

# Aromatic Oxidation by Electron Transfer. II.<sup>1</sup> Oxidations of Aromatic Ethers and Amines by Manganic Acetate<sup>2</sup>

Takaaki Aratani<sup>3</sup> and Michael J. S. Dewar

Contribution from the Department of Chemistry, The University of Texas, Austin, Texas 78712. Received May 31, 1966

**Abstract:** The first paper<sup>1</sup> of this series reported kinetic studies of the oxidation of *p*-methoxytoluene by manganic acetate, which suggested strongly that the reaction is an electron-transfer type. Here we report the reactions between manganic acetate and anisole, phenetole, 1,2-, 1,3-, and 1,4-dimethoxybenzene, 1- and 2-methoxynaphthalene, *N,N*-dimethyl- and *N,N*-diethylaniline, and benz[*a*]anthracene. The reactions involving ethers seem definitely to be an electron-transfer type, and the same is probably true of the other reactions also.

The oxidation of aromatic compounds by electron transfer has been a relatively neglected field—surprisingly so in view of the current interest in electron-transfer processes and the possible synthetic value of reactions of this type. Most of the published work in this area has, moreover, been concerned with the stable radicals formed from materials such as phenols or aromatic amines, the emphasis being on the properties of the products, in particular their esr spectra, rather than on the reactions by which they are produced.

This series of papers is concerned with a general study of reactions in which the key step may be removal of an electron from an aromatic substrate; part I<sup>1</sup> described a kinetic study of one such process, the oxidation of *p*-methoxytoluene by manganic acetate in acetic acid, evidence being presented that the reaction was indeed an electron-transfer type. Following this clue, we decided to study the general behavior of manganic acetate as an oxidizing agent for aromatic compounds; this paper describes the products formed in such reactions with a number of aromatic ethers and amines.

## Results

The compounds studied were anisole (I), veratole (II), resorcinol dimethyl ether (III), hydroquinone dimethyl ether (IV),  $\alpha$ -methoxynaphthalene (V),  $\beta$ -methoxynaphthalene (VI), benz[*a*]anthracene (VII), *N,N*-dimethylaniline (VIII), phenetole (IX), and *N,N*-diethylaniline (X). The reactions were carried out in acetic acid at 100°, using 2 molar equiv of manganic acetate to 1 molar equiv of the aromatic substrate. Manganic acetate slowly oxidizes acetic acid at this temperature, presumably to acetoxy radicals; it was necessary to establish that the oxidations were due to attack by manganic acetate, and not by acetoxy radicals formed by reaction with the solvent. This was done by measuring roughly the rate of disappearance of Mn<sup>III</sup> by iodometric titration; if a reaction involves attack on the solvent, its rate should be the same as the rate of disappearance of Mn<sup>III</sup> in acetic acid containing no other material;<sup>4</sup> on the other hand, the rate

should be greatly enhanced by addition of any compound that can react directly with manganic acetate. Table I shows that this criterion was met by all the compounds studied, the decomposition of manganic acetate in acetic acid at 100° being slow. No attempt was made to measure the rates at all accurately since the kinetics of these reactions are likely to be complicated (*cf.* part I<sup>1</sup>).

**Table I.** Half-Lives for Disappearance of Mn<sup>III</sup> in Solutions of Mn(OAc)<sub>3</sub> in Acetic Acid Containing Various Aromatic Substrates (Mole Ratio, Mn(OAc)<sub>3</sub>:Substrate, 2:1), at 100°

Aromatic compound	Initial concn of Mn(OAc) <sub>3</sub> , ml <sup>-1</sup>	Half-life, min
Anisole (I)	0.122	950
Veratrole (II)	0.096	600
Resorcinol dimethyl ether (III)	0.095	320
Hydroquinone dimethyl ether (IV)	0.096	180
1-Methoxynaphthalene (V)	0.083	18
2-Methoxynaphthalene (VI)	0.083	20
Benz[ <i>a</i> ]anthracene (VII)	0.063	<3
Dimethylaniline (VIII)	0.111	2 < 3
Phenetole (IX)	0.101	800
Diethylaniline (X)	0.868	<<3

The products from large scale runs were then studied, each reaction being continued until no Mn<sup>III</sup> remained. The results are summarized below. In most cases yields are not quoted, since in this exploratory work the recovery of products was far from quantitative.

## Discussion

The most striking feature of the reactions involving methoxybenzenes (I–IV), or dimethylaniline (VIII), is the formation of products containing additional carbon atoms. It seems fairly clear from the nature of these that they arose by condensation of formaldehyde with the aromatic substrates, the products isolated being those expected on this basis. Presumably the diaryl-methanes from II and III underwent rapid further oxidation to benzophenones, that from III then condensing with unchanged starting material to form XVII. The results also show that the formaldehyde must have arisen by oxidation of the aromatic substrate rather

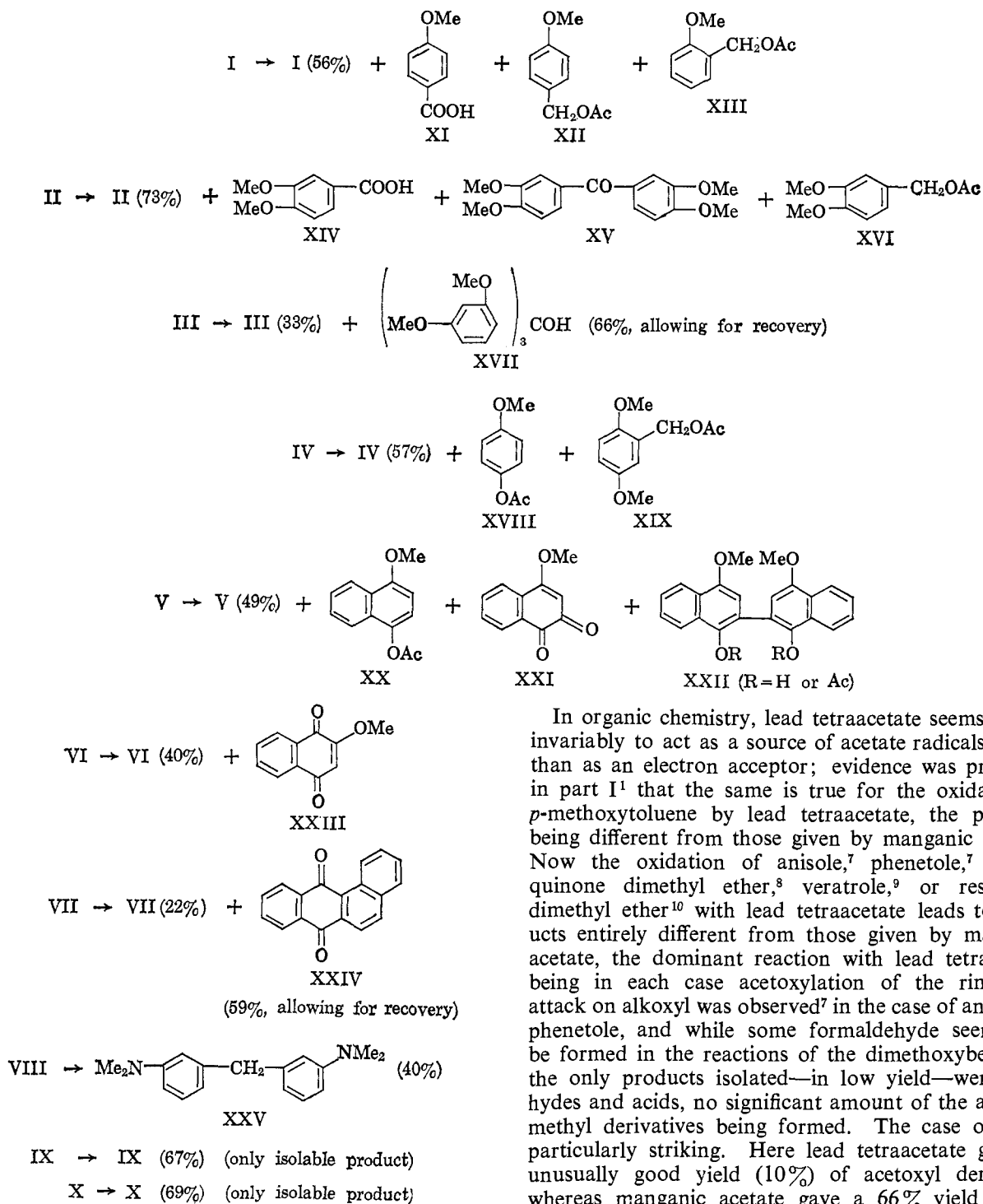
being attack by acetoxy radicals on the aromatic substrate. Such a mechanism seems very improbable, however, in view of the known thermal instability of the acetate radical.

(1) Part I: P. J. Andrusis, Jr., M. J. S. Dewar, R. Dietz, and R. L. Hunt, *J. Am. Chem. Soc.*, **88**, 5473 (1966).

(2) This work was supported by the Air Force Office of Scientific Research through Grant AF-AFOSR-528-64.

(3) Chemical Laboratory, Department of General Education, Hiroshima University, Hiroshima-shi, Japan.

(4) This conclusion could conceivably be incorrect if Mn(OAc)<sub>3</sub> decomposed reversibly to Mn(OAc)<sub>2</sub> + AcO·, the rate-determining step



than the solvent, for phenetole (IX) and diethylaniline (X) react as easily with formaldehyde as do their methyl analogs, I and VIII.

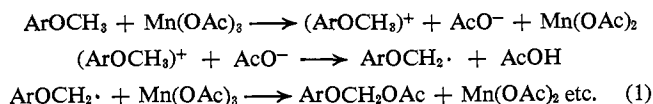
Dimethylaniline has also been oxidized to XXV with benzoyl peroxide<sup>5</sup> or *t*-butyl perbenzoate,<sup>6</sup> reactions undoubtedly involving abstraction of methyl hydrogen by free radicals derived from the oxidizing agent, leading ultimately to formaldehyde derivatives of the type PhNMeCH<sub>2</sub>OR. A similar mechanism could be written for the oxidations involving manganic acetate; however the products formed by its reaction with the methoxybenzenes seem to exclude a mechanism of this type.

(5) L. Horner and C. Betzel, *Ann.*, **579**, 175 (1953).

(6) G. Sosnovsky and N. C. Yang, *J. Org. Chem.*, **25**, 899 (1960).

In organic chemistry, lead tetraacetate seems almost invariably to act as a source of acetate radicals, rather than as an electron acceptor; evidence was presented in part I<sup>1</sup> that the same is true for the oxidation of *p*-methoxytoluene by lead tetraacetate, the products being different from those given by manganic acetate. Now the oxidation of anisole,<sup>7</sup> phenetole,<sup>7</sup> hydroquinone dimethyl ether,<sup>8</sup> veratrole,<sup>9</sup> or resorcinol dimethyl ether<sup>10</sup> with lead tetraacetate leads to products entirely different from those given by manganic acetate, the dominant reaction with lead tetraacetate being in each case acetoxylation of the ring. No attack on alkoxy was observed<sup>7</sup> in the case of anisole or phenetole, and while some formaldehyde seemed to be formed in the reactions of the dimethoxybenzenes, the only products isolated—in low yield—were aldehydes and acids, no significant amount of the acetoxy-methyl derivatives being formed. The case of III is particularly striking. Here lead tetraacetate gave an unusually good yield (10%) of acetoxy derivative, whereas manganic acetate gave a 66% yield of the triarylcarbinol XVII.

The production of formaldehyde in the Mn<sup>III</sup> oxidations of phenyl ethers can be rationalized very simply in terms of the electron-transfer mechanism of part I<sup>1</sup>; *i.e.*



This process leads to a relatively unstabilized aryloxy-methyl radical; it should be observed only in cases

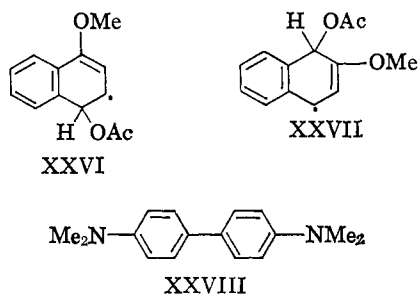
(7) G. W. K. Cavill and D. H. Solomon, *J. Chem. Soc.*, 1404 (1955).

(8) Fr. R. Preuss and R. Menzel, *Arch. Pharm.*, **291**, 350, 377 (1958).

(9) Fr. R. Preuss and L. Tan, *ibid.*, **293**, 505 (1960).

(10) Fr. R. Preuss and I. Janshen, *ibid.*, **293**, 933 (1960).

where alternative modes of reaction of the intermediate ion radical ( $\text{ArOCH}_2^+$ ) are less favorable. Thus in the case of *p*-methoxytoluene, loss of a proton from the ring methyl is preferred<sup>1</sup> since this leads to a highly stabilized *p*-methoxybenzyl radical, while the ion radicals from 1- and 2-methoxynaphthalene apparently undergo combination with solvent to form intermediates such as XXVI or XXVII rather than deprotonation, since the radical localization energies of substituted naphthalenes are less than those of corresponding benzene derivatives.



This mechanism also accounts well for the observed order of reactivity of the methoxybenzenes. If the oxidations involved abstraction of hydrogen atoms to form radicals  $\text{ArOCH}_2\cdot$  directly, their rates should not be much affected by the nature of the aryl group. If, however, the oxidations are an electron-transfer type, their rates should run parallel to the ionization potentials of the ethers; since the ionization potentials of the dimethoxybenzenes are apparently less than that of anisole,<sup>11</sup> they should then react more readily—as is the case (Table I). The electron-transfer mechanism also accounts for our failure to isolate the diaryl-methanes postulated as intermediates in the formation of XV and XVII; these would be expected to undergo oxidation much more readily than the parent ethers II and III. It also accounts nicely for the fact that the corresponding diaryl methane was the sole product isolated from the oxidation of VIII. Since electron abstraction from VIII would be hindered by protonation, oxidation of VIII by electron transfer would necessarily involve attack on the small proportion of free base present in the acid solution. In the case of XXV, such oxidation would involve the very much smaller proportion of free base in which neither nitrogen of XXV is protonated; XXV could then well be inert to further attack.

It might perhaps be thought surprising that the ion radicals ( $\text{PhNMe}_2^+$ ) from VIII should lose protons, rather than dimerize to tetramethylbenzidine (XXVIII); anodic oxidation of VIII is known<sup>12</sup> to give XXVIII as the first product, and XXVIII has also been prepared from VIII by the action of lead dioxide,<sup>13</sup> potassium permanganate,<sup>14</sup> or sodium dichromate<sup>15</sup> in dilute acid.

Dimerization would of course be favored in the case of anodic oxidation, or heterogeneous oxidation on

(11) See E. M. Voight, *J. Am. Chem. Soc.*, **82**, 3611 (1964); E. M. Voight and C. Reid, *ibid.*, **82**, 3630 (1964).

(12) T. Mizoguchi and R. N. Adams, *ibid.*, **84**, 2058 (1962); Z. Galus and R. N. Adams, *ibid.*, **84**, 2061 (1962); Z. Galus, R. M. White, F. S. Rowland, and R. N. Adams, *ibid.*, **84**, 2065 (1962).

(13) W. Michler and S. Pattinson, *Ber.*, **14**, 2163 (1881); **17**, 115 (1884).

(14) R. Willstätter and L. Kalb, *Ber.*, **37**, 3761 (1904).

(15) R. Rumpf, *Bull. Soc. Chim. France*, **7**, 634 (1940).

lead dioxide, by the high local concentration of ion radicals ( $\text{PhNMe}_2^+$ ); this, however, would not explain why VIII behaves differently with aqueous permanganate or dichromate on the one hand, and with manganic acetate in acetic acid on the other. The explanation probably lies in the nature of the gegenion formed together with  $\text{PhNMe}_2^+$ . When VIII is oxidized in aqueous mineral acid, the gegenion is an ion (e.g., sulfate) of low basicity; this will have little tendency to abstract a proton. Conversely the oxidation of VIII with manganic acetate in acetic acid gives rise to a basic gegenion (acetate); the reaction of this with  $\text{PhNMe}_2^+$  may well take place preferentially by proton transfer, giving the radical  $\text{PhNMeCH}_2\cdot$ . This process will be still further favored by the fact that the two ions ( $\text{PhNMe}_2^+$  and acetate) will be formed initially as an ion pair, the life of which is likely to be quite long since the dissociation constants of salts (e.g., sodium acetate) in acetic acid are small. Ion pairs also seem to play a role in the oxidation of *p*-methoxytoluene by manganic acetate in acetic acid (see part I<sup>1</sup>).

## Experimental Section

**Procedure.** The compound to be oxidized was added to a stirred solution of manganic acetate (2 mole equiv) in acetic acid, heated on a steam bath, and reaction continued until no  $\text{Mn}^{III}$  remained. The solvent was then removed under reduced pressure and the residue extracted with ether. Evaporation of the ethereal extract gave the crude reaction product. Analyses by glpc were carried out at 200° on a 8 ft  $\times$   $\frac{3}{8}$  in. o.d. column packed with silicone gum rubber on Chromosorb P, using helium as carrier (80 cc/min).

**Anisole (I).** Oxidation of I (30 g) gave a yellow viscous oil, separated by distillation into the following fractions: (a) bp 68–72° (4 mm), 16.9 g,  $n_D^{25}$  1.5181; (b) bp 120–122° (8 mm), 0.8 g,  $n_D^{25}$  1.5254; (c) bp 122–125° (8 mm), 6.5 g,  $n_D^{25}$  1.5130; (d) bp 125–130° (8 mm), 3.3 g,  $n_D^{25}$  1.5112; residue 1.7 g. Fraction a was unchanged VI (58%), identified by glpc and infrared spectrum. Fractions b and c showed acetate absorption in the infrared, lost on hydrolysis with alcoholic sodium hydroxide. Ether extraction gave a yellow oil (A, 2.0 g) and acidification of the aqueous layer followed by ether extraction a semisolid B (0.2 g). A distilled at 132–135° (30 mm); it was identified as anisyl alcohol (XIIa) by its infrared spectrum, by oxidation to anisic acid, mp and mmp 184.5–185° (from water), and by its urethan, mp and mmp 93.5–94° (from petroleum ether). A small amount of a second urethan was also isolated, identified as the urethan of *o*-methoxybenzyl alcohol (XIIIa), mp 104–104.5° (from carbon tetrachloride), by its infrared spectrum. Recrystallization of B from water gave anisic acid (XI), mp and mmp 184–185°.

**Veratrole (II).** Oxidation of II (40 g) gave a somewhat viscous oil (39.3 g), separated by distillation at 3 mm into the following fractions: (a) bp 63–65°, 27.5 g,  $n_D^{25}$  1.5304; (b) bp 65–84°, 1.6 g,  $n_D^{25}$  1.5316; (c) bp 84–120°, 2.3 g,  $n_D^{25}$  1.5417; (d) bp 120–134°, 4.7 g,  $n_D^{25}$  1.5483; residue, 2.8 g. Fraction a was unchanged II, and b mainly unchanged II (total recovery, 73%). The residue on chromatography from benzene on alumina gave XV (0.8 g), mp and mmp 146–146.5° (from aqueous ethanol), infrared spectrum identical with that of an authentic sample.

*Anal.* Calcd for  $\text{C}_{17}\text{H}_{18}\text{O}_5$ : C, 67.5; H, 6.0; mol wt, 302.3. Found: C, 67.6; H, 6.1; mol wt (mass spectroscopy), 302.

Hydrolysis of a portion (2.1 g) of fraction d with alcoholic potash, followed by ether extraction, gave a nonphenolic oil (0.9 g) containing hydroxyl (infrared spectrum), oxidized by permanganate to veratric acid, mp and mmp 181–182°. Acidification of the aqueous layer from the hydrolysis gave veratric acid (0.4 g), mp and mmp 181–182°.

**Resorcinol Dimethyl Ether (III).** Oxidation of III (30 g) gave a dark viscous oil (29.2 g) which gave unchanged III (9.8 g) on distillation, identified by glpc and infrared spectrum. The residue after chromatography from petroleum ether on alumina and crystallization from petroleum ether gave XVII, mp 150–150.5° (lit.<sup>6</sup> 149°).

*Anal.* Calcd for  $\text{C}_{25}\text{H}_{28}\text{O}_7$ : C, 68.2; H, 6.4; mol wt, 440.5. Found: C, 68.4; H, 6.4; mol wt (osmometric in  $\text{CHCl}_3$ ), 421.

The infrared spectrum had bands at 3509 (OH) and 820  $\text{cm}^{-1}$  (1,2,4-trisubstituted benzene). The ultraviolet spectrum in ethanol

had  $\lambda_{\max}$  226 and 281 m $\mu$ . The proton nmr spectrum (7% solution in  $\text{CCl}_4$ ) had singlets at  $\tau$  6.55 (methyl), 6.27 (methyl), and 5.53 (hydroxyl), a complex multiplet at  $\tau$  3.66 (aromatic protons), and a doublet at  $\tau$  3.00 (aromatic protons); integrated absorptions in ratio 9:9:1:6:3. Treatment of XVII with concentrated or dilute sulfuric acid gave deep violet solutions from which XVII could be recovered by dilution and basification.

Extraction with benzene of the column from which XVII had been eluted gave a dark, brown, semisolid material (3.8 g) from which no definite compounds could be isolated.

**Hydroquinone Dimethyl Ether (IV).** Oxidation of IV (30 g) gave a viscous, partly crystalline oil, separated by distillation at 8 mm into the following fractions: (a) bp 63–65°, 15.5 g; (b) bp 122–142°, 4.0 g; (c) bp 142–154°, 3.7 g; residue, 5.1 g. Fraction a solidified, mp 56°, identified as unchanged IV by mixture melting point and infrared spectrum. Fractions b and c showed absorption in the infrared characteristic of acetic esters (1729  $\text{cm}^{-1}$ ). Fractions b and c were combined and chromatographed on alumina. Elution with benzene gave unchanged IV (1.7 g). The column was then eluted with ethanol, the extract hydrolyzed with alcoholic sodium hydroxide and extracted with ether (A), and the aqueous layer acidified and extracted with ether (B). Extract A on evaporation gave a nonphenolic oil (0.6 g), oxidized by a cold 2% solution of potassium permanganate in acetic acid to 2,5-dimethoxybenzaldehyde, identified as its 2,4-dinitrophenylhydrazone, mp 198°, and semicarbazone, mp 210–211°. Oxidation with a hot (60°) 5% solution of potassium permanganate gave 2,5-dimethoxybenzoic acid, mp and mmp 78–79°. A was thus 2,5-dimethoxybenzyl alcohol (XIXa). Further material (0.8 g) was obtained by alkaline hydrolysis of the residue from the distillation. Evaporation of the second extract (B) gave phenolic material, identified as *p*-methoxyphenol (XVIII) by mp and mmp 55–56°, and by its benzoate, mp and mmp 87.5–88°.

**1-Methoxynaphthalene (V).** Oxidation of V (24 g) gave a dark viscous oil (23.8 g), separated by distillation into unchanged V (11.7 g, 49%) identified by glpc and infrared spectrum, a fraction (A), bp 135–151° (4 mm) (7.6 g), and a dark residue (B) (4.2 g). The infrared spectrum of A showed characteristic acetate absorption (1739  $\text{cm}^{-1}$ ); alkaline hydrolysis of a portion (2.1 g) gave 4-methoxy-1-naphthol (XXa) (1.4 g), crystallizing from aqueous ethanol in needles, mp 126–126.5° (lit.<sup>16</sup> 126°).

*Anal.* Calcd for  $\text{C}_{11}\text{H}_{10}\text{O}_2$ : C, 75.9; H, 5.8; mol wt, 174.2. Found: C, 76.1; H, 5.9; mol wt (mass spectroscopy), 174.

The infrared spectrum of XXa showed a strong hydroxyl band (3279  $\text{cm}^{-1}$ ); A was thus 4-methoxy-1-naphthyl acetate (XXb). Fractional crystallization of the residue B from aqueous ethanol gave 4-methoxy-1,2-naphthoquinone (XXI) (1.0 g), mp 188–189° (lit.<sup>17</sup> 190°).

*Anal.* Calcd for  $\text{C}_{11}\text{H}_8\text{O}_3$ : C, 70.2; H, 4.3; mol wt, 188.2. Found: C, 69.8; H, 4.3; mol wt (mass spectroscopy), 188.

Evaporation of the mother liquor from XXI gave a gum with strong acetate absorption in the infrared. Hydrolysis with 10% sulfuric acid, followed by treatment with picric acid in chloroform, gave a picrate, orange-red needles from aqueous ethanol, mp 108.5–109°. Decomposition of the picrate with potassium hydroxide

and extraction with ether gave XXII (0.8 g) which crystallized from benzene in pale blue needles, mp 205–205.5° (lit.<sup>18</sup> 205°).

*Anal.* Calcd for  $\text{C}_{22}\text{H}_{18}\text{O}_4$ : C, 76.3; H, 5.2; mol wt, 346.4. Found: C, 75.9; H, 5.1; mol wt (mass spectroscopy), 345.

The infrared spectrum showed strong bands at 3425 (OH) and 1028 and 1258  $\text{cm}^{-1}$  (aromatic ether).

**2-Methoxynaphthalene (VI).** Oxidation of VI (30 g) gave a brown semisolid material (29.7 g). A portion (25 g) of this on treatment with aqueous ethanol gave unchanged VI (10.6 g, 40%), mp and mmp 73.5–74°. Evaporation of the filtrate left a residue which showed no acetate absorption in the infrared. Chromatography from ethanol on alumina gave 2-methoxy-1,4-naphthoquinone (XXIII) (8.0 g) which crystallized from aqueous ethanol in yellow needles, mp and mmp (with an authentic<sup>19</sup> sample) 183.5–184°.

*Anal.* Calcd for  $\text{C}_{11}\text{H}_{10}\text{O}_3$ : C, 70.2; H, 4.3; mol wt, 188.2. Found: C, 70.2; H, 4.3; mol wt (mass spectroscopy), 188.

The infrared spectrum (KBr disk) was identical with that of the authentic material, having strong carbonyl bands at 1642 and 1678  $\text{cm}^{-1}$ .

Extraction with acetone of the column from which XXIII had been eluted gave black polymeric material (5.3 g).

**1,2-Benzanthracene (VII).** Oxidation of VII (8 g) gave a dark glutinous product (7.6 g) which was chromatographed on alumina. Elution with ethanol gave benz[*a*]anthraquinone (XXIV) (3.7 g), identical (mp and mmp 167.5–168°, and infrared spectrum) with an authentic sample.

*Anal.* Calcd for  $\text{C}_{18}\text{H}_{10}\text{O}_2$ : C, 83.7; H, 3.9; mol wt, 258.3. Found: C, 83.6; H, 4.2; mol wt (mass spectroscopy), 258.

Further elution of the column with benzene gave unchanged VII (1.7 g), and extraction with acetone then gave a polymeric gum (2.1 g).

***N,N*-Dimethylaniline (VIII).** Oxidation of VIII (30 g) gave a dark brown resinous material which was extracted first with benzene (fraction A, 16.4 g), then chloroform (fraction B, 11.8 g). Chromatography of A from benzene on alumina gave unchanged VIII (0.2 g) followed by a yellow solid (12.4 g) which crystallized from petroleum ether in colorless plates, mp 89–89.5°, identified as bis(*p*-dimethylaminophenyl)methane (XXV) by mixture melting point and comparison of infrared spectra with an authentic sample.<sup>20</sup>

*Anal.* Calcd for  $\text{C}_{17}\text{H}_{22}\text{N}_2$ : C, 80.3; H, 8.7; N, 11.0; mol wt, 254.4. Found: C, 80.4; H, 8.4; N, 11.0; mol wt (mass spectroscopy), 254.

The proton nmr spectrum of XXV showed sharp singlets at  $\tau$  7.16 (methyl) and 6.20 ( $\text{CH}_2$ ), and an AB quartet at  $\tau$  3.54, 3.40, 3.15, and 3.01 (aromatic CH), the integrated intensities being in the ratio 6:1:4.

The second fraction (B) consisted of intractable polymeric material from which no definite product could be isolated. All attempts to detect the presence of *N,N,N',N'*-tetramethylbenzidine failed.

Similar products were formed when the reaction between VIII and  $\text{Mn}(\text{OAc})_3$  was carried out at 35°.

(16) F. Russig, *J. Prakt. Chem.*, [2] 62, 50 (1926).

(17) L. F. Fieser, *J. Am. Chem. Soc.*, 48, 2922 (1926).

(18) S. Goldschmidt and H. Wessbecher, *Chem. Ber.*, 61, 375 (1928).

(19) F. Wessely, *Monatsch.*, 84, 69 (1954).

(20) L. Horner and C. Betzel, *Ann. Chem.*, 579, 175 (1953).