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Convenient Preparation of Quinones *via* the Catalytic Autoxidation of Hydroquinones with Nitrogen Oxides

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Abstract: An efficient, inexpensive, catalytic method for the autoxidation of hydroquinones utilizes the gaseous (NO_x) catalyst which allows a simple workup procedure for quinone isolation merely by solvent removal.

A wide variety of oxidants have been used for the preparative conversion of hydroquinones to quinones - amongst which are silver oxide, ceric ammonium nitrate, thallium nitrate, lead oxide, sodium dichromate, and nitric acid.[1] These reagents are employed in stoichiometric amounts, and they are either expensive or used in strongly acidic aqueous media. Furthermore, all of these methods require tedious workup and purification procedures. The direct autoxidation of hydroquinone is complicated by the coproduction of hydrogen peroxide which leads to humic acid-like byproducts.[2] In 1952, Brook reported that substituted hydroquinones can be oxidized to quinones using excess nitrogen dioxide, but the method was not suitable for the oxidation of hydroquinone itself.[3]

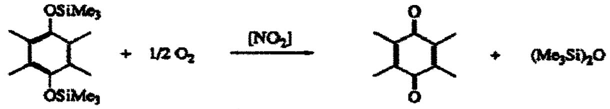
We have now shown that the oxidation of hydroquinones can be carried out with dioxygen in presence of catalytic amounts of nitrogen dioxide under mild conditions. For example, when 200 mmol of hydroquinone **3** (H_2Q) was mixed with 1 mole% of nitrogen dioxide in dichloromethane at -10°C under an O_2 atmosphere, a quantitative yield of pure quinone **3** (Q) was isolated by simply removing the solvent *in vacuo*. The yield of quinone was in excess of 10000%, based on the amount of added nitrogen dioxide. The time required for the reaction varied with the molar ratio of $NO_2 : H_2Q$. Thus quantitative yields of **9** (Q) were obtained in 1, 3, 6, and 12 h, when molar ratios for NO_2 : **9** (H_2Q) of 1 : 10, 1 : 20, 1 : 50, and 1 : 100, respectively, were used. This corresponded to catalytic turnovers of at least 100 with respect to nitrogen dioxide. The uptake of O_2 was also quantitative based on each equiv. of H_2Q consuming 0.5 equiv. of dioxygen according to eq 1.

(1)

With this procedure, various types of hydroquinones could be oxidized to quinones in excellent yields (see Table). It should be noted that the mild methodology allows the [$H_2Q \rightarrow Q$] transformation to be selectively effected in the presence of a remote double bond (see entry 12). Hydroquinone itself reacted somewhat slowly due to the initial precipitation of dark-blue quinhydrone crystals,[4] which in turn disappeared upon continued stirring at room temperature to afford a clear yellow solution of benzoquinone in quantitative yield. [The formation of quinhydrone may have led Brook[3] to believe that the stoichiometric reaction was not applicable to hydroquinone.]

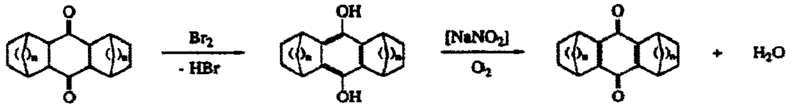
General Procedure: Hydroquinone (100 mmol) is suspended in CH_2Cl_2 (95 mL) and the flask purged with O_2. The side arm of the flask is equipped with an O_2-filled balloon to maintain the oxygen atmosphere. The mixture is cooled in a ice-acetone bath to approx. -10 °C, and a solution of NO_2 in CH_2Cl_2 (5 mL, 0.2 M) is added with the aid of a hypodermic syringe. The reaction mixture is stirred until the slurry yields a clear yellow solution (see Table). Evaporation of the solvent *in vacuo* leads to crystalline quinone which upon GC and NMR analysis is found to be free of impurities (< 1 %).

It is noteworthy that the bis-trimethylsilyl ether[5] **16** of hydroquinone **9** was also effectively converted under the same conditions to quinone **9** and hexamethylsiloxane in quantitative yields, *i.e.*



(2)

The catalytic autoxidation can be performed with small amounts of other nitrogen oxides such as nitrosonium salts ($NO^+BF_4^-$) or nitric oxide (NO). Alternatively, small amounts of a mixture of sodium nitrite and hydrochloric acid under an O_2 atmosphere could serve as a source of NO_2.[6] Thus the exposure of **9** (H_2Q) and dioxygen to catalytic amounts of $NaNO_2$ / HCl in CH_2Cl_2 afforded **9** (Q) in quantitative yield. A convenient application of this procedure was made in the one-pot synthesis of quinones from 1,4-diketones (**17 a-c**), which were readily accessible by the Diels-Alder reaction of benzoquinone with various dienes.[7] Bromination of these diketones in chloroform followed by the addition of 2 mole% of $NaNO_2$ under an O_2 atmosphere gave the corresponding quinones in quantitative yields.



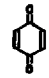
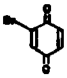
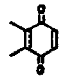
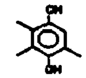
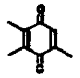
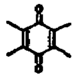
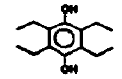
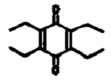
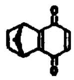
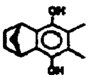
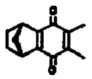
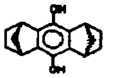
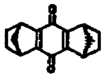
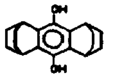
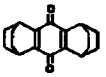
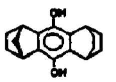
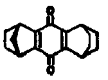
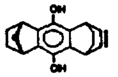
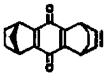
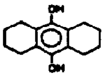
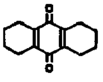
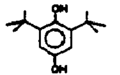
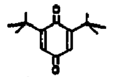
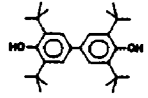
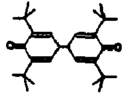
(3)

17 (butadiene - adduct); **18a**, n = 1; **18b**, n = 2

Some insight into the mechanism of this interesting catalysis was provided by the equimolar reaction of NO_2 and H_2Q in CH_2Cl_2 at -78 °C under *anaerobic* conditions (argon atmosphere) to initially produce a blue-green solution of N_2O_3[8]. The solution upon warming to room temperature liberated nitric oxide (NO) and gave quantitative yield of the quinone to clearly establish the stoichiometry in eq 4. [Note the reversible equilibrium: $N_2O_3 \rightleftharpoons NO + NO_2$]

$$H_2Q + NO_2 \longrightarrow Q + NO + H_2O \qquad (4)$$

Table: Catalytic Autoxidation of Hydroquinones to Quinones.

No.	Hydroquinone (H_2Q)	$(H_2Q)^a$ (mmol)	NO_2^b (M)	Time^c (h)	Quinone (Q)	%^{d}
1		50	0.04	20		94
2		20	0.10	10		99
3		200	0.01	12		100
4		180	0.01	10		100
5		50	0.04	6		100
6		20	0.10	2		100
7		200	0.01	10		99
8		50	0.04	3		100
9		100	0.02	12		98
10		100	0.02	18		98
11		20	0.10	2		98
12		15	0.13	2		99
13		40	0.05	4		97
14		100	0.02	8		100
15		50	0.04	4		98

(a) Dichloromethane (1mL) was used for each mmol of H_2Q at -10 °C under an O_2 atmosphere (*e.g.* 1 M solution of H_2Q in dichloromethane). (b) Concentration of added NO_2 (arbitrarily chosen to reflect typical reaction times) for various types of hydroquinones. (c) See text. (d) Isolated yields.

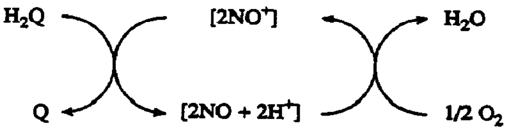
The reaction of ^{18}O-enriched **9** (H_2Q)[9] with an equimolar amount of NO_2 in CH_2Cl_2 resulted in the complete retention of the ^{18}O label in the quinone, which demonstrated that the oxidation of hydroquinones proceeded *via* an O-H bond cleavage.

Formally, the oxidation of hydroquinones to quinones involves the removal of two electrons and two protons. This redox stoichiometry is established in the anaerobic oxidation of hydroquinone **9** with 2 equiv. of NO^+ to yield the quinone **9** and NO according to eq 5.

$$H_2Q + 2\,NO^+ \longrightarrow Q + 2\,NO + 2\,H^+ \qquad (5)$$

Accordingly, we propose the catalytic cycle for the NO^+-catalyzed autoxidation of H_2Q to be

Scheme



In a related manner, the catalytic action of NO_2 can be traced to its prior disproportionation *in situ* to nitrosonium nitrate (NO^+ NO_3^-), as established in a recent study.[10]

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References and Notes

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