(a) Optimum Conditions in PPA. A large number of runs were made to find the best conditions for the reaction between acetohydroxamic acid and anisole. In contrast to the report of Wassmundt and Padegimas,[3] we were able to get isolated yields as high as 59% with a molar ratio of only 1:1. Wassmundt and Padegimas gave few experimental details, but we believe that the improvement is the result of more efficient stirring (PPA is a viscous solvent). The optimum conditions consist of mixing the anisole (0.05–0.10 mol) and the hydroxamic acid (0.05–0.10 mol) in 45–46 g of PPA over a period of 2–3 min and then heating the well-stirred mixture at 110–115 °C for 90–120 min. The order of addition of the two reagents is not important.

(b) Other Substrates. The optimum conditions given below (in the Experimental Section) were used in extending the reaction to other substrates. We found the scope to be quite limited. Satisfactory yields were obtained with *o*-, *m*-, and *p*-methylanisole (63%, 46%, and 54% yields, respectively), 2,6-dimethylanisole (49%), and phenetole (49%). The product with phenetole is the important drug phenacetin [*N*-(4-ethoxyphenyl)acetamide], and this reaction provides a simple way to make it. *o*-Chloro- and *o*-iodoanisole and 1,2,3-trimethylbenzene gave much lower yields (25%, 8%, and 18%, respectively), while essentially no yields at all were obtained with 1,2- or 1,4-dimethoxybenzene, *o*-methoxyacetophenone, methyl *o*-methoxybenzoate, or a series of compounds PhX, where X = OH, $OCOCH_3$, $NHCOCH_3$, SCH_3, cyclohexyl, ethyl, Br, OPh, or NO_2. The scope is therefore essentially limited to alkyl aryl ethers whose aromatic group is either unsubstituted or substituted with alkyl groups. Where the reactions failed it was either because the PPA caused extensive decomposition of the aromatic substrate or because the aromatic ring was unreactive.

(c) Possible Substitutes for PPA. Because of the decomposition noted in the previous sentence, we attempted to replace PPA by other solvents. It has been reported[4] that a solution of P_2O_5 in methanesulfonic acid can substitute for PPA in other applications, but in this case, heating of anisole and acetohydroxamic acid in a 1:10 P_2O_5-methanesulfonic acid solution gave only sulfur-containing products[5] and no nitrogen-containing products. Also unsuccessful as solvents were polyphosphate ester,[6] a mixture of P_2O_5 and bromoform, and a mixture of trichloracetic acid and acetic anhydride.

Experimental Section

***N*-(4-Methoxyphenyl)acetamide.** The reaction was carried out in a 150-mL two-piece reaction flask, the upper piece of which had three necks fitted with a mechanical stirrer, a condenser, and a stopper. Polyphosphoric acid (45 g, obtained from the Research Organic/Inorganic Chemical Corp.) was placed in the lower portion of the flask, and the two pieces were clamped together. The contents of the flask were moderately stirred while being heated to 115 °C by an oil bath. Then, over a 2-min period was added 3.75 g (0.050 mol) of acetohydroxamic acid[7] and 5.41 g (0.050 mol) of anisole. The mixture was maintained at 115 °C, with vigorous stirring, for 2 h. It was then allowed to cool with moderate stirring. When room temperature was reached, the stopper was replaced by an addition funnel, and 50 mL of water was slowly added, followed by 50 mL of chloroform. The water layer was extracted several times with chloroform, the combined chloroform extracts were treated with anhydrous magnesium sulfate and activated charcoal, and the chloroform was removed by an aspirator. The resulting solid was sublimed at 130–140 °C, and the sublimed solid was recrystallized from water and then twice from *n*-butyl ether. The yield of *N*-(4-methoxyphenyl)acetamide (mp 123–123.5 °C) was 4.88 g (59%). IR spectra and VPC showed the absence of the ortho and meta isomers.

***N*-(4-Ethoxyphenyl)acetamide (Phenacetin).** The procedure was the same as above, except that 12.22 g (0.10 mol) of phenetole was used instead of anisole, 7.51 g (0.10 mol) of acetohydroxamic acid was used, and the product was recrystallized once from water and three times from *n*-butyl ether. The yield of phenacetin (mp 132.0–132.8 °C) was 8.7 g (49%). IR spectra and VPC showed the absence of the ortho and meta isomers.

Registry No. *N*-(4-Methoxyphenyl)acetamide, 51-66-1; acetohydroxamic acid, 546-88-3; anisole, 100-66-3; phenacetin, 62-44-2; phenetole, 103-73-1; *o*-methylanisole, 578-58-5; *m*-methylanisole, 100-84-5; *p*-methylanisole, 104-93-8; 2,6-dimethylanisole, 1004-66-6; *o*-chloroanisole, 766-51-8; *o*-iodoanisole, 615-37-2; 1,2,3-trimethylbenzene, 526-73-8.

(4) Eaton, P. E.; Carlson, G. R.; Lee, J. T. *J. Org. Chem.* **1973**, *38*, 4071.
(5) These probably consisted largely of sulfones. See: Graybill, B. M. *J. Org. Chem.* **1967**, *32*, 2931.
(6) Fieser, L. F.; Fieser, M. "Reagents for Organic Synthesis"; Wiley: New York, 1967; p 892. The polyphosphate ester used here was similar to one reported by: Cava, M. P.; Lakshmikantham, M. V.; Mitchell, M. J. *J. Org. Chem.* **1969**, *34*, 2665.
(7) Prepared in 60% yield by the method of: Fishbein, W. N.; Daly, J.; Streeter, C. *Anal. Biochem.* **1969**, *28*, 13.

Oxyfunctionalization of Hydrocarbons. 11.[1] Hydroxylation of Benzene and Alkylbenzenes with Hydrogen Peroxide in Hydrogen Fluoride/Boron Trifluoride

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The utility of hydrogen peroxide as source of electrophilic oxygen has gained increasing importance. Various studies on electrophilic hydroxylation of aromatics have been reported, including the $AlCl_3$-catalyzed reaction with H_2O_2/urea adducts,[2] with anhydrous HF (in the presence of CO_2,[3,4] highly concentrated H_2O_2 in the presence of $AlCl_3$,[5] BF_3 etherate,[6] or strong acids[7] such as FSO_3H, FSO_3H, or FSO_3H–SbF_5/SO_2ClF), and with H_2O_2/HF_x/pyridine.[1] The major difficulty encountered was the ease of further oxidation of the initially formed hydroxyarenes to a wide range of byproducts. This was substantially decreased in superacidic FSO_3H or FSO_3H–SbF_5 systems which protonate the formed phenols.[8] However, these systems are not always easy to handle, and acid recovery is inconvenient.

We now report that 30% hydrogen peroxide with superacidic hydrogen fluoride/boron trifluoride smoothly converts benzene and alkylbenzenes into their monohydroxylated products at −78 to −60 °C in a clean reaction with a satisfactory to good yields (eq 1). No appreciable (<1%) amount of (poly)hydroxylated products are formed,

(1) For part 10, see: G. A. Olah, T. Keumi, and A. P. Fung, *Synthesis*, 536 (1979).
(2) J. Sugano, Y. Kariyama, Y. Ishinshin, and K. Minamikawa, Japanese Kokai 74 07,234 (1974); *Chem. Abstr.*, **80**, 120535 (1974).
(3) J. A. Vesely and L. Schmerling, *J. Org. Chem.*, **35**, 4028 (1970).
(4) J. A. Vesely, U.S. Patent 3 839 467 (1974); *Chem. Abstr.*, **82**, 3974 (1975).
(5) M. E. Kurz and G. J. Johnson, *J. Org. Chem.*, **29**, 2397 (1964).
(6) J. D. McClure and P. H. Williams, *J. Org. Chem.*, **27**, 124 (1962).
(7) J. Varagnut, *Ind. Eng. Chem. Prod. Res. Dev.*, **15**, 212 (1976).
(8) G. A. Olah and R. Ohnishi, *J. Org. Chem.*, **43**, 865 (1978).
(9) G. A. Olah and Y. K. Mo, *J. Org. Chem.*, **38**, 353 (1973).

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Table I. Hydroxylation of Aromatics with 30% H_2O_2 in HF/BF_3 at −78 °C

starting aromatic	% yield[a]	isomeric alkylphenol distribution,[b] %
benzene	37	
toluene	52	70 (2), 9 (3), 21 (4)
ethylbenzene	58	65 (2), 11 (3), 24 (4)
cumene	43	48 (2), 12 (3), 40 (4)
tert-butylbenzene	36	30 (2), 14 (3), 56 (4)
p-xylene	50	65 (2, 5), 35 (2, 4)
o-xylene	53	7 (2, 6), 66 (2, 3), 27 (3, 4)
mesitylene	41	100 (2, 4, 6)

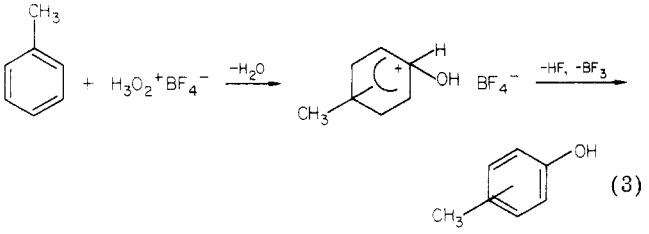
[a] Isolated yield based on aromatics. [b] Based on gas-liquid chromatographic analysis of trimethylsilylated phenolic products. Parentheses show the position of the substituents. The amount of dihydroxylated byproducts in all experiments was less than 1%, the limit of observation taking into account possible loss during silylation.

and acid recovery is feasible when needed. Data are summarized in Table I.

$$\mathrm{ArH} \xrightarrow[30\%\ H_2O_2]{HF/BF_3} \mathrm{ArOH} \qquad (1)$$

A probable mechanism of the reaction involves electrophilic hydroxylation of the aromatics by the hydroperoxonium ion (eq 2 and 3).

$$\mathrm{HOOH + HF\text{-}BF_3 \rightarrow H_3O_2^+BF_4^-} \qquad (2)$$



(3)

For the monosubstituted alkylbenzenes, the ortho–para isomer ratio follows the predicted trend (from 3.33 for toluene to 0.54 for *tert*-butylbenzene) on consideration of the increasing steric hindrance to ortho substitution as a consequence of the increasing bulk of the alkyl group. The isomer ratios of hydroxyalkylbenzenes (shown in Table I) reflect the isomerizing ability of the superacidic $HF\text{-}BF_3$ system. *p*-Xylene also gives, besides the expected 2,5-dimethylphenol, the 2,4-product. Similarly, *o*-xylene also yields, besides the 3- and 4-hydroxylated products, some 2,6-dimethylphenol, indicative of methyl migration.

It is noteworthy to point out that polyhydroxylation is practically suppressed under the present reaction conditions because the phenols formed are protonated[8] by the superacid (HF/BF_3) and thus are deactivated against further electrophilic attack or secondary oxidation. As HF/BF_3 is readily handled, inexpensive, and recoverable, the method described represents a significant improvement in direct aromatic hydroxylation.

Experimental Section

To a vigorously stirred solution of the corresponding aromatic (0.1 mol) in HF (60 mL, saturated with BF_3) in a polyolefin or Teflon reaction flask is added dropwise a solution of 30% H_2O_2 (4.1 g, 0.125 mol; Mallinckrodt Co.) in HF/BF_3 (25 mL) by using a polyolefin or Teflon dropping funnel at −78 °C over a period of 20–25 min. The reaction mixture is then further saturated with BF_3 and stirred for an additional 30 min while the temperature is maintained at −60 °C by external cooling. Thereafter, the solution is carefully quenched with ice–water, extracted with ether, washed with 10% sodium bicarbonate solution to remove acid, and then extracted by 10% sodium hydroxide solution. No insoluble residue remained. Following acidification of the basic extract and extraction with ether, the organic layer is dried over mangesium sulfate and the solvent removed to yield crude phenolic product which is further puridied by distillation. Products were characterized by NMR and/or IR spectroscopy. The aliquots of the product were silylated by *N,O*-bis(trimethylsilyl)trifluoroacetamide (Pierce) and identified as the trimethylsilyl ethers by GLC. Gas chromatographic analyses were carried out by using a Varian Associates Model 3700 gas chromatograph equipped with an electronic intergator and using a 25 ft × 0.25 mm i.d. OV-101 glass capillary column coated with MBMA (*m*-diphenoxybenzene plus Apiezon L) and eluted with Helium. Gas chromatograph analysis was used to determine isomer ratios.

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Registry No. Benzene, 71-43-2; toluene, 108-88-3; 2-methylphenol, 95-48-7; 3-methylphenol, 108-39-4; 4-methylphenol, 106-44-5; ethylbenzene, 100-41-4; 2-ethylphenol, 90-00-6; 3-ethylphenol, 620-17-7; 4-ethylphenol, 123-07-9; cumene, 98-82-8; 2-(1-methylethyl)-phenol, 88-69-7; 3-(1-methylethyl)phenol, 618-45-1; 4-(1-methylethyl)phenol, 99-89-8; *tert*-butylbenzene, 98-06-6; 2-(*tert*-butyl)-phenol, 88-18-6; 3-(*tert*-butyl)phenol, 585-34-2; 4-(*tert*-butyl)phenol, 98-54-4; *p*-xylene, 106-42-3; 2,5-dimethylphenol, 95-87-4; 2,4-dimethylphenol, 105-67-9; *o*-xylene, 95-47-6; 2,6-dimethylphenol, 576-26-1; 2,3-dimethylphenol, 526-75-0; 3,4-dimethylphenol, 95-65-8; mesitylene, 108-67-8; 2,4,6-trimethylphenol, 527-60-6; phenol, 108-95-2; H_2O_2, 7722-84-1.

Direct Conversion of Alcohols to Alkanes

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We have recently described the reaction of microcrystalline cellulose (ROH) with hydrogen and iodine and with hydrogen and hydrogen iodide.[1] These reactions afforded a number of alkanes and alkenes and represent an interesting conversion sequence for the generation of hydrocarbons from wood and other cellulosic materials.

In order to examine the general utility of these reactions, we elected to study them on monofunctional model compounds. Since the major reactivity of the microcrystalline cellulose must be associated with the presence of hydroxyl groups, and since the conversion of alcohols to alkyl iodides by HI are well-known, we studied these reactions on primary (*n*-butyl alcohol), secondary (cyclohexanol), and tertiary alcohols (*tert*-butyl alcohol).

It is well-known that hydrogen and iodine react to form HI in a thermally reversible manner (K_{eq} = 70 at 300 °C).[2] Thus, a priori, it is established that these conversions can involve any or all of the following inorganic species: H_2, I_2, HI.

When *n*-butyl alcohol was treated with molecular iodine in an atmosphere of hydrogen, at 1000 lb/in.^{2} and at 300 °C, a high yield of hydrocarbons was obtained. Gas chromatographic analyses in conjunction with mass spectroscopy and comparison with authentic samples established that the volatile products are composed of *n*-butane and isobutane, along with some propane (see Table I). A similar distribution of hydrocarbons is obtained

(1) (a) T. E. Walton and W. W. Paudler, *Fuel*, 1981, in press; (b) J. J. Th. M. Geerards, D. W. van Krevelen and H. I. Waterman, *Brennst.-Chem.*, 11 (*1958*).

(2) W. J. Moore, "Physical Chemistry", Prentice-Hall, Englewood, Cliffs, NJ, 1972, p 341.

0022-3263/81/1946-4306$01.25/0