cf.* above).

Some of the experiments reported in the present work have been carried out by civilingenjör Britt Berggren and civilingenjör C.-G. Setterquist.

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EXPERIMENTAL

Periodate consumption. For oxidation in an aqueous medium a 0.02 M solution of the phenol was mixed with an equal volume of 0.14 M sodium periodate. The mixture was kept in a thermostat at 25° (in one case, cf. Fig. 1, at 4°) protected from direct daylight. The amount of periodate present was determined on 5 ml samples by the arsenite method.

In most cases 80 % acetic acid solutions were used, and the residual periodate was determined by a potassium iodide-thiosulphate method. As the quinones formed would consume thiosulphate, they had to be removed. The following procedure was used.

The reaction mixture sample (5 ml) was added to a separatory funnel containing 20 ml of water, and the mixture was extracted with three 10 ml portions of methylene chloride. The aqueous layer was added to a mixture of 0.1 N sodium thiosulphate (30 ml) and 10 % potassium iodide (15 ml). After the addition of a few millilitres of 2 N sulphuric acid, the unconsumed thiosulphate was determined by iodine titration. A blank determination was made on a solution without phenol, and the amount of periodate consumed was obtained by difference.

Methanol was determined as described previously¹.

Oxidation of guaiacol. a) To an ice-cold aqueous solution (150 ml) of guaiacol (3.0 g = 24.2 mmole) a similarly cooled solution of sodium metaperiodate (10.5 g = 49.1 mmole) in water (75 ml) was added at once, and the resulting dark-red mixture immediately extracted with methylene chloride (100 ml). The extract was shortly dried over anhydrous sodium sulphate, filtered, and rapidly concentrated to a volume of about 20 ml by means of a rotating vacuum evaporator. After the addition of hexane the solution deposited dark-red crystals of *o*-benzoquinone, no sharp m.p., decomposition beginning at 60–70°, as described by Willstätter and Pfannenstiel¹⁹; yield 64 %.

b) In another experiment the methylene chloride solution obtained as above was brought to dryness under reduced pressure, and the dark-red, crystalline residue (2.5 g) immediately treated with aqueous sulphur dioxide. From the resulting solution a very small amount of undissolved material (identified as dimeric *o*-benzoquinone, see below) was removed by filtration. Continuous extraction of the solution with ether yielded *pyrocatechol* (56 %, based on the amount of guaiacol used), m.p. 103–104° after recrystallisation from benzene-hexane.

c) If the methylene chloride solution of *o*-benzoquinone obtained according to a) was kept in the refrigerator for several hours, it deposited a brown crystalline product, which became yellow on washing with acetone. Yield 45 %. It was identified by m.p., mixed m.p., and infra-red absorption spectrum with the dimeric *o*-benzoquinone which was recently obtained²⁰ from acetone solutions of *o*-benzoquinone.

4-Methyl-o-benzoquinone (homo-o-quinone). a) Creosol (4-methylguaiacol, 414 mg = 3 mmole) dissolved in ether (5 ml), was added to an aqueous solution (100 ml) of sodium metaperiodate (706 mg = 3.3 mmole) which was cooled by ice-water. After 15 min, the orange-red reaction mixture was extracted four times with methylene chloride, the red-green dichroic extract was dried over anhydrous calcium sulphate and the solvent was removed under reduced pressure. The dark-red crystalline residue was dissolved in ether; on cooling to –60° the solution deposited red prismatic needles, m.p. 75°; yield 70 %. Recrystallisation from ether or ether-petroleum ether yielded 4-methyl-*o*-quinone, either the red modification, m.p. 80°, or the yellowish-pink modification, m.p. 65–67°^{3,5}. Admixture of similar samples, obtained from *p*-cresol according to Teuber and Staiger⁵, gave no depression of the m.p. The infra-red absorption spectra of the two modifications, obtained by either method, were identical.

b) 4-Methyl-*o*-quinone was obtained in a similar way by oxidation of 4-methyl-*pyrocatechol* (see below) with periodate. The yield of the crude product, m.p. 75°, was 95 %.

4-Methyl-pyrocatechol (homopyrocatechol). The orange-red aqueous solution obtained by periodate oxidation of creosol as described above was saturated with sulphur dioxide and, after addition of sodium chloride, extracted with ether. The ethereal solution was dried and evaporated, and the slightly brown, oily residue was extracted several times with boiling hexane. The combined hexane solutions yielded 4-methyl-*pyrocatechol*, colourless thin plates, m.p. 66–67°; yield 62 %.

Oxidation of 4-hydroxydibenzofuran (X). a) 4-Hydroxydibenzofuran (2.0 g = 10.9 mmole) was added in portions to a solution of sodium metaperiodate (12.0 g = 56 mmole)

in 60 % aqueous acetic acid (400 ml). The reaction mixture was shielded from daylight and kept at 25° for 15 h. The addition of water (400 ml) to the red-brown solution produced a flocculent brown precipitate which was filtered off. The filtrate was extracted with methylene chloride and the extract was washed with water, dried over anhydrous sodium sulphate and evaporated under reduced pressure. Sublimation of the residue (bath temperature 100°, 3 mm Hg) and recrystallisation of the sublimate from hexane yielded *dibenzofuran-1,4-quinone* (XII) as yellow needles, m.p. 187–188°; yield 108 mg (5 %). (Found: C 72.13, 72.12; H 3.36, 3.21. Calc. for C₁₂H₆O₃: C 72.73; H 3.05.)

Reduction of XII (10 mg) with zinc dust in glacial acetic acid, followed by dilution with water and extraction with ether yielded the known *1,4-dihydroxydibenzofuran* (XIII), needles, m.p. 217–219° (217–218°¹⁰) after recrystallisation from water.

b) 4-Hydroxydibenzofuran (XII) (3.0 g) was oxidised with periodate as above. The solid residue obtained after evaporation of the methylene chloride solution (crude quinone XII) was reduced with zinc in acetic acid and the reaction mixture was diluted with water, heated and filtered. The filtrate deposited 0.50 g of the hydroquinone XIII; yield 15 %.

Methylation of XIII with dimethyl sulphate yielded *1,4-dimethoxydibenzofuran* (XIV), m.p. 76–78° (78.5°¹⁰) after recrystallisation from hexane.

A solution of *1,4-dihydroxydibenzofuran* (XIII) (10 mg) in glacial acetic acid (1 ml) was mixed with a solution of sodium metaperiodate (60 mg) in 60 % acetic acid (2 ml). Dilution with water and extraction with methylene chloride gave the quinone XII in quantitative yield.

Oxidation of hydroquinone monomethyl ether (XIX). Hydroquinone monomethyl ether (1.0 g = 8.06 mmole), dissolved in water (100 ml), was oxidised with sodium metaperiodate (5.17 g = 24.2 mmole) in aqueous solution (75 ml). Extraction with methylene chloride after a reaction time of 10 min yielded *p-benzoquinone*; yield, after sublimation, 80 %.

Solutions of hydroquinone monomethyl ether (5 mmole) and sodium metaperiodate (35 mmole) in water (25 ml) were cooled to 4° and mixed. After 5 min, 15 % lead nitrate solution (25 ml) was added. The methanol formed was determined as described by Adler and Hernestam¹. The *p*-quinone in the filtrate was irreversibly adsorbed during the filtration through the anion exchange resin. The yield of *methanol* was 15.1 mg (94 %). In a similar experiment with a reaction time of 19 h the yield of *methanol* was 93 %.

Oxidation of hydroquinone monobenzyl ether (XX). A solution of sodium metaperiodate (8.0 g) in 60 % acetic acid (50 ml) was added to a solution of XX (4.0 g) in glacial acetic acid (250 ml). After 15 min the mixture was diluted with water and extracted with methylene chloride. The methylene chloride solution was washed with sodium hydroxide solution to remove *p*-quinone and then with water, dried over anhydrous sodium sulphate and evaporated. Distillation of the liquid residue gave *benzyl alcohol* (b.p. 200–205°, about 2 ml), which yielded a 3,5-dinitrobenzoate, m.p. 112°, undepressed on admixture with authentic benzyl-3,5-dinitrobenzoate (m.p. 112°).

p-Quinone was isolated from a second experiment.

Oxidation of hydroquinone monophenyl ether (XXI). a) A solution of XXI (1.0 g = 5.38 mmole) in glacial acetic acid (10 ml) was mixed with sodium periodate (3.0 g = 14.0 mmole) dissolved in 60 % acetic acid (100 ml). After 30 min the mixture was diluted with water to a volume of 1 l, the brown amorphous precipitate formed was removed by filtration, and the filtrate was extracted with methylene chloride. The methylene chloride solution was washed with water and evaporated, and the residue was steam-distilled. The yellow distillate was made up to a volume of 250 ml. The ultra-violet absorption showed that the solution contained 0.21 g of *p*-quinone (yield 35 %; control experiments showed that steam distillation of *p*-quinone involves appreciable loss of material). The solution was extracted with ether. Careful evaporation of the yellow ether extract gave a red residue recrystallised from hexane to give red needles, m.p. 70°, identical with «*phenoquinone*», the addition compound of phenol (2 mole) and *p*-quinone (1 mole).

The phenoquinone isolated was combined with the residue from evaporation of the hexane mother liquor and the combined products were dissolved in aqueous sodium hydroxide and shaken with air until the quinone odour had disappeared. The mixture was then neutralised with carbon dioxide and extracted with ether. The ether extract was evaporated and the residue dissolved in water. Addition of bromine yielded *tri*-

bromophenol (0.86 g), m.p. 89°, after recrystallisation and sublimation m.p. 93.5°, undepressed by an authentic sample; yield 54 %.

b) A solution of XXI (1.62 g = 8.72 mmole) in glacial acetic acid (25 ml) was treated with sodium periodate (4.20 g = 19.6 mmole) dissolved in 60 % acetic acid (75 ml). After 30 min the mixture was diluted with water (500 ml) and the amorphous precipitate formed was collected, washed with water, and dried. Yield 13.5 % of the weight of the starting material. The filtrate was extracted several times with methylene chloride and the extract was washed with water, dried over anhydrous sodium sulphate, and evaporated. The volatile phenoquinone was removed by sublimation (0.1 mm Hg) for 2 h. Recrystallisation of the residual product from ethyl acetate gave red prisms (0.18 g), m.p. 196°. Admixture of (2-hydroxyphenyl)-*p*-quinone (XXII) prepared according to Grundmann¹⁴, m.p. 196° after recrystallisation from ethyl acetate, did not depress the m.p. Yield 10 %. (Found: C 71.97, 72.14; H 4.37, 4.33. Calc. for C₁₆H₈O₃: C 71.99; H 4.03.)

Substance XXII (98.60 mg), partially dissolved in a mixture of acetic acid and water, was slowly titrated with 0.1000 N sodium thiosulphate¹⁵; towards the end of the titration the mixture was heated to 40°. The substance gradually dissolved, yielding a colourless solution. Thiosulphate consumed: 4.94 ml, indicating a molecular weight of 199. Calc. for C₁₆H₈O₃: 200.18.

2,2',5'-Trihydroxydiphenyl (XXVII). Substance XXII (166 mg), dissolved in glacial acetic acid, was reduced with zinc dust. The solution obtained was diluted with water, extracted with ether, and the ethereal solution was washed with water and aqueous sodium bicarbonate, dried over anhydrous sodium sulphate, and evaporated giving a viscous oil which distilled at 150°/0.001 mm Hg. At room temperature the distillate (106 mg) was a colourless glass. (Found: C 69.96; H 5.13. Calc. for C₁₂H₁₀O₃: C 71.28; H 4.99.) Attempts to obtain crystalline derivatives (acetate, methyl ether, aryloxyacetic acid) were unsuccessful.

Substance XXVII (0.1 g), dissolved in glacial acetic acid (10 ml), was added to a solution of sodium metaperiodate (0.3 g) in 60 % acetic acid (10 ml). After 5 min the mixture was diluted with water, and the red quinone XXII was extracted with ether. It was recrystallised from ethyl acetate, m.p. and mixed m.p. 196°; yield nearly quantitative.

Similar oxidation of 2,2'-dihydroxydiphenyl (XXIII) with periodate yielded the quinone XXII in 5 % yield.

Oxidative degradation of (2-hydroxyphenyl)-p-quinone (XXII). Treatment of XXII (115 mg) with alkaline hydrogen peroxide, following the procedure used by Kögl, Erxleben, and Jänecke²¹ for the degradation of 4,2',5'-trihydroxydiphenyl yielded *salicylic acid*, m.p. 157–159°, undepressed by an authentic sample. Yield 23 mg (26 %).

Oxidation of 2-hydroxydibenzofuran (XXIV). Substance XXIV (0.468 mmole), dissolved in glacial acetic acid (15 ml) was oxidised with sodium metaperiodate (2.10 mmole) dissolved in 60 % acetic acid (15 ml). The quinone XXII (45 mg) was obtained; yield 49 %.

Oxidation of hydroquinone monophenyl ether (XXI) with Fremy's salt. Substance XXI (0.5 g = 2.69 mmole) dissolved in methanol (12.5 ml) was added to an aqueous solution (150 ml) of Fremy's salt (3.0 g = 11.2 mmole). A red precipitate formed instantly, m.p. 180–185°. After recrystallisation from ethyl acetate the m.p. was 195–196°, undepressed on admixture of quinone XXII. Yield 63 %.

Oxidation of pyrogallol-1-methyl ether (XXX). a) Aqueous solutions of XXX (250 ml, containing 0.35 g = 2.5 mmole) and sodium metaperiodate (250 ml, containing 0.535 g = 2.5 mmole), cooled with ice-water, were mixed, and, after 2 min, the resulting dark-red solution was repeatedly extracted with methylene chloride. The extract was shortly dried over anhydrous sodium sulphate and evaporated to dryness under reduced pressure. The residue was dissolved in boiling ether, and the ethereal solution, after filtration and cooling to -80°, deposited red-brown crystals of 3-methoxy-*o*-quinone (VI) (yield 57 %), m.p. 106–109°, undepressed on admixture of VI prepared according to Willstätter and Müller³, m.p. 107–110°. The occurrence of a weak carbonyl band at 5.75 μ in the infrared absorption curve of the periodate product indicated the presence, in the latter product, of small amounts of the dimeric 3-methoxy-*o*-quinone, which will be described in a forthcoming communication.

b) In a similar experiment aqueous solutions (25 ml) of 73.5 mg of XXX (= 0.53 mmole) and 750 mg of periodate (= 3.5 mmole) (molar ratio about 1 : 7) were mixed. The yield of 3-methoxy-*o*-quinone was 58 %.

c) In an oxidation experiment according to b) the reaction time was increased to 24 h. The reaction mixture was found to contain 14.72 mg of methanol; yield 96 %.

Oxidation of methoxyhydroquinone (XXXI). Methoxyhydroquinone (67 mg = 0.62 mmole) was added to an aqueous solution (15 ml) of sodium metaperiodate (450 mg = 2.10 mmole), and the mixture was shaken for 1 h in a separatory funnel. The resultant yellow solution contained yellow crystalline material; it was extracted with methylene chloride. The extract yielded *methoxy-p-quinone* (IV) (65.4 mg), m.p. 142–146°, undepressed by authentic material. Yield 99 %.

Oxidation of 2,5-dimethoxyhydroquinone (XXXII). An aqueous solution (15 ml) of sodium metaperiodate (450 mg = 2.10 mmole) was added to a solution of the hydroquinone (131 mg = 0.77 mmole) in water (10 ml). After 30 min the crystalline precipitate formed (120 mg) was collected; extraction of the filtrate with methylene chloride yielded 5 mg of the same product, *2,5-dimethoxy-p-quinone* (XXXIV). The substance darkens at 310° without melting. Yield 96 %. At a bath-temperature of 160–180° and 0.1 mm Hg the material sublimed almost completely.

Reduction with zinc dust in glacial acetic acid regenerated the hydroquinone XXXII, m.p. 167–70°.

Oxidation of 2,4-dimethoxyphenol (XXXIII). a) Aqueous solutions of 2,4-dimethoxyphenol (50 ml containing 168 mg = 1.1 mmole of the phenol) and of sodium metaperiodate (1.5 g = 7.0 mmole in 100 ml) were mixed; after 15 min the yellow solution was extracted with methylene chloride. The solvent was evaporated and the residue was sublimed (100°, 20 mm Hg) giving *methoxy-p-quinone* (91 mg), identified by m.p. and mixed m.p. Yield 60 %.

b) Two reaction mixtures were prepared in the same way as in a) and kept at 4°; an excess of sodium pyrosulphite was added after reaction times of 15 and 120 min, respectively. From each solution 100 millilitres were distilled off, the distillate was made alkaline and redistilled, and the amount of methanol present in the final distillate was determined⁴. Both experiments gave 0.90 mole of methanol per mole of 2,4-dimethoxyphenol.

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