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LETTERS

# Oxidation of 4,4'-diphenoquinones giving *p*-benzoquinones

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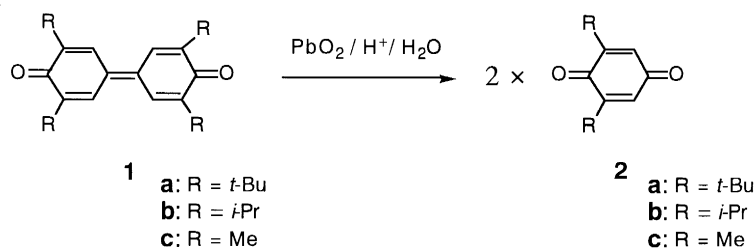
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## Abstract

4,4'-Diphenoquinone **1a** can be oxygenated to give *p*-benzoquinone **2a** when treated with PbO<sub>2</sub> in a solvent containing an aqueous acid. The conversion of **1a** is facilitated when the acid is strong and the solvent is of low basicity. The concentration of H<sub>2</sub>O in the medium also has a profound effect on the rate of conversion of **1a**. These facts may indicate that protonation of **1a** is the first step in the conversion into **2a**. 4,4'-Diphenoquinones **1b** and **1c** can be analogously converted into *p*-benzoquinones **2a** and **2b**, respectively. Benzoquinones **2** can thus be the ultimate products of both oxygenation and dehydrogenative dimerization of phenols **3**. © 2000 Elsevier Science Ltd. All rights reserved.

*p*-Benzoquinones are versatile starting materials for the preparation of various compounds.<sup>1</sup> A number of reagents can produce *p*-benzoquinones from 4-unsubstituted phenols as the ultimate products of oxygenation. In such oxidations, however, the benzoquinones are frequently accompanied by 4,4'-diphenoquinones, the eventual products of dehydrogenative C–C coupling of the phenols, as the minor products or as the major ones.<sup>2</sup> Isolation of *p*-benzoquinones from mixtures containing the corresponding 4,4'-diphenoquinones is often tedious principally because the latter, crystalline products, show significantly poorer solubility than the former ones in common organic solvents. Up to now, only a limited number of oxidation methods including Fremy's salt,<sup>3</sup> Jones reagent<sup>4</sup> and thallium(III) nitrate<sup>5</sup> have been used for preparation of *p*-benzoquinones from 4-unsubstituted phenols. These methods provide little or no 4,4'-diphenoquinones. We herein wish to report that in the presence of a strong aqueous acid, 4,4'-diphenoquinones can be oxygenated by PbO<sub>2</sub> to give the corresponding *p*-benzoquinones and that *p*-benzoquinones can thus be the ultimate products of both oxygenation and dehydrogenative coupling of 4-unsubstituted phenols.

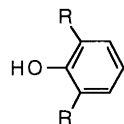


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We have recently reported a new method of the preparation of *p*-benzoquinones from 4-unsubstituted phenols. It consists of treating the phenols briefly with PbO<sub>2</sub> in AcOH containing 70% HClO<sub>4</sub>.<sup>6</sup> In this conversion, the choice of solvent is important. For instance, the oxidation of 2,6-di-*tert*-butylphenol (**3a**) with this method affords 2,6-di-*tert*-butyl-*p*-benzoquinone (**2a**) in nearly quantitative yield and no 3,5,3',5'-tetra-*tert*-butyl-4,4'-diphenoquinone (**1a**), whereas varied amounts of **1a** are yielded in addition to **2a** if AcOH is replaced by other solvents such as acetone or DME. In continuation of this study, prolonging the reaction time of **3a** with PbO<sub>2</sub>/70% HClO<sub>4</sub> in, for example, DME was found to increase the yield of **2a** and decrease that of **1a**, although relatively slowly. The result appeared to indicate that both oxygenation (giving **2a**) and dehydrogenative dimerization (giving **1a**), of **3a** took place rapidly and, unexpectedly, conversion of **1a** into **2a** followed under the reaction conditions.



- 3**
- a:** R = *t*-Bu
  - b:** R = *i*Pr
  - c:** R = Me

To confirm that **1a** could indeed be oxygenated, the reaction of **1a** with PbO<sub>2</sub>/70% HClO<sub>4</sub> was carried out in various solvents (Table 1). As expected, **1a** was found to be converted into **2a**. However, the rate of conversion was very much dependent on the solvent. Consumption of **1a** was complete or almost complete and **2a** was obtained in 45–74% yield when the reaction was done in MeCN, acetone or AcOH. A significant amount of **1a** was recovered unchanged from the reaction in DME. The reaction in MeOH was quite slow and only a small amount of **2a** was yielded. It appeared that the rate of oxidation of **1a** is enhanced by a solvent with low basicity.<sup>7</sup> If so, the concentration of H<sub>2</sub>O, which is relatively basic,<sup>7</sup> in the medium should also have a profound effect on the rate of reaction of **1a**. In fact, a substantial decrease in the rate of conversion of **1a** was observed when the reaction in acetone (run 5, Table 1) was carried out in the presence of a relatively small amount (0.5 mL) of added H<sub>2</sub>O: only 44% of **1a** was consumed. Employing more H<sub>2</sub>O (2 mL) totally inhibited the reaction of **1a**.<sup>8</sup>

Table 1  
Conversion of **1a** into **2a** with PbO<sub>2</sub> and 70% HClO<sub>4</sub> in various solvents<sup>a</sup>

Run	Solvent	Recovery of <b>1a</b> (%)	Yield of <b>2a</b> (%) <sup>b</sup>
1	MeOH	97	1
2	DME	50	32
3	AcOH	trace	53
4	MeCN	0	45
5	acetone	0	74

<sup>a</sup> To a stirred mixture of **1a** (0.5 mmol), 70% HClO<sub>4</sub> (2 mL) and a solvent (30 mL), PbO<sub>2</sub> (2.5 mmol) was added, and the resulting mixture was stirred for 15 min.

<sup>b</sup> Calculated based on assumption that one equiv of **1a** produces two equiv of **2a**.

The reaction of **1a** to give **2a** with  $\text{PbO}_2$  and various aqueous acids in acetone was also tested (Table 2). Compound **1a** was quantitatively recovered when  $\text{CF}_3\text{CO}_2\text{H}$  was employed as the acid. With  $\text{MeSO}_3\text{H}$ , **2a** was obtained but recovery of **1a** was also substantial. The reaction with  $\text{CF}_3\text{SO}_3\text{H}$  was fast and only a small amount of **1a** was recovered. As described above, consumption of **1a** was complete in the reaction in the presence of  $\text{HClO}_4$ . The results appeared to suggest that a stronger acid accelerates the reaction of **1a**.

Table 2  
Conversion of **1a** into **2a** with  $\text{PbO}_2$  and various aqueous acids in acetone<sup>a</sup>

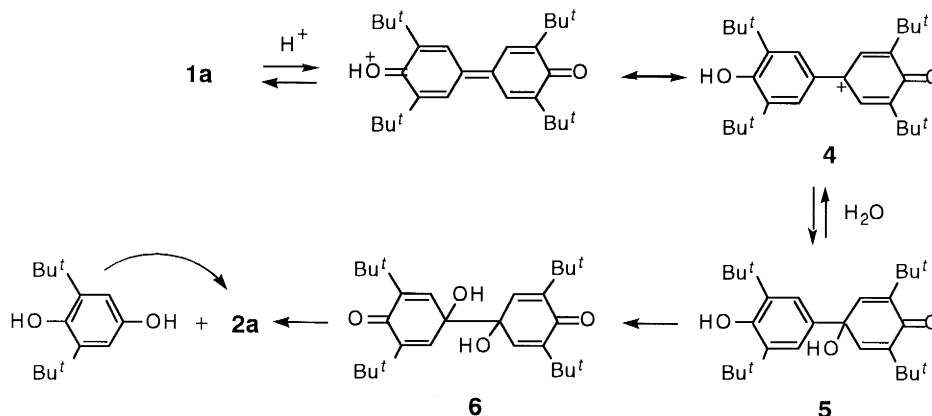
Run	Acid	Recovery of <b>1a</b> (%)	Yield of <b>2a</b> (%) <sup>b</sup>
1	$\text{CF}_3\text{CO}_2\text{H}$	100	0
2	$\text{MeSO}_3\text{H}$	60	25
3	$\text{CF}_3\text{SO}_3\text{H}$	8	62
4 <sup>c</sup>	$\text{HClO}_4$	0	74

<sup>a</sup> To a stirred mixture of **1a** (0.5 mmol),  $\text{H}_2\text{O}$  (1 mL), an acid (23 mmol) and acetone (30 mL),  $\text{PbO}_2$  (2.5 mmol) was added, and the resulting mixture was stirred for 15 min.

<sup>b</sup> Calculated based on assumption that one equiv of **1a** produces two equiv of **2a**.

<sup>c</sup> Identical with run 5, Table 1. One mL of 70%  $\text{HClO}_4$  consists of  $\text{HClO}_4$  (11.6 mmol) and  $\text{H}_2\text{O}$  (0.5 mL).

From the facts shown above, it may be reasonably assumed that reaction of **1a** proceeds as shown in Scheme 1. Protonation of **1a** to generate cation **4** is the primary step in the conversion into **2a**. To protonate **1a** effectively, which may be weakly basic, employment of a strong acid and a weakly basic medium is required. The reaction of **4** with  $\text{H}_2\text{O}$  to give phenol **5** must be reversible as exposure of **1a** to a mixture of 70%  $\text{HClO}_4$  and acetone resulted in the complete recovery of **1a**. Since **3a** can be directly oxygenated by  $\text{PbO}_2/70\% \text{HClO}_4$  (see above), oxygenation of **5** with the same oxidant or with  $\text{PbO}_2$  and other strong aqueous acids to give bis(cyclohexadienone) **6** ought to be a feasible process.<sup>9</sup>



Scheme 1.

The conversion of a 4,4'-diphenoquinone to a *p*-benzoquinone appears to be a general reaction. This was supported by the fact that 3,5,3',5'-tetraisopropyl- (**1b**) and 3,5,3',5'-tetramethyl-4,4'-diphenoquinone (**1c**) were converted into 2,6-diisopropyl- (**2b**) and 2,6-dimethyl-*p*-benzoquinone (**2c**), respectively, by oxidation with PbO<sub>2</sub>/70% HClO<sub>4</sub> in acetone, although the yields were not high (42 and 29%, respectively).<sup>10</sup> Lack of stability of the diphenoquinones to 70% HClO<sub>4</sub> in acetone perhaps contributed to low yields of the benzoquinones. The selectivities of formation of **2b** and **2c** were improved when aqueous MeSO<sub>3</sub>H, to which **1b** and **1c** were inert in acetone, replaced 70% HClO<sub>4</sub> in the above reactions, although the rates of consumption of **1b** and **1c** were decreased.

The overall effect of HClO<sub>4</sub> on the oxidation of **3a**, 2,6-diisopropylphenol (**3b**) and 2,6-dimethylphenol (**3c**) with PbO<sub>2</sub> in acetone/H<sub>2</sub>O was remarkable (Table 3). With HClO<sub>4</sub>, the reactions of **3** for a sufficient time gave the *p*-benzoquinones in good to high yields and no 4,4'-diphenoquinones. Without HClO<sub>4</sub>, in contrast, the reactions of **3a** and **3b** afforded the 4,4'-diphenoquinones in good yields and no *p*-benzoquinones. The reaction of **3c** without HClO<sub>4</sub> yielded only a small amount of **1c** and no **2c**, the principal products being unidentified.

Table 3  
Effect of HClO<sub>4</sub> on oxidation of phenols **3** with PbO<sub>2</sub> in acetone/H<sub>2</sub>O<sup>a</sup>

<b>3</b>	Additive	Recovery of <b>3</b> (%)	Product (%)	
			<b>1</b>	<b>2</b>
<b>3a</b>	HClO <sub>4</sub>	0	<b>1a</b> (0)	<b>2a</b> (92)
<b>3a</b>	none	21	<b>1a</b> (78)	<b>2a</b> (0)
<b>3b</b>	HClO <sub>4</sub>	0	<b>1b</b> (0)	<b>2b</b> (74)
<b>3b</b>	none	27	<b>1b</b> (63)	<b>2b</b> (0)
<b>3c</b>	HClO <sub>4</sub>	0	<b>1c</b> (0)	<b>2c</b> (73)
<b>3c</b>	none	14	<b>1c</b> (3) <sup>b</sup>	<b>2c</b> (0)

<sup>a</sup> To a stirred mixture of **3** (4 mmol), 70% HClO<sub>4</sub> (5 mL) or H<sub>2</sub>O (2.5 mL), and acetone (30 mL), PbO<sub>2</sub> (15 mmol) was added, and the resulting mixture was stirred for 30 min.

<sup>b</sup> In addition, 3,5,3',5'-tetramethyl-4,4'-biphenol (2%) was obtained.

It is emphasized that PbO<sub>2</sub> may not be the sole oxidant which, in the presence of a strong aqueous acid, can convert 4,4'-diphenoquinones to *p*-benzoquinones. Any oxidant that can oxygenate phenols (in the presence or absence of a strong acid) may also bring about this conversion in the presence of a strong acid (cf. Scheme 1). An example is shown below. Reaction of **1a** with ceric ammonium nitrate (CAN), another one-electron oxidant, in acetone containing 70% HClO<sub>4</sub> was completed rapidly and **2a** was produced in 63% yield. If HClO<sub>4</sub> was omitted in this run, most of the starting material (**1a**) (96%) was recovered unchanged. Accordingly, oxidation of **3a** with CAN/70% HClO<sub>4</sub> in acetone gave **2a** (65%) and no **1a**, while both **2a** (25%) and **1a** (66%) were obtained when HClO<sub>4</sub> was omitted.

Our study may present a principle of reducing or eliminating formation of 4,4'-diphenoquinones while increasing that of *p*-benzoquinones in the oxidation of 4-unsubstituted phenols.

## Acknowledgements

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- One might suspect that the slowdown of the reaction rate is ascribed to decreased solubility of **1a** in the reaction medium due to the addition of H<sub>2</sub>O, although only a small fraction of **1a** employed was soluble in the mixture of acetone and 70% HClO<sub>4</sub> even without added H<sub>2</sub>O. This possibility, however, was ruled out by the following fact. A solution of a relatively small amount (0.25 mmol) of **1a**, 70% HClO<sub>4</sub> (1 mL) and H<sub>2</sub>O (1 mL) in DME (30 mL) was prepared. Treatment of the solution with PbO<sub>2</sub> (2.5 mmol) for 45 min resulted in the almost complete recovery of **1a**. If the H<sub>2</sub>O was omitted in this run, a substantial amount (49%) of **1a** was consumed.
- Not only H<sub>2</sub>O but also MeOH and AcOH may participate in the conversion of **1a** to **2a** in these solvents. For the sake of simplicity, the participation of MeOH and AcOH is not shown in the scheme.
- The reaction was carried out by adding 70% HClO<sub>4</sub> (2 mL) to a stirred mixture of **1b** or **1c** (0.5 mmol), PbO<sub>2</sub> (2.5 mmol) and acetone (30 mL) and stirring the resulting mixture for 15 min.