CHEMISTRY LETTERS, pp. 1267-1268, 1989.

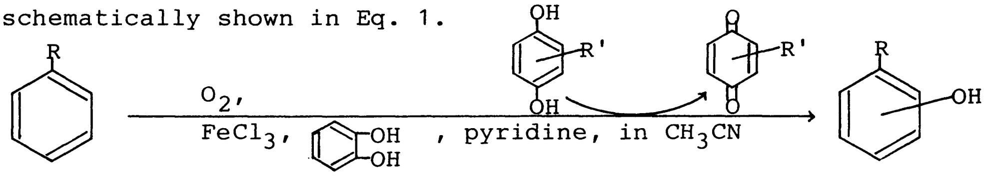
Catalytic Hydroxylation of Aromatic Compounds with O_2 by a Catecholatoiron Complex in Acetonitrile Using Hydroquinones as Reductants

Takuzo FUNABIKI,* Motoyoshi TSUJIMOTO, Satoshi OZAWA, and Satohiro YOSHIDA
Department of Hydrocarbon Chemistry and Division of Molecular Engineering,
Faculty of Engineering, Kyoto University, Kyoto 606

Hydroquinones have been found to be useful as reductants for one-step hydroxylation of aromatic compounds by nonheme iron complex with activation of O_2 in anhydrous organic solvents. The iron complex is easily prepared by mixing $FeCl_3$, pyrocatechol, and pyridine. The efficiency of hydroquinones as reductants is greatly dependent on the substituent: t-Bu->2,5-t-Bu_2->>H-hydroquinone.

Development of a new catalytic system for one-step hydroxylation of aromatics with activation of O_2 is of current interests not only for industrial synthesis of phenols, but also for elucidation of mechanisms of enzymatic oxygenations. In the biomimetic studies on the metabolism of aromatics by iron enzymes with the aim of development of new catalytic oxygenation processes, we have found previously the oxygenative cleavage of 3,5-di-t-butylcatechol by (bipyridine)(pyridine)iron complexes.1) We here report the new catalytic system for hydroxylation of aromatics by the catecholatoiron complex which is assumed as an intermediate in the above reaction. We used here pyrocatechol which is not oxygenatively cloven.

Different from the Fenton's reagent which uses H_2O_2, hydroxylation with O_2 requires the presence of a reductant. Ascorbic acid (AsA) has been used in the modified Fenton's reagent,2) but AsA is less soluble in organic solvents and oxygenatively cloven. We found here that some specific hydroquinones, e.g. t-butylhydroquinone (TBHQ) and 2,5-di-t-butylhydroquinone (DTBHQ), are useful reductants for the catalytic hydroxylation in anhydrous organic solvents. Hydroxylation in anhydrous organic solvents is known to be characteristic, e.g. for a large NIH shift3) and the formation of the highly electrophilic Fe(O) species,4) and useful for the reaction of substrates less soluble in aqueous solutions. The present system may substitute for hydroxylation in anhydrous solvents by using pure H_2O_2, which requires special care to prepare, store, and use.4) In addition, hydroquinones are not oxygenatively cloven, and quinones are easily and chemically reduced back to hydroquinones. This is important and advantageous for the recycle system of the reductant without the aid of the electrochemical reduction. The present reaction is schematically shown in Eq. 1.



(1)

Table 1. Hydroxylation of Anisole by Catecholatoiron Complex/hydroquinone/O_2[a)]

Fe Salt	Fe:Cat:Py[b)]	Reductant[c)]	Yield of products/mol %[d)]			Isomer ratio/%[e)]		
			Total	CH_3O-PhOH	PhOH	o	m	p
$FeCl_3$	1:1:0	AsA	0					
$FeCl_3$	1:1:2	AsA	96	86	10	66	1	33
$FeCl_3$	1:1:2	HQ	28	25	3	79	1	20
$FeCl_3$	1:1:0	TBHQ	13	11	2	65	0	35
$FeCl_3$	1:1:2	TBHQ	172	150	22	75	1	24
$FeCl_3$	1:1:2	TBHQ	406[f)]	355	51	75	1	24
$FeCl_3$	1:1:2	TBHQ	513[f,g)]	458	55	75	1	24
$FeCl_3$	1:1:2	DTBHQ	286	256	30	81	2	17
$FeCl_3$	1:0:2	DTBHQ	85	73	12	72	3	25
$Fe(ClO_4)_3 \cdot 6H_2O$	1:1:2	DTBHQ	8	7	1	65	0	35
$Fe(NO_3)_3 \cdot 9H_2O$	1:1:2	DTBHQ	20	17	3	71	0	29

a)Fe salt:0.125 mmol, anisole:5 cm^3, CH_3CN:2.5 cm^3, 25 °C, 1 atm O_2. b)Mole ratio of [Fe]:[pyrocatechol]:[pyridine]. c)HQ:hydroquinone, [Fe]:[reductant] =1:40. d)Yield after 24 h, based on [Fe]. e)Composition of o:m:p-methoxyphenol. f)Reaction at 45 °C. g)In anisole (2.5 cm^3) and CH_3CN (5 cm^3).

The reaction of anisole was performed as follows: $FeCl_3$ (20.3 mg, 0.125 mmol) dissolved in CH_3CN (2.5 cm^3) and pyridine (0.02 cm^3, 0.25 mmol) was added to pyrocatechol (13.8 mg, 0.125 mmol) and TBHQ (0.830 g, 5.00 mmol) in 5 cm^3 anisole. The solution was mixed under 1 atm O_2 and at 25 °C. Products extracted with ether were quantitatively analyzed by GLC (25 m capillary column of PEG 20M).

The results are shown in Table 1. Characteristic results are summarized as follows: (1)Hydroxylation proceeds catalytically with DTBHQ and TBHQ, but not with HQ and AsA. Only TBHQ keeps the solution homogenous throughout the reaction and gives the highest yield. (2)Pyridine is essential. (3)Pyrocatechol is very effective to promote the reaction. (4)$FeCl_3$ is much more effective than other iron salts. (5)Excess hydroquinones are required for the catalytic reaction, but yield increases with the amount of reductants without deactivation of the iron complex. (6)The reactivity of aromatics, anisole>toluene>benzene, and the product composition in Table 1 (o>p>>m) are similar to those observed in other systems.

We believe that monooxygenation with O_2 by nonheme iron complexes is more convenient and important for the synthetic use than that by heme iron complexes. Studies on improvement of efficiency of the reductant, clarification of reaction mechanism, and application of the present simple nonheme iron catalyst to monooxygenation of substrates other than aromatics are in progress.

References

1) T.Funabiki, H.Sakamoto, S.Yoshida, and K.Tarama, J.Chem.Soc.,Chem.Commun., 1979, 754; T.Funabiki, A.Mizoguchi, T.Sugimoto, S.Tada, M.Tsuji, H.Sakamoto, and S. Yoshida, J.Am.Chem.Soc., 108, 2921 (1986); T.Funabiki, S.Tada, T.Yoshioka, M. Takano, and S.Yoshida, J.Chem.Soc.,Chem.Commun., 1986, 1699.

2) R.R.Grinstead, J.Am.Chem.Soc., 82, 3472 (1960); B.B.Brodie, J.Axelrod, P.A. Shore, and S.Udenfriend, J.Biol.Chem., 208, 741 (1954); J-M.Maissant, C. Bouchoule, and M.Blanchard, J.Mol.Cat., 14, 333 (1982).

3) T.Kurata, Y.Watanabe, M.Katoh, and Y.Sawaki, J.Am.Chem.Soc.,110, 7472 (1988).

4) H.Sugimoto, L.Spencer, and D.T.Sawyer, Proc.Natl.Acad.Sci.U.S.A., 84, 1731 (1987).

(Received April 24, 1989)