Copper(I)-Induced Bromo-Hydrogen Exchange of 2,3-Dibromoanilines

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The copper(I)-induced bromine-hydrogen exchange reaction of 2,3-dibromoaniline and 5-substituted 2,3-dibromoanilines in the 2-position has been kinetically studied in water-acetic acid-hydrochloric acid medium at 90 °C. The dehalogenation reaction is of second order, first order in both substrate and Cu^+, and may be interpreted as a reductive substitution, composed of two one-electron steps. The 2,3-dibromophenol was only qualitatively investigated, but gave similar results.

In the investigations of copper(I) chloride-catalysed halogen exchange reactions of 3- and 5-substituted 2-bromonitrobenzenes in water-acetic acid-hydrochloric acid medium debromination products (*ca.* 1 %), as well as traces of 2-bromoanilines, were noticed.[1-2] It was concluded that the $CuCl_2^-$ complex was responsible for the halogen exchange reaction. When the degassed reaction mixture of 2-bromo-3-methyl-nitrobenzene and copper(I) chloride was irradiated at 350 nm, the reduction of the nitro group dominated over the bromine-chlorine exchange. A common step *via* the radical anion was suggested for the copper(I)-promoted reduction of the nitro group and the dehalogenation of 2-halogenonitrobenzenes.[2]

The dehalogenation, in the same medium, has now been kinetically studied in 2,3-dibromoaniline, 5-substituted 2,3-dibromoanilines and, qualitatively, in 2,3-dibromophenol. These compounds were chosen because of their reluctance to undergo the halogen exchange reaction.

Comprehensive investigations of electrochemically, as well as photochemically, induced reduc-

tions of aromatic halides are frequently found in the literature,[3-5] while transition-metal catalysed reductions of aryl halides in aqueous medium are rare. Van Koten *et al.*[6] reported *N,N*-dimethyl-aniline as a by-product in the reaction of 2-iodo-*N,N*-dimethylaniline and copper(I) chloride in DMF. Ashby and Lin[7] obtained 100 % reduction of aryl halides with $NiCl_2$−$LiAlH_4$ (1:1) in THF.

RESULTS AND CALCULATIONS

The copper(I) chloride-induced dehalogenation of 5-substituted 2,3-dibromoanilines in the 2-position was kinetically studied in the dark in an argon atmosphere at 90 °C. The concentrations of the substrate, Cu^+, Cl^- and H^+ were varied. With a chloride ion concentration of 5.25 mol dm^{-3} the bromo-hydrogen exchange could be followed to about 80 % consumption of substrate without the formation of by-products, while by-products appeared at an earlier stage of the reaction with lower chloride ion concentrations, see below.

The dehalogenation under similar conditions did not occur with Cu^{2+}. It became evident, from the GLC analysis and the redox titrations, that two Cu^+ ions had disappeared for every substrate molecule reduced, see Table 1. An ESR spectrum of a sample also confirmed the formation of two Cu^{2+} ions for every reacting substrate molecule (Scheme 1).
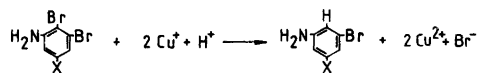
Scheme 1.

Table 1. The substrate- Cu^+ ratio in the dehalogenation of 2,3-dibromoaniline at 90 °C. The chloride ion concentration is 5.25 mol dm^{-3}.

[Sub-strate]init. /mol dm^{-3}	[Cu^+]init. /mol dm^{-3}	Reaction time t/min	[Sub-strate] /mol dm^{-3a}	[Sub-strate]$_{red}$ /mol dm^{-3a}	[Cu^+] /mol dm^{-3b}	[Cu^+]con-sumed /mol dm^{-3}
0.056	0.225	225	0.0446	0.0115	0.2028	0.0219
0.056	0.225	415	0.0377	0.0185	0.1856	0.0392
0.056	0.225	690	0.0290	0.0272	0.1737	0.0511
0.056	0.225	1145	0.0195	0.0367	0.1511	0.0737
0.056	0.225	1290	0.0164	0.0398	0.140	0.0845
0.056	0.336	180	0.0446	0.0114	0.3133	0.0231
0.056	0.336	360	0.0335	0.0226	0.2928	0.0436
0.056	0.113	180	0.0505	0.0057	0.1017	0.0110
0.056	0.113	800	0.0357	0.0206	0.0744	0.0383

^{a} Determined by GLC. ^{b} Determined by redox titration.

The exchange reaction was studied at chloride ion concentrations varying from 2.0 to 5.25 mol dm^{-3}. At a chloride ion concentration of 2.0 mol dm^{-3} the bromo-hydrogen exchange was hardly observable. At extended reaction time the main product was 2,3-dibromo-4-chloroaniline, but the bromo-hydrogen exchange increased with increasing chloride ion concentration, see Fig. 1. At low chloride ion concentration the copper(I) is presumed to be present as $CuCl_2^-$, but at higher chloride concentrations the $CuCl_3^{2-}$ complex becomes important,[8] and the latter comp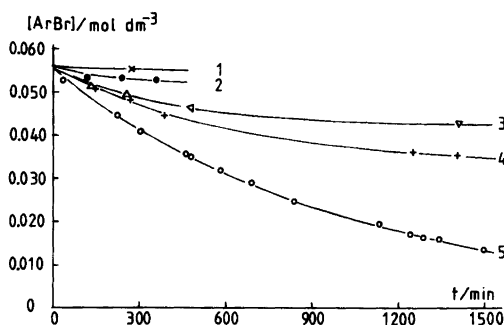lex is thought to be the reacting species in the present reduction reaction. The copper(I) concentration was varied from 0.113 to 0.336 mol dm^{-3} in the bromo-hydrogen exchange reaction.

The kinetics of the reduction reaction followed second order, first order in both aniline and copper(I), see Fig. 2. The following rate expression is applicable:[9]

$$\frac{dx}{dt} = k_2 \, ([ArBr]_o - x)([Cu^+]_o - 2x) =$$

$$k_2 \, (A_o - x)(B_o - 2x) = k_2 A \cdot B$$

where x is the concentration of substrate consumed.

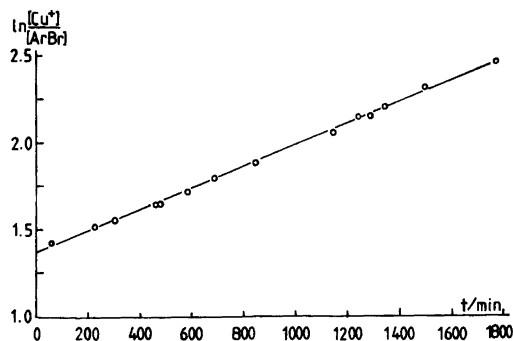The second-order rate constant, k_2, was calculated from the integrated form:

Fig.1. The Cu^+-induced bromo-hydrogen exchange of 2,3-dibromoaniline at variable [Cl^-] in water-acetic acid-hydrochloric acid medium [Substrate]$_o$=0.056 M, [Cu^+]$_o$=0.225 M, [H^+]=5.25 M, [Cl^-]: *1* 2.0 M, *2* 3.0 M, *3* 4.0 M, *4* 4.6 M and *5* 5.25 M. The reaction was interrupted when the formation of by-products exceeded 2 %.

Fig. 2. Representative run of the second order bromo-hydrogen exchange reaction in 2,3-dibromoaniline (initial conc. 0.056 M) at 90 °C. [Cu^+]$_o$=0.225 M, [Cl^-]=5.25 M.

Table 2. Rate constants for Cu^+- induced bromo-hydrogen exchange in 2-pos. of 5-X-substituted 2,3-dibromoanilines in hydrochloric acid-water-acetic acid medium at 90 °C. $[Cl^-]=5.25$ mol dm^{-3}.

[2,3-Dibromo-5-X-aniline /mol dm^{-3}	X	$[Cu^+]$ /mol dm^{-3}	$k_2/10^{-4}$	s^{-1} $M^{-1a,b}$
0.028	H	0.113	0.932	±0.016
0.056	H	0.113	0.925	±0.036
0.056	H	0.169	0.915	±0.062
0.056	H	0.225	0.917	±0.023
0.056	H	0.336	0.796	±0.025
0.056	CH_3	0.225	5.98	±0.35
0.028	CH_3	0.113	5.77	±0.28
0.028	Cl	0.113	3.50	±0.19
0.028	OCH_3	0.113	725	±15

[a] The errors are 2 S.E. from the least-squares method calculations. 2−4 different runs in each calculation. [b] In this medium copper(I) is presumed to be present as $CuCl_2^-$ and $CuCl_3^{2-}$ complex. $[CuCl_3^{2-}]/[Cl^-][CuCl_2^-]=K$. During the reduction reaction the active $CuCl_3^{2-}$ complex will be a fixed fraction of the Cu^+ concentration present. Therefore, the observed k_2 diverges only with a factor from the true rate constant.

$$\frac{1}{B_o-2A_o} \ln\frac{A_o \cdot B}{B_o \cdot A} = k_2 \cdot t \qquad B_o \neq 2A_o$$

$$\frac{1}{A} - \frac{1}{A_o} = 2k_2 \cdot t \qquad B_o = 2A_o$$

Moderate variation of the acid concentration did not affect the rate constant. Introduction of a substituent, CH_3, Cl or OCH_3, in the 5-position of the aromatic bromo compound caused an enhancement of the reduction rate, see Table 2. When the 5-substituent was OCH_3, the rate constant increased by a factor of 10^3, compared to hydrogen. A nitro group in the 5-position was reduced in the exchange reaction; the copper(I)-induced dehalogenation of 2,3-dibromo-5-nitro-aniline, as seen from ^1H NMR and mass spectra, resulted in 1,3-diamino-5-bromobenzene and traces of 1,3-diamino-4,5-dibromobenzene and 3-bromo-5-nitroaniline. A tentative reaction course is outlined in Scheme 2.

When 2,3-dibromoaniline was allowed to react beyond about 80 % consumption at a chloride ion concentration of 5.25 mol dm^{-3}, another reaction occurred, *viz.* halogenation of the reduction product, 3-bromoaniline, and of the substrate. The main product was 3,4-dibromoaniline while 2,3,4-tribromoaniline, 3-bromo-4-chloro-aniline and 2,3-dibromo-4-chloroaniline were also formed, all of them being identified by ^1H NMR and mass spectra. Obviously, the Cu^{2+} and Br^- ions formed in the reduction step are involved in the halogenation reactions. These halogenation reactions, however, are outside the scope of this paper, but in hope of further elucidating the reactions, a sequence of experiments was carried out at 90 °C and a reaction time of 45 h. An attempt with 2,3-dibromoaniline, Cu^+ and a chloride ion concentration of 3.0 mol dm^{-3} gave the same main product as an experiment where Cu^+ was replaced by Cu^{2+}, *viz.* 2,3-dibromo-4-chloroaniline, see Table 3. When 3-bromoaniline with the addition of an equal amount of HBr was subjected to the same experiments, the main product in both cases was 3,4-dibromoaniline, see Table 3.

The Cu^+-induced reaction of 2,3-dibromophenol was only qualitatively investigated. However, the products isolated indicate that the reduction, as well as the halogenation steps described above for the anilines, also occurred in the phenol system. 3-Bromophenol, 3,4-dibromophenol and 3-bromo-4-chlorophenol were identified by ^1H NMR and mass spectra.
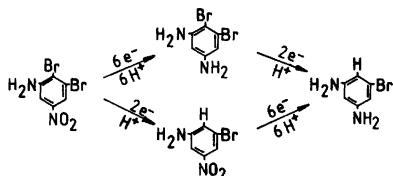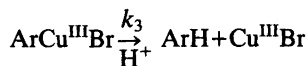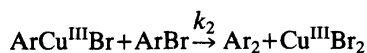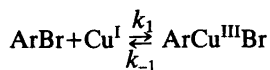

Scheme 2.

Table 3. Halogenation reactions at 90 °C, reaction time 45 h. $[H^+]=5.25$ mol dm^{-3}.

Substrate 0.056 M	$[Cu^+]/$ mol dm^{-3}	$[Cu^{2+}]/$ mol dm^{-3}	$[Cl^-]/$ mol dm^{-3}	$[Br^-]/$ mol dm^{-3}	Product yield %					
					2,3-Dibromo-4-chloro-aniline	2,3,4-Tri-bromo-aniline	3-Bromo-aniline	3,4-Di-bromo-aniline	3-Bromo-4-chloro-aniline	2,3-Di-bromo-aniline
2,3-Dibromo-aniline	0.113		3.0		15	5	5			
2,3-Dibromo-aniline		0.113	5.25		36	2	2			
3-Bromoaniline	0.113		5.25	0.056				trace	trace	
3-Bromoaniline	0.113		5.25	0.056				15	2	4
3-Bromoaniline	0.113		3.0	0.056				52	4	6

DISCUSSION

It would be tempting to characterize the $CuCl_3^{2-}$-induced debromination as an electrophilic substitution reaction, where the $CuCl_3^{2-}$ complex acts as acceptor for Br^+. Myhre[10] has investigated the debromination of the highly hindered 2,4,6-tri-*t*-butylbromobenzene in strong acid solution with bromide ion present as acceptor for Br^+. The debromination was viewed as an electrophilic replacement of bromine by hydrogen or the reverse of aromatic bromination. This mechanism, however, is not entirely in accordance with the kinetic results of our investigations. A substituent *para* to the reaction center of 2,3-dibromoaniline, increased the rate of reduction irrespective of the σ_p-value, as seen from Table 2. In an electrophilic substitution reaction, it may be difficult to justify a higher value of the rate constant for the 5-Cl-compound as compared to the 5-H-compound, considering the positive σ_p-value of Cl (σ_p of H=0).

Cohen and Cristea[11] have investigated the copper(I)-induced reactions of 2-bromonitrobenzene in acetone in the formation of 2,2'-dinitrobiphenyl and nitrobenzene. The suggested mechanism involves a reversible oxidative addition of the C−Br bond to copper(I) to form an organocopper(III) intermediate, which may either displace a bromide ion from a second arylbromide molecule or become protonated by the medium.

$$ArBr + Cu^I \underset{k_{-1}}{\overset{k_1}{\rightleftarrows}} ArCu^{III}Br$$

$$ArCu^{III}Br + ArBr \overset{k_2}{\rightarrow} Ar_2 + Cu^{III}Br_2$$

$$ArCu^{III}Br \overset{k_3}{\underset{H^+}{\rightarrow}} ArH + Cu^{III}Br$$

However, this proposal is questioned by van Koten *et al.*,[6] who have investigated the reactions of 2-iodo-*N,N*-dimethylaniline with copper(I) chloride in DMF. Their results show that ArH need not be formed by protolysis of an organocopper intermediate. They propose instead single electron transfer from copper(I) to the arylhalide as a possible route to ArH. Nor is the presence of copper(III) consistent with the results obtained in

our work, *viz.* the disappearing to two copper(I) and the formation of two copper(II) ions for every substrate molecule reduced.

In consideration of these facts, including the *para* substituent effects and previous results from irradiation of halonitrobenzenes,[1-2] it seems plausible that radicals are involved in the dehalogenation step of the 2,3-dibromoanilines. The Cu^+-induced dehalogenation step is probably a reductive substitution, composed of two one electron transfer steps with an intervening bond cleavage step.[5b]

1. $ArBr + Cu^I Cl_3^{2-} \rightarrow ArBr^{\cdot-} + Cu^{II}\text{-complex}$

2. $ArBr^{\cdot-} \rightarrow Ar^{\cdot} + Br^-$

3. $Ar^{\cdot} + Cu^I Cl_3^{2-} + H^+ \rightarrow ArH + Cu^{II}\text{-complex}$

Step 1 is an electron transfer from Cu^+ to the aryl halide forming an anion radical in a nonbonded adiabatic process. Step 2 is a bond cleavage and step 3 is an electron transfer involving bond formation to H^+ from the solvent. Step 1 is believed to be the rate-determining step. No radicals were detected by an ESR study which, however, does not exclude their presence.

The reduction reaction, which took place in the dark, ought to be compared to electron transfers in biological systems, the mechanistic details of which are still ambiguous.[12-13]

Variation of the copper(I) concentration in the bromo-hydrogen exchange of 2,3-dibromoaniline gave an invariable rate constant, k_2, except for the highest copper(I) concentration, which caused a lower k_2 value, see Table 2. The existence of some dimeric copper(I) complex in more concentrated solutions can not be excluded.

The halogenation reaction *ortho* and *para* to NH_2, which was only qualitatively investigated, is probably an oxidative substitution reaction,[5b] where Cu^{2+}, Br^- and Cl^- are involved. Nonhebel and Russell[14] have reported halogenation of 9-alkyl and 9-arylanthracenes with copper(II) halides in the 10-position. A radical mechanism was suggested. Doyle *et al.*[15] have investigated the formation of 2-bromo-4-chloroaniline in >95 % yield in the reaction of 4-chloroaniline with copper(II) bromide in acetonitrile at 65 °C, and Crocker and Walser[16] have reported chlorination of phenols by copper(II) chloride in both

water and nonhydroxylic solvents. A surprising result of our investigations is that at low chloride ion concentrations Cu^+, presumably existing as $CuCl_2^-$, also brings about halogenation, see Table 3. Quite different reaction mechanisms are probably prevailing in these two cases. Bell and De Maria,[17] for instance, have investigated the kinetics of the bromination of 2,4-dichloro- and 2,6-dichloroanilines with bromine in aqueous perchloric acid at variable bromide ion concentration. For both the dichloroanilines, k_2 decreased sharply with increasing bromide ion concentration. It is assumed by Bell and De Maria that Br_2 and Br_3^- are the only effective brominating species. At low bromide ion concentrations, the rate-determining step is the reaction between Br_2 and the aniline, but at higher bromide ion concentrations the decomposition of the Wheland intermediate becomes partially rate limiting.

EXPERIMENTAL

Melting points were determined with a Kofler Hot-Stage Microscope. ^1H NMR spectra were obtained with a Bruker WH 270 instrument with TMS as internal standard. The mass spectra were recorded on a Finnigan 1020 instrument. The GLC investigations were carried out on a Perkin-Elmer 3920 B instrument with Hot Wire Detector and equipped with a Hewlett Packard 3380 A Integrator. A 3 mm×2 m SE-30 column was used, carrier gas was He.

Calibration curves were made from known mixtures of pure anilines. The melting points of the reference substances, used only for NMR and mass spectra purposes, are given without recrystallization.

2,3-Dibromoaniline. 2,3-Dibromonitrobenzene[8] (5.6 g, 0.02 mol) was reduced with iron (3.35 g, 0.06 mol) in 50 % ethanol, acidified with hydrochloric acid.[18] Yield 3.7 g (74.3 %). The m.p. of the 2,3-dibromoaniline was 44−45 °C, Lit.[19a] 43 °C. ^1H NMR (270 MHz, $CDCl_3$): δ 7.01 (H-4, q), 6.95 (H-5, q), 6.67 (H-6, q) and 4.28 (NH_2, s, 2H). $J_{4-5}=7.75$ Hz, $J_{5-6}=7.65$ Hz and $J_{4-6}=1.65$ Hz. MS: A 1:2:1 triplet at *m/e* 249, 251 och 253.

2,3-Dibromophenol was prepared from 2,3-dibromoaniline.[20] An amount of 2.5 g (0.01 mol) gave a yield of 1.3 g (52.8 %). After recrystallization from water the m.p. was 67−68.5 °C. Lit.[21] 68−69 °C. ^1H NMR (270 MHz, $CDCl_3$): δ 7.20 (H-4, q), 7.10 (H-5, q), 6.97 (H-6,q) and 5.68

(OH, s, 1H). J_{4-5}=7.85 Hz, J_{5-6}=8.0 Hz and J_{4-6}=1.55 Hz. MS: A 1:2:1 triplet at m/e 250, 252 and 254.

3,4-Dibromoaniline was prepared from 3,4-dibromonitrobenzene by reduction, as described above for 2,3-dibromoaniline. An amount of 4.2 g (0.015 mol) of the nitro compound gave a yield of 1.2 g (32 %). M.p. was 78−79.5 °C, lit.[19b] 81 °C.
^{1}H NMR (270 MHz, CDCl$_3$): δ 7.28 (H-5, d), 6.91 (H-2, d), 6.44 (H-6, q) and 3.72 (NH$_2$, s, 2 H). J_{5-6}=8.5 Hz and J_{2-6}=2.2 Hz. MS: A 1:2:1 triplet at 249, 251 and 253 m/e.

3-Bromo-4-chloroaniline was prepared from 3-bromo-4-chloronitrobenzene as described above for 2,3-dibromoaniline. An amount of 3.55 g (0.015 mol) gave a yield of 1.05 g (34 %). The m.p. was 77−80 °C, lit.[22] 81−82 °C. ^{1}H NMR (270 MHz, CDCl$_3$): δ 7.15 (H-5, d), 6.91 (H-2, d), 6.52 (H-6, q) and 3.67 (NH$_2$, s, 2 H). J_{5-6}=8.45 Hz and J_{2-6}=2.6 Hz. MS: A 3:4:1 triplet at m/e 205, 207, 209.

3,4-Dibromophenol was synthesized from 3,4-dibromoaniline[20] (3.7 g, 0.015 mol) and gave a yield of 50.3 % (1.9 g) of the phenol. M.p. was 71−73 °C. Lit[23] 80 °C. ^{1}H NMR (270 MHz, CDCl$_3$): δ 7.40 (H-5, d), 7.10 (H-2, d), 6.65 (H-6, q) and 4.96 (OH, s, 1H). J_{5-6}=8.7 Hz and J_{2-6}=2.8 Hz. MS: A 1:2:1 triplet at 250,252,254 m/e.

3-Bromo-4-chlorophenol was synthesized from 3-bromo-4-chloroaniline[20] (3.1 g, 0.015 mol) and gave a yield of 51.4 % (1.6 g) of 3-bromo-4-chlorophenol. M.p. was 59−60 °C. Lit.[24] 59−60 °C. ^{1}H NMR (270 MHz, CDCl$_3$): δ 7.25 (H-5, d), 7.10 (H-2, d), 6.72 (H-6 q) and 4.92 (OH, s, 1H). J_{5-6}=8.6 Hz and J_{2-6}=2.65 Hz. MS: A 3:4:1 triplet at m/e 206,208,210.

2,3,4-Tribromoaniline was prepared from 2,3,4-tribromonitrobenzene with the method described above for 2,3-dibromoaniline.[18] An amount of 3.6 g (0.01 mol) of the 2,3,4-tribromonitrobenzene gave a yield of 2.2 g (66 %) of the aniline. The m.p. was 97−99 °C, lit.[25] 100.6 °C ^{1}H NMR (270 MHz, CDCl$_3$); δ 7.3 (H-5, d), 6.57 (H-6, d) and 4.28 (NH$_2$ s, 2 H). J_{5-6}=8.55 Hz. MS: A 1:3:3:1 quartet at m/e 327, 329, 331, 333.

2-Bromo-3-chloroaniline was prepared from 2-bromo-3-chloronitrobenzene which was available.[8] An amount of 2.85 g (0.012 mol) was reduced as described above for 2,3-dibromoaniline[18] and gave a yield of 1.95 g (79 %) of the 2-bromo-3-chloroaniline. M.p. was 41−42 °C. ^{1}H NMR (270 MHz, CDCl$_3$): δ 7.0 (H-5, q), 6.82 (H-4, q), 6.62 (H-6, q) and 4.24 (NH$_2$, s, 2 H). $J_{4-5,5-6}$=7.9 Hz and J_{4-6}=1.5 Hz. MS: A 3:4:1 triplet at m/e 205, 207, 209.

2-Amino-3-bromo-4-chloronitrobenzene and *4-amino-3-bromo-2-chloronitrobenzene*. 2-Bromo-3-chloroaniline was acetylated, nitrated and the isomeric nitration products were separated and hydrolysed according to the methods described for 2-bromo-6-nitroaniline.[8] The 2-bromo-3-chloroaniline (1.95 g, 0.0095 mol) gave a yield of 19 % (0.45 g) of 2-amino-3-bromo-4-chloronitrobenzene and 27 % (0.65 g) of the 4-amino-3-bromo-2-chloronitrobenzene isomer. The m.p. for the 2-amino-3-bromo-4-chloronitrobenzene was 143−144.5 °C.
^{1}H NMR for *2-amino-3-bromo-4-chloronitrobenzene* (270 MHz, CDCl$_3$): δ 8.07 (H-6, d), 6.82 (H-5, d) and 6.83 (NH$_2$, s, 2 H). J_{5-6}=9.1 Hz. MS: A 3:4:1 triplet at 250,252,254 m/e.
The *4-amino-3-bromo-2-chloronitrobenzene* had the m.p. 149.5−150.5 °C ^{1}H NMR (270 MHz, CDCl$_3$): δ 7.82 (H-6, d), 6.67 (H-5, d) and 4.88 (NH$_2$, s, 2H). J_{5-6}=8.82 Hz.

2,3-Dibromo-4-chloroaniline. The 2-amino-3-bromo-4-chloronitrobenzene was diazotized and bromine was introduced *via* a Sandmeyer reaction following the procedure by Gunstone and Tucker.[26-27] The 2,3-dibromo-4-chloronitrobenzene was reduced as described above for 2,3-dibromoaniline. An amount of 3 g (0.012 mol) of the 2-amino-3-bromo-4-chloronitrobenzene gave a yield of 1.0 g (29.2%) of 2,3-dibromo-4-chloroaniline. M.p. was 84−86 °C. ^{1}H NMR (270 MHz, CDCl$_3$): δ 7.18 (H-5, d), 6.64 (H-6, d) and 4.27 (NH$_2$, s, 2 H). J_{5-6}=8.65 Hz. MS: A 3:7:5:1 quartet at 283, 285, 287, 289 m/e.

2,3-Dibromo-5-methylaniline. 2,3-Dibromo-5-methylnitrobenzene (5.9 g, 0.02 mol) was reduced[18] and gave a yield of 23.6 % (1.25 g) of 2,3-dibromo-5-methylaniline. M.p. 57.8−59.3 °C, lit. 58−59 °C.[28] ^{1}H NMR (270 MHz, CDCl$_3$): δ 6.85 (H-4, d), 6.49 (H-6, d), 4.17 (NH$_2$, s, 2 H) and 2.18 (CH$_3$, s, 3 H). J_{4-6}=1.90 Hz. MS: A 1:2:1 triplet at 263, 265 and 267 m/e.

3-Bromo-5-methylaniline. ^{1}H NMR (270 MHz, CDCl$_3$): δ 6.70 (q, 1 H), 6.62 (q, 1 H), 6.38 (q, 1H), 3.65 (NH$_2$, s, 2 H) and 2.12 (CH$_3$, s, 3 H). J=1.85 Hz. The assignment of coupling constants of the methyl compounds was confirmed by decoupling of the CH$_3$ group. MS: A 1:1 doublet at m/e 185 and 187.

2,3-Dibromo-5-chloroaniline was obtained by reduction[18] of 2,3-dibromo-5-chloronitrobenzene (0.75 g, 0.0024 mol) in a yield of 58.8 % (0.4 g). M.p. 84−85 °C. ^{1}H NMR (270 MHz, CDCl$_3$): δ 7.01 (H-4, d), 6.68 (H-6, d) and 4.33 (NH$_2$, s, 2 H). J_{4-6}=2.2 Hz. MS: A 3:7:5:1 quartet at 283, 285, 287 and 289 m/e.

3-Bromo-5-chloroaniline. ^{1}H NMR (270 MHz,

CDCl$_3$): δ 6.87 (q, 1 H), 6.70 (q, 1 H), 6.57 (q, 1 H) and 4.02 (NH$_2$, s, 2 H). J=1.90 Hz. MS: A 3:4:1 triplet at 205, 207 and 209 m/e.

2,3-Dibromo-5-methoxyaminobenzene. 2,3-Dibromo-5-methoxynitrobenzene (0.4 g, 0.0013 mol) dissolved in 10 ml of ethanol was reduced with 15 % aqueous titanium(III) chloride (8.5 g) at 40 °C. After 24 h the ethanol was removed. The mixture was made alkaline and then extracted with ether. HCl gas was introduced and the amine was filtered off as HCl salt. The yield of 2,3-dibromo-5-methoxyaminobenzene was 0.2 g (55 %). M.p. 61−62.5 °C. ^{1}H NMR (270 MHz, CDCl$_3$): δ 6.65 (H-4, d), 6.28 (H-6, d) and 3.85 (NH$_2$, OCH$_3$, s, 5 H). J_{4-6}=2.65 Hz. MS: A 1:2:1 triplet at 279, 281 and 283 m/e.

3-Bromo-5-methoxyaminobenzene. ^{1}H NMR (270 MHz, CDCl$_3$): 6.47 (q, 1 H), 6.44 (q, 1 H), 6.13 (q, 1 H) and 3.73 (OCH$_3$, NH$_2$, s, 5 H). J=2.25 Hz. MS: A 1:1 doublet at 201 and 203 m/e.

1-Amino-2,3-dibromo-5-nitrobenzene. 2,3-Dibromo-1,5-dinitrobenzene (13 g, 0.04 mol) was reduced with titanium(III) chloride, see above, and gave a yield of 88.3 % of 1-amino-2,3-dibromo-5-nitrobenzene and 5-amino-2,3-dibromonitrobenzene (10.45 g). The isomers were separated by column chromatography, silica gel (0.063−0.2 mm) with toluene as eluent and gave 1.05 g (9 %) of the 1-amino-2,3-dibromo-5-nitrobenzene isomer. M.p. 145.2−145.7 °C. Deamination gave 3,4-dibromonitrobenzene, identified by its NMR spectrum. ^{1}H NMR for 1-amino-2,3-dibromo-5-nitrobenzene (270 MHz, CDCl$_3$): δ 7.82 (H-4, d), 7.50 (H-6, d) and 4.63 (NH$_2$, s, 2 H). J_{4-6}=2.4 Hz. MS: A 1:2:1 triplet at m/e 294, 296 and 298.

5-Amino-2,3-dibromonitrobenzene. M.p. was 129.5−130 °C. ^{1}H NMR (270 MHz, CDCl$_3$): δ 7.12 (H-6, d), 6.90 (H-4, d) and 4.0 (NH$_2$, s, 2 H). J_{4-6}=2.65 Hz.

1-Amino-3-bromo-5-nitrobenzene was obtained from 2-amino-3-bromo-1,5-dinitrobenzene by means of deamination and reduction with titanium(III) chloride. ^{1}H NMR (270 MHz, CDCl$_3$): δ7.65 (1 H, q), 7.37 (1 H, q), 7.05 (1 H, q) and 4.15 (NH$_2$, s, 2 H). J=2.1 Hz.

1,3-Diamino-4,5-dibromobenzene was prepared from 5-amino-2,3-dibromonitrobenzene by reduction with iron. ^{1}H NMR (270 MHz, CDCl$_3$): δ 6.4 (H-6, d), 5.98 (H-4, d) and 3.87 (NH$_2$, s, 4 H). J_{4-6}=2.25 Hz.

1,3-Diamino-5-bromobenzene. ^{1}H NMR (270 MHz, CDCl$_3$): δ 6.24 (H-4,H-6,d), 5.89 (H-2, triplet) and 3.57 (NH$_2$, s, 4 H). J=1.9 Hz. MS: A 1:1 doublet at m/e 186 and 188.

Copper(I) chloride was purified according to Keller and Wycoff.[29]

Copper(I) chloride induced bromo-hydrogen exchange. The reaction of the 2,3-dibromoanilines and of the 2,3-dibromophenol in aqueous hydrochloric acid − acetic acid (45 volume % of acetic acid) was performed at 90 °C in an argon atmosphere in the dark and with the apparatus and method described in Ref. 8. The HCl concentration was 5.25 mol dm^{-3}. At different times aliquots were taken from the reaction mixture. They were cooled, their pH was adjusted to about 8, and extraction with ether was performed. The concentrated ether solution, containing the aromatic compounds, was analysed by GLC. The remaining copper(I) of the reaction mixture was determined in separate aliquots by redox titration. Ammonium iron(III) sulfate was added to the sample in excess and then titrated with 0.02 M potassium dichromate with the sodium salt of 4-phenylaminobenzenesulfonic acid as indicator.

The stoichiometric chloride ion concentration was determined by Mohr titration. In the runs where the chloride ion concentration was varied, the concentration of H$^+$ was kept constant, 5.25 mol dm,$^{-3}$ with perchloric acid.

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