Diazotization of Aromatic Primary Amines of Weak Basicity. II.[1] Reduction of Arenediazonium Salts with Alkylbenzene Derivatives

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The diazonio group of arenediazonium salts derived from weakly basic amines were efficiently substituted by hydrogen with alkylbenzenes in sulfuric acid. Several types of evidence, including kinetic results and experiments to trap an intermediate, indicated that the reduction occurs *via* an aryl radical intermediate. In the reduction with toluene, analyses of by-products suggested a radical chain mechanism, which would involve a propagation cycle caused by electron transfer from the benzyl radical to the diazonio group.

The diazonio group of arenediazonium salts is known to be replaced by hydrogen with various reducing agents. These include alcohols,[2] alcohols in combination with metals or metal oxides,[3] ethers,[4] formaldehyde,[5] formic acid and its esters and amides:[6] the ordinary reducing agents of the organic type. However, there has been no report on the reduction of arenediazonium salts by aromatic hydrocarbons.

During the course of our studies on the reaction of arenediazonium salts derived from weakly basic amines, we found that the diazonio group was effectively replaced by hydrogen with alkylbenzene derivatives in sulfuric acid. This paper reports this novel reduction of arenediazonium salts with alkylbenzenes.

Results and Discussion

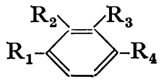
Reaction of 2-Bromo-4,6-dinitrobenzenediazonium Salt with Alkylbenzenes and Their Derivarives. In this paper, 2-bromo-4,6-dinitrobenzenediazonium salt was chosen as typical of those derived from weakly basic amines. The diazotization was carried out in nitrosylsulfuric acid, which was prepared by adding an 20% excess of sodium nitrite into sulfuric acid. When benzene, halobenzene, or phenol was added to the diazonium solution, the corresponding 2-bromo-4,6-dinitrobiphenyl derivatives resulting from an arylation (acidic Gomberg reaction)[7] of the aromatic substrates with the diazonium compound were obtained, along with a tarry substance.

On the contrary, in the presence of toluene, 1-bromo-3,5-dinitrobenzene was obtained as the main product, showing that the diazonio group was replaced by hydrogen. Similarly, other alkylbenzenes such as ethylbenzene, cumene, and *p*-xylene reduced the diazonium salt effectively. Derivatives of toluene are also able to reduce the diazonium salt very quickly. The results are summarized in Table 1.

TABLE 1. REDUCTION OF 2-BROMO-4,6-DINITROBENZENEDIAZONIUM SALT WITH ALKYLBENZENES

Alkylbenzene^a)				Yield (%) of 1-bromo-3,5-dinitrobenzene
R_1	R_2	R_3	R_4	
CH_3	H	H	CH_3	76
CH_3	H	H	H	70
CH_2CH_3	H	H	H	52
$CH(CH_3)_2$	H	H	H	30
CH_3	H	H	SO_3H	81
CH_3	H	H	NO_2	80
CH_3	H	H	OCH_3	70
CH_3	H	Br	H	82
CH_3	OCH_3	H	NO_2	60
CH_3	Cl	H	NO_2	27
CH_3	NO_2	H	NO_2	0

a) Alkylbenzene:



As can be seen, there is no observable correlation between *m*- and *p*-substituents and product yields. But the introduction of *o*-substituents into toluene decreases their reducing ability; *e.g.* the reaction with 2,4-dinitrotoluene gave only a tarry substance and unchanged 2,4-dinitrotoluene was recovered quantitatively. In the reaction with *p*-nitrotoluene, *p*-nitrobenzaldehyde was obtained in 51% yield along with 1-bromo-3,5-dinitrobenzene (80%). This observation and the fact that no reduction took place in the presence of benzene indicate that alkyl groups are responsible for the reduction.

TABLE 2. REDUCTION OF 2-BROMO-4,6-DINITROBENZENEDIAZONIUM SALT WITH BENZENE DERIVATIVES

Reducing agent	Yield (%) of 1-bromo-3,5-dinitrobenzene
Tetralin	44
$C_6H_5CH_2OH$	16
C_6H_5CHO	18
$C_6H_5OCH_3$	11
$C_6H_5C(CH_3)_3$	37

Therefore, to answer the question whether the reducing ability is really limited to alkyl groups, several benzene derivatives containing side chains other than an alkyl group were examined (Table 2).

Table 2 shows that, even though the reducing ability is not high, side chains such as hydroxymethyl-, formyl-, and methoxyl groups are also able to reduce the diazonium compound, as was expected. Since aldehyde[5] and ethers[4] have been known to reduce diazonium compounds, a hydroxymethyl compound would be an intermediate on the course of reduction from methyl compound to aldehyde.

Reactions of 2-Bromo-4,6-dinitrobenzenediazonium Salt with Aliphatic Compounds. From the results described above, it has become apparent that an alkyl group attached to an aromatic nucleus is effective for the reduction. However, it is questionable whether the

TABLE 3. REDUCTION OF 2-BROMO-4,6-DINITROBENZENEDIAZONIUM SALT WITH ALCOHOLS AND NITRO COMPOUND

Reducing agent	Yield (%) of 1-bromo-3,5-dinitrobenzene
CH_3OH	77
CH_3CH_2OH	66
$(CH_3)_2CHOH$	52
$(CH_3)_3COH$	trace
$(CH_3)_2CHNO_2$	62

presence of the aromatic nucleus is really necessary for the reducing ability. To answer this question and to get an insight into the reduction mechanism, the reducing ability of some aliphatic compounds was examined (Table 3).

In accord with our expectation, aliphatic alcohols reduced the diazonium salt. It is noteworthy that the reactions with alcohols gave only the 1-bromo-3,5-dinitrobenzene, suggesting that the reaction proceeded by a radical mechanism, *via* an aryl radical intermediate.[8] Furthermore, diazonium salt could be reduced with an aliphatic nitro compound, resulting in the formation of 1-bromo-3,5-dinitrobenzene. This observation also suggests a radical process for the reaction, because arenediazonium salts are known to decompose in nitroalkanes to give phenols by a heterolytic process.[9]

Reactions of Some Arenediazonium Salts with p-*Toluenesulfonic Acid.* No detailed study has been reported on the reduction of an diazonio group with alkylbenzene.[10] Therefore, to make clear the relation between the chemical constitution of a diazonium salt and its susceptibility to reduction by alkylbenzene, reactions of several arenediazonium salts derived from weakly basic amines with *p*-toluenesulfonic acid were investigated (Table 4).

From Table 4 it is evident that for the effective reduction by *p*-toluenesulfonic acid, a diazonium salt should fulfil the following conditions: 1) The presence of at least two strong electron-withdrawing groups. 2) The presence of a bulky group at the 2 and 6 positions to the diazonio group; 2,6-dinitrobenzenediazonium salt yielded the reduced product in 45% yield, while in the case of 2,4-dinitrobenzenediazonium salt no reduced product was obtained.[11]

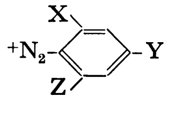
Effects of Sodium Nitrite. In the previous paper[1] we reported that 2-bromo-4,6-dinitrobenzenediazonium salt reacted with sodium nitrite to effect a replacement of the diazonio group by the nitro group. However, in the presence of alkylbenzenes, sodium nitrite was found to act in a different manner. When 2-bromo-4,6-dinitrobenzenediazonium salt was allowed to react with *p*-toluenesulfonic acid in nitrosylsulfuric acid containing an equivalent amount of sodium nitrite, the yield of the reduced product was very poor (≈2%). But when nitrosylsulfuric acid containing 20% excess of sodium nitrite was used, the reduced product was obtained in 81% yield. Figure 1 shows the effect of the amount of sodium nitrite on the decomposition rate of 2-bromo-4,6-dinitrobenzenediazonium salt in sulfuric acid; in the absence of an excess of sodium nitrite, most of the diazonium salt remained unchanged even after 200 min.

These results suggest that an excess of sodium nitrite plays an important role in the decomposition of the diazonium salt to yield the reduced product. It is known that the nitrite ion promotes the homolytic decomposition of a diazonium ion in water[12] and in DMSO;[13] the function of a nitrite ion for the decomposition of a diazonium ion has been explained by suggesting that it combines with the diazonium ion to form a covalent azo compound which decomposes homolytically.[12–15] A similar radical process may be expected in our system. This assumption may be supported by the fact that, when 2,2-diphenyl-1-picrylhydrazyl radical was employed instead of an excess of sodium nitrite, the diazonium salt easily decomposed to give the reduced product in 60% yield. Furthermore, when *p*-iodobenzenesulfonic acid was added to the reaction mixture as a scavenger for the aryl radical[16] in place of *p*-toluenesulfonic acid, 1-

TABLE 4. REDUCTION OF ARENEDIAZONIUM SALT WITH *p*-TOLUENESULFONIC ACID

Diazonium salt[a]			Yield (%) of 1-bromo-3,5-dinitrobenzene
X	Y	Z	
NO_2	NO_2	Br	81
NO_2	NO_2	Cl	77
NO_2	NO_2	NO_2	67
NO_2	Br	NO_2	80
NO_2	H	NO_2	45
NO_2	NO_2	H	trace
Br	NO_2	Br	2
Cl	NO_2	Cl	4
Br	Br	NO_2	6
H	NO_2	H	0

a) Diazonium salt:



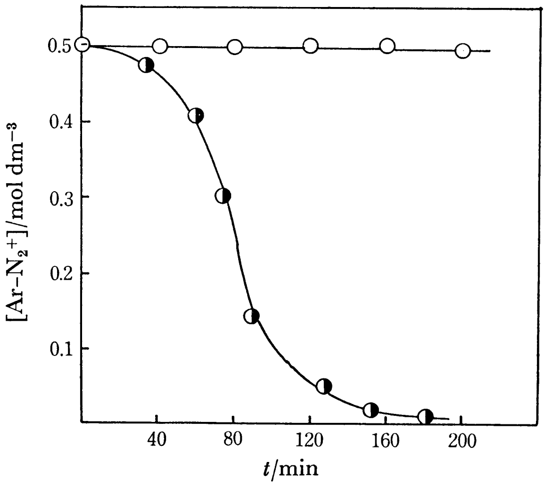


Fig. 1. Plots of the concentration of 2-bromo-4,6-dinitrobenzenediazonium ion as a function of time in sulfuric acid at 52 °C. ○: $NaNO_2/ArNH_2$ (molar ratio) = 1.00, ◑: $NaNO_2/ArNH_2$ (molar ratio) = 1.24.

bromo-2-iodo-3,5-dinitrobenzene was obtained. This result supports the assumption that an intermediary aryl radical abstracts an iodo atom from *p*-iodobenzenesulfonic acid.

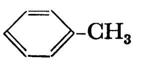
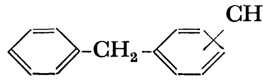
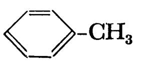
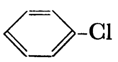
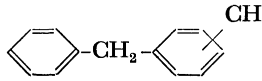
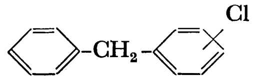
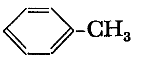
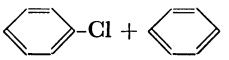
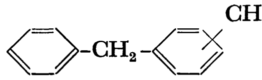
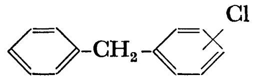
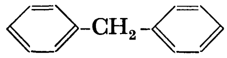
By-products of the Reaction of 2-Bromo-4,6-dinitrobenzenediazonium Salt with Toluene. It seemed worthwhile to check the by-products in this reduction from a mechanical point of view.

When toluene was employed as the reducing reagent, phenyltolylmethane was obtained in 10% yield together with the reduced product. Phenyltolylmethane was a mixture of two isomers: one of the isomers was found to be phenyl-*p*-tolylmethane by a comparison with an authentic sample, while the other isomer is still unidentified because of the difficulty in purification.

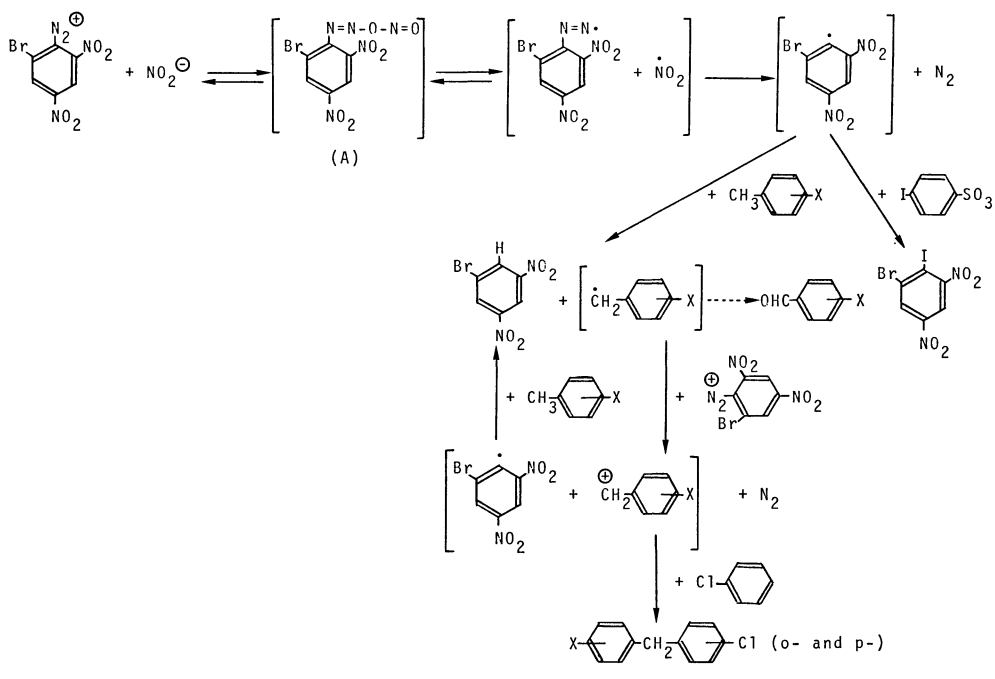
On the other hand, when a mixture of toluene and chlorobenzene was added to the diazonium solution, a mixture of chlorodiphenylmethanes was obtained, together with phenyltolylmethanes (Table 5).

Chlorodiphenylmethanes were found to consist of a mixture of 60% *o*- and 40% *p*-chlorodiphenylmethane; no *m*-derivative could be detected, suggesting that an electrophilic attack by the benzyl cation upon chlorobenzene took place.[17] In addition, competitive benzylations of mixtures of benzene and chlorobenzene with diazonium salt gave a ratio of chlorodiphenylmethanes (*o*- and *p*-isomer)/diphenylmethane of 0.29, which is close to that of the Friedel-Crafts benzylation in

Table 5. Minor products in the decomposition of 2-bromo-4,6-dinitrobenzenediazonium ion in the presence of an aromatic substrate

No.	Reducing agent	Substrate	By-product	Isomer ratio (%) *o*-	*m*-	*p*-	k_X/k_H[a)]
1				—	—	—	—
2				—	—	—	—
				60	0	40	—
3				—	—	—	—
				60	0	40	0.29
							1.00

a) Relative rate for benzylation.



Scheme 1.

nitromethane (0.24).[17] Moreover, when oxygen was bubbled into the reaction mixture as a radical scavenger, the yield of diphenylmethane derivatives decreased to a great extent.[18] These results clearly suggest that the reduction process involves a radical intermediate, but the benzylation of aromatic substrate was performed by the benzyl cation, not by the benzyl radical.

Reduction Process of Arenediazonium Salts with Alkylbenzenes. From the results and considerations described above, the process of reduction of arenediazonium ions may be reasonably explained by Scheme 1.

In a benzenediazonium salt containing several strong electron-withdrawing groups, the electrophilicity of the diazonio group is undoubtedly large. Thus, it can combine with a nitrite ion even in sulfuric acid to give an intermediate (**A**), which easily decomposes, resulting in the formation of an aryl radical. The bulky groups at 2- and 6-positions would accelerate the decomposition of the intermediate (**A**), because the resulting aryl radical is more free from steric strain than the intermediate (**A**). The resulting aryl radical abstracts a hydrogen from toluene to give benzyl radical and reduced product. A subsequent electron transfer from benzyl radical to diazonium ion results in the formation of benzyl cation and aryl radical, which enters the propagation cycle as indicated in Scheme 1. This interpretation is consistent with the observation that slight excess of sodium nitrite is enough to decompose the diazonium ion in our system.

Experimental

Materials. 2,6-Dinitroaniline,[20] 2,6-dibromo-4-nitroaniline,[21] 4-bromo-2,6-dinitroaniline,[22] 2,4-dibromo-6-nitroaniline,[23] and *p*-iodobenzenesulfonic acid[24] were prepared according to the procedures described in the literature. Other reagents, solvents, and starting materials were purchased from standard sources and purified according to literature procedures.

General Procedure for Reduction: Summarized in Tables 1 and 4. Let us take as an example the reaction of 2-bromo-4,6-dinitrobenzenediazonium salt with *p*-nitrotoluene. To nitrosylsulfuric acid, which was prepared from sulfuric acid (20 ml) and sodium nitrite (1.65 g, 0.024 mol), was added in portions 2-bromo-4,6-dinitroaniline (5.20 g, 0.020 mol) at room temperature. The mixture was warmed up to 50 °C and stirred for 3 h to complete the diazotization. Then, with mechanical stirring, *p*-nitrotoluene (2.74 g, 0.02 mol) was added into the diazonium solution and stirring was continued for 3 h at 50 °C. The mixture was then poured into a mixture of ice and water and was extracted with chloroform. The extract was dried with sodium sulfate and concentrated by distillation. The residue was subjected to column chromatography on silica gel eluting with benzene–petroleum ether (1:1 v/v) to yield 1-bromo-3,5-dinitrobenzene (3.87 g, 78%) and *p*-nitrobenzaldehyde (1.38 g, 51%). The products obtained were identified by their NMR, IR, and MS spectra and by a mixed-melting point test with an authentic sample.

The reactions of diazonium salt with substituted benzenes (Table 2) and alcohols (Table 3) were carried out in the same way.

Thermolysis of 2-bromo-4,6-dinitrobenzenediazonium salt (0.02 mol) in the presence of *p*-iodobenzenesulfonic acid (0.06 mol) was carried out in the same way to yield 1-bromo-2-iodo-3,5-dinitrobenzene (1.34 g, 18%), which was identified by a mixed-melting point test with an authentic sample.[1]

Kinetic Measurements. In a volumetric flask, a solution of *ca.* 0.5 mol/dm^3 of diazonium salt containing *p*-toluenesulfonic acid (0.5 mol/dm^3) was prepared at thermostat temperature as described previously. An aliquot of this diazonium solution was taken at a recorded time and was added to an alkaline R-salt (2-naphthol-3,6-disulfonic acid) solution to quench the remaining diazonium salt. After the diazo-coupling, the solution was diluted to a fixed volume and its optical density was measured at the maximum wavelength of absorbance of the dye formed (497 nm).

Analyses of By-products from 2-Bromo-4,6-dinitrobenzenediazonium Salt: Summarized in Table 5. 2-Bromo-4,6-dinitrobenzenediazonium salt (5.20 g, 0.02 mol) was allowed to decompose completely in the presence of toluene (1.84 g, 0.02 mol) and worked up as previously described. Chromatography on silica gel with petroleum ether as the eluent yielded the reduced product (3.52 g, 71.1%) and crude phenyltolylmethane (0.36 g, 10%). The phenyltolylmethane was further fractionated by preparative GLC, and one of the components was identified as phenyl-*p*-tolylmethane by comparison of its NMR spectrum and retention time of GLC to those of an authentic sample.[25] The benzylation in the presence of a mixture of toluene (0.04 mol), benzene (0.04 mol), and chlorobenzene (0.04 mol) was performed as previously described. The isomer ratio and the relative reactivity for the benzylation of chlorobenzene were determined by GLC (10% Carbowax 20M-Diasolide, He; 20 ml/min, 170 °C, 4 mm × 4 m) using biphenyl as the internal standard. 2-Chloro- and 4-chlorodiphenylmethane employed as reference compounds for GLC were prepared as described in the literature.[26]

References

1) Part I: E. Ohtubo, T. Kuroda, Y. Hashida, S. Sekiguchi, and K. Matsui, *Nippon Kagaku Kaishi*, 2178 (1975).

2) P. Griess, *Justus Liebigs Ann. Chem.*, **113**, 210 (1860); **117**, 63 (1861).

3) P. Ruggli and E. Peyer, *Helv. Chim. Acta*, **9**, 950 (1926); P. Ruggli, F. Knapp, E. Merz, and A. Zimmermann, *Helv. Chim. Acta*, **12**, 1043 (1929); P. Ruggli and M. Welge, *Helv. Chim. Acta*, **15**, 586 (1932).

4) H. Meerwein, H. Allendörfer, P. Beekmann, F. R. Kunert, H. Morschel, F. Pawellek, and K. L. Wunderlich, *Angew. Chem.*, **70**, 211 (1958).

5) R. G. Brewster and J. A. Poje, *J. Am. Chem. Soc.*, **61**, 2418 (1939).

6) W. Zerweck, M. Schubert, and R. Fleischauer, *Chem. Zentr.*, **1954**, 9141.

7) M. G. Bartle, P. K. Mackie, and J. M. Tedder, *J. Chem. Soc., Chem. Commun.*, **1974**, 271; M. G. Bartle, S. T. Gore, R. K. Mackie, S. Mhatre, and J. M. Tedder, *J. Chem. Soc., Perkin Trans. 1*, **1978**, 401.

8) In the thermolysis of arenediazonium salts in methanol, a replacement of diazonio group by methoxyl group occurs by a ionic mechanism, *via* an aryl cation intermediate, whereas a replacement by hydrogen occurs by a radical mechanism. a) D. F. DeTar and T. Kosuge, *J. Am. Chem. Soc.*, **80**, 6072 (1958); b) T. J. Broxton, J. F. Bunnett, and C. H. Paik, *J. Org. Chem.*, **42**, 643 (1977).

9) Thermolyses of *p*-nitrobenzenediazonium fluoroborate in nitromethane and in 2-nitropropane at 80 °C yield *p*-nitrophenol in 53 and 67% yields, along with a fluorinated compound. But the thermolyses in the presence of pyridine inducing homolytic decomposition yields only the reduction

product. (Y. Hashida, Y. Takeda, and K. Matsui, to be published.)

10) *E.g.* thermolysis of benzenediazonium salt in the presence of toluene in 2,2,2-trifluoroethanol gives normal arylation products [P. Burri and H. Zollinger, *Helv. Chim. Acta*, **50**, 2204 (1973)].

11) In this case, substantial decomposition of diazonium salt did not occur under the given conditions, *e.g.* stirring for 3 h at 50 °C.

12) H. J. Opgenorth and Ch. Rüchardt, *Justus Liebigs Ann. Chem.*, **1974**, 1333.

13) M. Kobayashi, H. Minato, N. Kobori, and E. Yamada, *Bull. Chem. Soc. Jpn.*, **43**, 1131 (1970).

14) H. Zollinger, *Acc. Chem. Res.*, **6**, 335 (1973).

15) H. Zollinger, *Angew. Chem. Int. Ed. Engl.*, **17**, 141 (1978).

16) J. F. Bunnett and C. C. Wasmer, *J. Am. Chem. Soc.*, **88**, 5334 (1966).

17) Friedel-Crafts benzylation of chlorobenzene with benzyl chloride in the presence of $AlCl_3$ in nitromethane give 33% *o*-, 0.6% *m*-, and 66.4% *p*-isomer [G. A. Olah, S. J. Kuhn, and S. H. Flood, *J. Am. Chem. Soc.*, **84**, 1688; 1695 (1962)]. For more detailed data on the isomer ratio, see O. Tsuge and M. Tashiro, *Bull. Chem. Soc. Jpn.*, **40**, 119 (1967).

18) The yield of diphenylmethane was reduced to one-third.

19) See the reference cited in Ref. 8b.

20) F. Ullmann, G. Engi, N. Wosnessensky, E. Kuhn, and E. Herre, *Justus Liebigs Ann. Chem.*, **366**, 79 (1909).

21) S. M. Rosanitsch, *Ber.*, **15**, 471 (1882).

22) P. T. Austen, *Ber.*, **9**, 918 (1876).

23) C. Jackson, *Am. Chem. J.*, **35**, 149 (1906).

24) W. Lenz, *Ber.*, **10**, 1135 (1877).

25) W. H. C. Rueggeberg, M. L. Cushing, and W. A. Cook, *J. Am. Chem. Soc.*, **68**, 191 (1946).

26) A. J. Birch and J. Grimshaw, *J. Chem. Soc.*, **1961**, 1405.