CCCLXXXV.—*Some Substitution Products of Azobenzene.*

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Among the systems containing two phenyl nuclei which are of interest, from the point of view of substitution, is azobenzene. The order of substitution in this series derives its importance from the fact that the system contains two tervalent nitrogen atoms free from hydrogen atoms; it might be expected, therefore, that analogies in behaviour between this series and nitrosobenzene or the diacyl derivatives of aminodiphenyl (compare Scarborough and Waters, J., 1927, 1139) would be found. The formation of quinonoid compounds in this series is a possibility which must not be excluded as a factor which would influence in a marked manner the sequence in which progressive substitution would occur.

The first substitution reaction in this series was carried out by Laurent and Gerhardt (*Annalen*, 1850, **75**, 73), who examined the reaction between azobenzene and nitric acid. A dibromoazobenzene was obtained by Werigo (*Annalen*, 1865, **135**, 178; 1873, **165**, 199). An extensive study of the substitution products of azobenzene with nitric acid, sulphuric acid, and bromine, in which as many as four similar or dissimilar groups were introduced, was made by Janovsky (*Monatsh.*, 1881, **2**, 221; *et seq.*). The nature of the nitration products of azobenzene which were described by Janovsky was the subject of a mild criticism by Klinger and Zurdeeg (*Annalen*, 1889, **255**, 336); but it remained for Werner and Stiasny (*Ber.*, 1899, **32**, 3257) to point out that of some twelve mono-, di-, and tri-nitro-derivatives of azobenzene, described by Janovsky, there was not one which might be described as a single individual and as a consequence the structures assigned could only be justified in two cases where a reasonable degree of purity had been obtained.

An examination made in these laboratories by Mr. J. Dexter has shown that the destructive criticism of Werner and Stiasny is fully justified; further, he has shown that of the three monobromo- and two dibromo-azobenzenes described by Janovsky, only one mono- and one dibromo-azobenzene could be isolated.

In view of all these criticisms of the work of Janovsky, the remaining substitution products which he obtained cannot be accepted without revision or independent confirmatory evidence.

The number of direct substitution products of azobenzene itself whose constitution may be regarded as established is therefore limited to 4-nitroazobenzene, m. p. 149°, 4 : 4′-dinitroazobenzene,

m. p. 221°, 4-bromoazobenzene, m. p. 94°, 4 : 4′-dibromoazobenzene, m. p. 205°, and azobenzene-4-sulphonic acid, m. p. 127°. It would thus appear that only the two 4-positions are readily substituted.

The introduction of substituents into the molecule of any of the three possible methylazobenzenes (benzeneazotoluenes) does not appear to have been attempted. In an attempt to nitrate 4-methylazobenzene in acetic acid solution the initial substance was recovered, and a nitro-group could only be introduced by the action of fuming nitric acid; whereas 2- and 3-methylazobenzene nitrated easily in acetic acid solution to yield products substituted in the 4 : 4′-positions. On bromination 4-methylazobenzene could only be converted into 4′-*bromo*-4-*methylazobenzene* by the action of neat bromine, whereas 3-methylazobenzene was converted into 4-*bromo*-3-*methylazobenzene* by bromination in acetic acid solution. The product obtained by the action of bromine on 2-methylazobenzene is apparently not an azo-derivative and its constitution could not be elucidated. The nature of the substitution products of 2- and 4-methylazobenzenes indicates that the $C_6H_5{\cdot}N{:}N{\cdot}$ group is more strongly directive than the methyl group; but when in the 2- or 3-position the methyl group makes it possible to effect substitution by less drastic methods than when it occurs in the 4-position and must thus have an activating effect.

The presence of chlorine as a substituent in azobenzene causes further substitution to take place in the unsubstituted phenyl nucleus and, since the $C_6H_5{\cdot}N{:}N{\cdot}$ group is strongly *p*-directive, the entering substituent occupies the 4′-position. Thus on nitration, chlorination and bromination, 4-chloroazobenzene yielded 4′-*nitro*-, 4′-chloro-, and 4′-*bromo*-4-*chloroazobenzene*, respectively; similarly, 3-chloroazobenzene yielded 4′-*nitro*- and 4′-*bromo*-3-*chloroazobenzene*. This behaviour of the halogen atom was to be expected from a consideration of the results obtained in the diphenyl and benzophenone series.

The further substitution of 4-hydroxyazobenzene was first investigated by Noelting (*Ber.*, 1887, **20**, 2997), who showed that on nitration, in concentrated sulphuric acid solution, 4′-nitro-4-hydroxyazobenzene was formed; it has also been shown by Hewitt (J., 1900, **77**, 99) that if this nitration is carried out in nitric acid (*ca.* 20%) solution the product is 3-nitro-4-hydroxyazobenzene. This difference in behaviour was ascribed to the formation of a salt between the concentrated sulphuric acid and the azophenol, acting in its tautomeric form as quinonephenylhydrazone. In later communications Hewitt and Aston (*ibid.*, pp. 713, 811) have shown that on bromination, in the presence of fused sodium acetate, 4-hydroxyazobenzene yielded a product substituted in the 3 : 5-positions, whereas bromination in the absence of the sodium acetate yielded 3 : 5 : 4′-tribromo-4-hydroxyazobenzene. It has been found that 4-methoxyazobenzene on chlorination yielded 3 : 5-*dichloro*-4-*methoxyazobenzene*, and regulated bromination gave 3-*bromo*- and 3 : 5 : 4′-*tribromo*-4-*methoxyazobenzenes*. On nitration, 3 : 4′-*dinitro*-4-*methoxyazobenzene* was obtained. It is thus seen that the methoxyl group has a stronger directive effect than the $C_6H_5{\cdot}N{:}N{\cdot}$ group. Since two chlorine atoms enter the methoxylated nucleus successively, and since bromine appears to enter the 4′- and 5-positions simultaneously, it would seem that the $C_6H_5{\cdot}N{:}N{\cdot}$ group, though strongly *p*-directive, tends to lessen the reactivity of the nuclei to which it is attached. This view is supported by the parallel results which were obtained with 4-methoxybenzophenone (Blakey, Jones, and Scarborough, J., 1927, 2865).

The only substitution product of 4-aminoazobenzene or of its acetyl derivative whose structure is established is 4′-nitro-4-acetamidoazobenzene. This compound was formed on nitration in sulphuric acid solution (Friedländer, " Fortschritte in der Teerfarbenfabrikation," IV, 1021).

It has been found that 4-acetamidoazobenzene on chlorination, in acetic acid solution, yielded 3-*chloro*-4-*acetamidoazobenzene*. Attempts to introduce other substituents into the molecule of 4-acetamidoazobenzene failed.

Chlorination of 4-aminoazobenzene in carbon tetrachloride solution yielded an inseparable mixture of di- and tri-chloro-derivatives. In acetic acid solution, the base brominated smoothly and yielded 3 : 5-dibromo-4-aminoazobenzene (compare Berju, *Ber.*, 1884, **17**, 1403). Iodination and nitration were attempted under various conditions, but the product was always a tar.

The difference in structure of the two substitution products of 4-acetamidoazobenzene is the same as that observed in the case of 3-acetamidodiphenyl (Blakey and Scarborough, J., 1927, 3002) and must therefore be ascribed to the influence of a concentrated acid upon the acetamido-group and not to such a change in the structure of the azo-group as occurs in the case of 4-hydroxyazobenzene. The inactive nature of 4-acetamidoazobenzene was an unexpected factor in this section of the work.

For the determination of the structure of the substituted azobenzenes, at least three methods were available :

(*a*) The oxidation of a hydrazo-compound formed by the condensation of appropriately substituted hydrazines and *o*- and *p*-halogenonitrobenzenes.

(*b*) The complete reduction of the compound to its constituent bases, their separation, and identification.

(*c*) The condensation of appropriately substituted nitrosobenzenes and anilines.

Not one of the three methods is free from experimental difficulties, but since the third method leads to the most direct comparison it has been employed in nearly every case. This method, however, proves unsatisfactory or impossible when an *o*-nitro-group or an accumulation of nitro-groups is present in either the nitrosobenzene or the aniline molecule.

EXPERIMENTAL.

4-Methylazobenzene was obtained when a glacial acetic acid solution of equimolecular quantities of nitrosobenzene and *p*-toluidine was kept over-night. It separated from dilute alcohol in deep yellow plates, m. p. 72° (compare Mills, J., 1895, **67**, 929).

4′-*Nitro*-4-*methylazobenzene* was prepared by keeping a solution of 5 g. of 4-methylazobenzene in 100 c.c. of nitric acid (*d* 1·5) below 5° for 2 hours. The semi-solid mass which was precipitated when the mixture was poured into water yielded 3·5 g. of pure product. The same substance was obtained by condensing *p*-nitrosotoluene with *p*-nitroaniline. It crystallised from alcohol in deep red needles, m. p. 183° (Found: N, 17·35. $C_{13}H_{11}O_2N_3$ requires N, 17·4%).

4′-*Bromo*-4-*methylazobenzene*.—A solution of 5 g. of 4-methylazobenzene in dry bromine (4 c.c.) was kept for some hours. The residue after removal of the excess of bromine with sodium bisulphite solution was repeatedly crystallised from alcohol and gave orange needles, m. p. 152° (Found: Br, 28·95. $C_{13}H_{11}N_2Br$ requires Br, 29·1%).

3-*Nitro*-4-*methylazobenzene* was obtained when 2-nitro-*p*-toluidine was condensed with nitrosobenzene. It separated from alcohol in long, golden needles, m. p. 105° (Found: N, 17·35. $C_{13}H_{11}O_2N_3$ requires N, 17·4%).

3-*Bromo*-4-*methylazobenzene* was prepared by condensing 2-bromo-*p*-toluidine with nitrosobenzene. It crystallised from alcohol in yellow needles, m. p. 84° (Found: Br, 29·0. $C_{13}H_{11}N_2Br$ requires Br, 29·1%).

ω-*Bromo*-4-*methylazobenzene*.—5 G. of 4-methylazobenzene were dissolved in 80 c.c. of a 10% solution of bromine in acetic acid together with 4 g. of fused sodium acetate and the solution was heated on the water-bath for 8 hours. After some days it deposited about 1 g. of red needles, m. p. 115° after recrystallisation from alcohol (Found: N, 10·25; Br, 29·1. $C_{13}H_{11}N_2Br$ requires N, 10·15; Br, 29·1%). The substance remaining in the acetic acid mother-liquor was unchanged 4-methylazobenzene. The product reacted with dilute aqueous-alcoholic potash, the bromine being liberated as potassium bromide.

3-Methylazobenzene was prepared by condensing nitrosobenzene with *m*-toluidine. The product was distilled under diminished pressure and frozen. It is a light red oil, b. p. 165°/15 mm., and solidifies as red needles, m. p. 18°.

4 : 4′-*Dinitro*-3-*methylazobenzene*.—A solution of 3-methylazobenzene in nitric acid (*d* 1·5) was maintained below 5° for 90 minutes. The product crystallised from alcohol in bright red needles, m. p. 183° (Found : N, 19·75. $C_{13}H_{10}O_4N_4$ requires N, 19·6%).

The compound was completely reduced with stannous chloride in alcoholic hydrochloric acid solution and the mixed bases were liberated and acetylated in pyridine solution. Diacetyl-*p*-phenylenediamine, m. p. 310°, was isolated from the mixture by crystallisation from acetone; the acetone mother-liquor was evaporated to dryness and the residue, repeatedly crystallised from glacial acetic acid, gave 2-methyldiacetyl-*p*-phenylenediamine, m. p. 224°.

4-*Bromo*-3-*methylazobenzene*.—5 G. of 3-methylazobenzene were dissolved in 40 c.c. of a 10% solution of bromine in acetic acid, and the mixture heated on the water-bath for 6 hours. The product separated from dilute alcohol in light yellow needles, m. p. 69° (Found : Br, 29·15. $C_{13}H_{11}N_2Br$ requires Br, 29·1%). It was also obtained when 6-bromo-*m*-toluidine was condensed with nitrosobenzene.

2-Methylazobenzene was obtained when nitrosobenzene was condensed with *o*-toluidine. The product, after distillation under diminished pressure, was a light red oil, b. p. 180°/20 mm.

4 : 4′-*Dinitro*-2-*methylazobenzene* was prepared by keeping a solution of 2-methylazobenzene in nitric acid (*d* 1·5) below 5°. It was crystallised from alcohol and from acetone, from which it separated in dark red needles, m. p. 220° (Found : N, 19·6. $C_{13}H_{10}O_4N_4$ requires N, 19·6%).

The compound was completely reduced with stannous chloride in alcoholic hydrochloric acid solution and the liberated bases were acetylated. Diacetyl-*p*-phenylenediamine, m. p. 310°, and 2-methyldiacetyl-*p*-phenylenediamine, m. p. 224°, were isolated and identified by comparison with synthetic products.

Action of Bromine on 2-*Methylazobenzene*.—A solution of 5 g. of 2-methylazobenzene in 120 c.c. of a 10% solution of bromine in glacial acetic acid containing 5 g. of fused sodium acetate, after standing at room temperature for some hours, deposited white needles (4 g.), m. p. 210° after recrystallisation from much acetone (Found : C, 35·0, 35·4; H, 1·75, 1·65; N, 6·6, 6·4; Br, 57·5, 57·3; *M*, in bromoform, 390, 403. $C_{13}H_9N_2Br_3$ requires C, 36·0; H, 2·1;

N, 6·5; Br, 55·4%; *M*, 433). This *substance* appeared to be unattacked by aqueous permanganate or by stannous chloride in alcoholic hydrochloric acid solution.

4-Chloroazobenzene was obtained when *p*-chloroaniline was condensed with nitrosobenzene. It separated from alcohol in red plates, m. p. 92°.

4-*Chloro*-4′-*bromoazobenzene*.—5 G. of 4-chloroazobenzene were intimately mixed with 0·5 g. of ferric chloride, and 4 g. of bromine added; after the reaction had become less violent, 10 c.c. of water were added and the paste was heated on the water-bath for 1 hour. The product crystallised from acetone in bright yellow needles, m. p. 195° (Found: 0·1859 g. gave 0·2097 g. of silver halides. Theory requires 0·2095 g.).

The same product was obtained when *p*-chloronitrosobenzene was condensed with *p*-bromoaniline.

4 : 4′-*Dichloroazobenzene*.—5 G. of 4-chloroazobenzene were intimately mixed with 0·5 g. of ferric chloride and chlorine in excess was passed into the molten mass at water-bath temperature. After the mass had solidified, it crystallised from acetone in light yellow needles, m. p. 188° (Found: Cl, 28·4. Calc. for $C_{12}H_8N_2Cl_2$: Cl, 28·3%). Busch and Hobein (*Ber.*, 1907, **40**, 2099) give m. p. 184°. *p*-Chloronitrosobenzene was condensed with *p*-chloroaniline in acetic acid solution and the same product was obtained.

4 : 4′-*Dichloroazoxybenzene*.—5 G. of 4 : 4′-dichloroazobenzene, dissolved in acetic acid, were treated with 8 g. of " Hyperol," added in small portions; the temperature was that of the water-bath. The product separated on standing over-night and crystallised from alcohol in light straw-coloured needles, m. p. 157° (Found: Cl, 26·7. $C_{12}H_8ON_2Cl_2$ requires Cl, 26·6%).

4-*Chloro*-4′-*nitroazobenzene* was prepared by dissolving 4-chloroazobenzene in nitric acid (*d* 1·5) and keeping this solution below 10° for 30 minutes. It separated from alcohol in long red needles, m. p. 169° (Found: Cl, 13·45. $C_{12}H_8O_2N_3Cl$ requires Cl, 13·55%).

The same compound was obtained when *p*-nitroaniline was condensed with *p*-chloronitrosobenzene, in acetic acid solution, at the temperature of the water-bath.

3-Chloroazobenzene was prepared by the condensation of nitrosobenzene with *m*-chloroaniline. It separated from alcohol in orange-red needles, m. p. 68° (compare Bamberger, *Ber.*, 1896, **29**, 103).

3-*Chloro*-4′-*nitroazobenzene*.—5 G. of 3-chloroazobenzene were dissolved in 80 c.c. of nitric acid (*d* 1·16) and the temperature was maintained at 0° for 20 minutes. The product separated from alcohol in red needles, m. p. 129° (Found: N, 16·15. $C_{12}H_8O_2N_3Cl$ requires N, 16·1%).

The same compound was obtained when *m*-chloronitrosobenzene was condensed with *p*-nitroaniline.

3-*Chloro*-4′-*bromoazobenzene*.—5 G. of 3-chloroazobenzene were ground into a paste with 5 c.c. of a concentrated ferric chloride solution, 5 c.c. of bromine were added, and the mixture was heated on the water-bath for 30 minutes. After repeated crystallisations from alcohol the product separated in deep yellow needles, m. p. 128° (Found : 0·1736 g. gave 0·1947 g. of silver halides. Theory requires 0·1950 g.). The same product was obtained when *m*-chloronitrosobenzene was condensed with *p*-bromoaniline.

4-Methoxyazobenzene was prepared by condensing nitrosobenzene with *p*-anisidine. It separated from alcohol in bright yellow plates, m. p. 64°.

3-*Bromo*-4-*methoxyazobenzene*.—5 G. of 4-methoxyazobenzene, 4 g. of fused sodium acetate, and 7·5 g. of bromine in 100 c.c. of acetic acid were heated on the water-bath for 4 hours. The product separated from alcohol in long yellow needles, m. p. 78° (Found : Br, 27·65. $C_{13}H_{11}ON_2Br$ requires Br, 27·5%).

2-*Bromo*-4-*nitroanisole* was prepared by adding bromine (1 mol.) to 4-nitroanisole in the presence of a little pyridine; the product separated from dilute alcohol in long needles, m. p. 108° (Found : Br, 34·6. $C_7H_6O_3NBr$ requires Br, 34·5%). The corresponding base, obtained by reduction with stannous chloride in alcoholic hydrochloric acid solution, was condensed with nitrosobenzene, and 3-bromo-4-methoxyazobenzene resulted.

3 : 4′-*Dibromo*-4-*methoxyazobenzene* was obtained when *p*-bromonitrosobenzene was condensed with 2-bromo-4-anisidine. It separated from alcohol in light yellow needles, m. p. 123° (Found : Br, 43·25. $C_{13}H_{10}ON_2Br_2$ requires Br, 43·3%).

3 : 4′ : 5-*Tribromo*-4-*methoxyazobenzene*.—(*a*) A solution of 5 g. of 4-methoxyazobenzene and 10 g. of fused sodium acetate in 100 c.c. of a 30% solution of bromine in acetic acid was heated on the water-bath for 24 hours and finally refluxed for about 30 minutes. Crystals separated on cooling. (*b*) 3-Bromo- and 3 : 4′-dibromo-4-methoxyazobenzenes were treated in the same manner. The *compound* crystallised from much alcohol in yellow needles, m. p. 130° (Found : Br, 53·6. $C_{13}H_9ON_2Br_3$ requires Br, 53·5%).

3 : 5-*Dichloro*-4-*methoxyazobenzene* was prepared by passing dry chlorine into a mixture of 5 g. of 4-methoxyazobenzene and 5 g. of sodium acetate in 100 c.c. of acetic acid until the solution was saturated. It crystallised from alcohol in long yellow needles, m. p. 98° (Found : Cl, 25·35. $C_{13}H_{10}ON_2Cl_2$ requires Cl, 25·3%).

3 : 5-*Dichloro*-4-*hydroxyazobenzene* was obtained when (*a*) 3 : 5-dichloro-4-methoxyazobenzene was refluxed with a mixture of

constant-boiling hydrobromic acid and acetic acid for 8 hours; and (*b*) nitrosobenzene was condensed with 2 : 6-dichloro-4-aminophenol in acetic acid solution. It separated from alcohol in brownish needles, m. p. 116° (Found : Cl, 26·5. $C_{12}H_8ON_2Cl_2$ requires Cl, 26·6%).

3 : 4′-*Dinitro*-4-*methoxyazobenzene*.—A solution of 5 g. of 4-methoxyazobenzene in 30 c.c. of sulphuric acid was treated with 5 g. of potassium nitrate and kept for 24 hours. The product separated from acetone in bright red needles, m. p. 190° (Found : N, 18·6. $C_{13}H_{10}O_5N_4$ requires N, 18·55%). The compound was completely reduced with stannous chloride in alcoholic hydrochloric acid solution and the bases were liberated and acetylated in pyridine solution. Diacetyl-*p*-phenylenediamine, m. p. 310°, was isolated.

4-Aminoazobenzene was prepared according to Staedel and Bauer (*Ber.*, 1886, **19**, 1953) and converted into 4-acetamidoazobenzene with acetic anhydride; this separated from dilute alcohol in needles, m. p. 144°.

3-*Chloro*-4-*acetamidoazobenzene*.—A 5% solution of 4-acetamidoazobenzene in glacial acetic acid together with an excess of fused sodium acetate was treated with dry chlorine at 10° until the solution was saturated. The product crystallised from alcohol in orange plates, m. p. 134° (Found : Cl, 13·0. $C_{14}H_{12}ON_3Cl$ requires Cl, 13·0%).

3-*Chloro*-4-*aminoazobenzene* was obtained when the acetyl derivative was refluxed with alcoholic hydrochloric acid for 6 hours. The base, which was liberated with dilute ammonia, crystallised from dilute alcohol in deep yellow needles, m. p. 99·5° (Found : Cl, 15·2. $C_{12}H_{10}N_3Cl$ requires Cl, 15·3%). The compound was diazotised in alcoholic solution and, after refluxing, 3-chloroazobenzene, m. p. 67·5°, was isolated.

2-*Chlorobenzidine* was obtained when 3-chloroazobenzene was refluxed with stannous chloride in alcoholic hydrochloric acid solution for 2 hours. It separated from dilute alcohol in long needles, m. p. 113° (Found : Cl, 16·3. $C_{12}H_{11}N_2Cl$ requires Cl, 16·2%).

3 : 5-*Dibromo*-4-*aminoazobenzene*.—10 G. of 4-aminoazobenzene, dissolved in 100 c.c. of acetic acid, together with 10 g. of fused sodium acetate, were treated with 180 c.c. of a 10% solution of bromine in acetic acid at 15°. The base crystallised from much alcohol in light yellow needles, m. p. 168° (compare Hewitt, *Ber.*, 1908, **41**, 1986) (Found : Br, 44·9. Calc. for $C_{12}H_9N_3Br_2$: Br, 45·05%). On reduction with stannous chloride in alcoholic hydrochloric acid solution a mixture of aniline and 2 -dibromo-*p*-phenylenediamine was obtained. The latter base crystallised from water in long silky needles, m. p. 138° (Found : Br, 60·15. Calc. for $C_6H_6N_2Br_2$:

Br, 60·15%). Hewitt and Walker (J., 1907, **91**, 1141) give m. p. 137°.

3 : 5-*Dibromoazobenzene* was obtained when (*a*) 3 : 5-dibromo-4-aminoazobenzene was diazotised with amyl nitrite in alcoholic solution; or (*b*) nitrosobenzene was condensed with 3 : 5-dibromoaniline. It separated from alcohol in dark red needles, m. p. 104° (Found: Br, 46·9. $C_{12}H_8N_2Br_2$ requires Br, 47·0%). On bromination in acetic acid solution at water-bath temperature, this compound gave 2 : 4 : 6-tribromoaniline, m. p. 119°.

3 : 5-*Dibromohydrazobenzene*.—5 G. of 3 : 5-dibromoazobenzene in 250 c.c. of alcohol were refluxed for 2 hours with 8·5 g. of stannous chloride and 10 g. of sodium hydroxide, also dissolved in 250 c.c. of alcohol. The alcohol was partly removed, the residue poured into water, and the product extracted with ether. It separated from light petroleum (b. p. 60—70°) in small plates, m. p. 114° (Found : Br, 46·7. $C_{12}H_{10}N_2Br_2$ requires Br, 46·75%).

2 : 6-*Dibromobenzidine* was obtained when (*a*) 3 : 5-dibromoazobenzene was reduced with stannous chloride in alcoholic hydrochloric acid solution; and (*b*) 3 : 5-dibromohydrazobenzene was refluxed with an excess of concentrated hydrochloric acid for 30 minutes. It crystallised from dilute alcohol in needles, m. p. 185° (Found : Br, 46·8. $C_{12}H_{10}N_2Br_2$ requires Br, 46·75%).

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