231. *The Mechanism of Aromatic Rearrangements. Part II. The Benzidine Change.*

By C. K. Ingold and H. V. Kidd.

Indications have frequently been obtained that the numerous formally similar rearrangements

$$C_6H_5\cdot NXR \longrightarrow (o\text{- or } p\text{-})X\cdot C_6H_4\cdot NHR \left[X = \begin{matrix}\text{Cl, OH, NH}_2\text{, NO}_2\text{, SO}_3\text{H,} \\ \text{Alk, NHAr, N}_2\text{Ar, etc.}\end{matrix}\right]$$

are by no means analogous in mechanism. The most completely investigated example is the chloroamine rearrangement (X = Cl), which has been shown (Wegscheider, *Monatsh.*, 1897, **18**, 329; Orton and Jones, J., 1909, **95**, 1456; Orton, *Brit. Assoc. Reports*, 1904, 85; Orton and King, J., 1911, **99**, 1369; Bradfield and Orton, J., 1928, 998) to be definitely intermolecular and to depend upon the intermediate production of an ordinary substituting agent, *viz.*, chlorine :

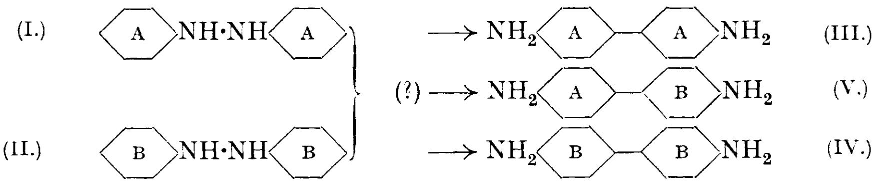
$$C_6H_5\cdot NClR + HCl \rightleftharpoons C_6H_5\cdot NHR + Cl_2 \longrightarrow (o\text{- or } p\text{-})Cl\cdot C_6H_4\cdot NHR + HCl.$$

A similar mechanism probably applies to the rearrangement of diazoaminobenzenes, although the evidence in this example is less satisfactory. In another group of cases (*e.g.*, X = NO_2,SO_3H,Alk) the situation appears to be ambiguous. Thus, in the example of the nitroamine rearrangement, the conclusion reached after a long series of investigations (Bamberger, *Ber.*, 1893, **26**, 471; 1894, **27**, 359; 1897, **30**, 1248; Orton, J., 1902, **81**, 807; Orton and Smith, J., 1905, **87**, 389; 1907, **91**, 146; Orton and Reed, *Brit. Assoc. Reports*, 1907, 101; 1909, 147; Orton and Pearson, J., 1908, **93**, 725; Bradfield and Orton, J., 1929, 915) is that an intramolecular process plays the important rôle, although the transference of the nitro-group from a nitroamine to a foreign aromatic nucleus has been realised. The hypothesis may be entertained that, in the presence of acids, the nitroamine itself effects nitration and thus in favourable circumstances may undergo rearrangement by an intermolecular method, although without the formation of any simple substituting agent by prior decomposition of the side chain. The experiments described in this paper make it certain that a third group of cases exists, in which rearrangement is unequivocally intramolecular. An indication that the isomerisation of phenylhydroxylamine belongs to this category was previously obtained by Ingold, Smith, and Vass (Part I; * J., 1927, 1245), who, despite many attempts, failed to realise the transference of the hydroxyl group from an arylhydroxylamine to the aromatic nucleus of a foreign amine or phenol. However, owing to the large number of side reactions which accompany the isomeric transformations of arylhydroxylamines, the case for an intramolecular mechanism could not be conclusively established. In the reaction now treated, *viz.*, the benzidine rearrangement, these difficulties can be avoided, and accordingly the demonstration of mechanism may be rendered more complete.

---

* Part I of this series was published under another title.

The method applied was to carry out, in the same homogeneous solution, two benzidine transformations (I) ⟶ (III) and (II) ⟶ (IV), which must be selected to fulfil certain conditions considered below. If two molecules of (I) are concerned in the production of a molecule of (III), and if, similarly, two molecules of (II) yield the parts which compose a single molecule (IV), then (the conditions referred to above being supposed satisfied) it follows that the two simultaneous reactions should be accompanied by a third in which a molecule of (I) and a molecule of (II) are together involved in the formation of (V). In this event, the product of the simultaneous reactions would be a ternary mixture of the benzidines (III), (IV), and (V). On the other hand, if only a single molecule of (I) is required for the production of a molecule of (III), and if a similar statement applies to the conversion of (II) into (IV), the product of the simultaneous reaction would be a binary mixture of the benzidines (III) and (IV). The presence of a third substance in a binary mixture of two known substances is readily detected by the use of the mixed melting-point diagram.



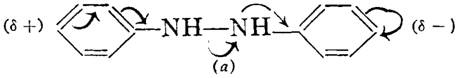
It was necessary first to find a series of hydrazobenzene derivatives which would undergo the benzidine conversion without a simultaneous semidine change, and attention was first directed to 2 : 6 : 2′ : 6′-tetra-substituted hydrazobenzenes in which an ortho-linking of aromatic nuclei is structurally precluded. It was found, however, that certain readily accessible 2 : 2′-di-substituted hydrazobenzenes do not exhibit the semidine transformation to an appreciable extent, and the main series of observations was therefore made on compounds of this type.

Although isomeric transformations other than the benzidine change were thus avoided, the conversions were still not quantitative. This was found to be due to the occurrence of a side reaction, which our preliminary experiments indicate to have considerable generality. It consists in the self-oxidation and reduction of a hydrazo-compound with the formation of the corresponding azo-derivative and mononuclear amine. We know of no previous record of this reaction, although van Loon (*Rec. trav. chim.*, 1904, **23**, 162) observed the formation of a mononuclear amine from a hydrazo-compound in the absence of an external reducing agent. It was not found possible to avoid this disturbance, and, in the examples with which the final series of experiments were performed, it diverted about 25% of the hydrazo-compound from the course of the reaction under investigation. The diversion of material is not disadvantageous, but the contamination or loss of rearrangement product would entirely vitiate the method, and the difficulty created by the side reaction had therefore to be met by proving that the method of isolation employed yielded in a pure condition the whole of the benzidine produced. By the method described, the rearrangement products are separated in a pure state, and, as special observations show, in yield corresponding at least to 97% of the quantities formed.

The condition of homogeneity was satisfied by carrying out the rearrangement by means of hydrogen chloride in dry alcohol as solvent with the exclusion of atmospheric oxygen.

The remaining condition to be fulfilled is that the two hydrazo-compounds (I) and (II) must undergo conversion at comparable speeds, for otherwise in the simultaneous rearrangement one reaction might be substantially completed before the other had effectively commenced, and, in that event, two benzidines only would be formed, whatever the mechanism. Measurements indicating the speeds of benzidine conversion have been recorded by Holleman and van Loon (*Proc. K. Akad. Wetensch. Amsterdam*, 1903, **6**, 262) and by Biilmann and Blom (*J.*, 1924, **125**, 1719), but under conditions corresponding to those of our experiments on simultaneous isomerisation, it was not possible to obtain satisfactory direct measurements of velocity, owing to the rapidity of the reactions. Recourse was therefore had to the competitive method of measuring reaction velocities, and in this way it was found that 2 : 2′-dimethoxy- and 2 : 2′-diethoxy-hydrazobenzene were a suitable pair of substances for the proposed test of mechanism.

The fusion diagram of the corresponding dimethoxy- and diethoxy-benzidines exhibits an abnormality in the neighbourhood usually occupied by a eutectic (see fig.) but the two main branches of the curve are sufficiently steep to permit an accurate test of the presence of a third substance in a mixture of the two components, the method being to carry the experimental mixture down one branch and across to and up the other by the addition of successive quantities of one component. The application of this test to the mixture of benzidines obtained by the simultaneous conversion of the two hydrazobenzenes showed that the product contained two components only. Thus, the conclusion follows that before the nitrogen link is severed (*a*) the 4- and 4′-positions come within each other's sphere of influence in a molecule activated during the formation or decomposition of the corresponding hydrazinium kation (cf. *Rec. trav. chim.*, 1929, **48**, 811):



EXPERIMENTAL.

2 : 2′-*Dimethoxy- and* 2 : 2′-*Diethoxy-hydrazobenzene*.—These were made by a modification of Starke's method (*J. pr. Chem.*, 1899, **59**, 210) for the preparation of the former. Zinc dust (500 g.) was added gradually to a mechanically stirred mixture of *o*-nitroanisole (250 g.), methyl alcohol (1 l.), and water (250 c.c.) containing dissolved sodium hydroxide (365 g.). The mixture was heated on the water-bath under reflux, and after 3 hours water (250 c.c.) was added, and the heating continued. After a further 7 hours, the product was filtered through muslin and the residue was washed with water, mixed with water, and filtered through copper gauze, which removed the zinc and zinc oxide from the bulk of the coarsely granular hydrazo-compound. Further quantities were obtained by diluting the aqueous-alcoholic filtrate and by drying and extracting the zinc–zinc oxide mixture with ethyl alcohol, the whole separation being conducted as rapidly as possible in order to avert undue atmospheric oxidation. The yield was 90% and the product was purified by crystallising twice from alcohol. In the first crystallisation, 10% aqueous ammonium sulphide, equivalent to 10 c.c. per litre of ethyl alcohol, was added, and the solution filtered from the sulphur, which separated during cooling. The second crystallisation was carried out in an atmosphere of nitrogen, and a few drops only of ammonium sulphide were added. The faintly yellow substance had m. p. 105° (lit. 102°) (Found: C, 68·6; H, 6·5; N, 11·7. Calc.: C, 68·9; H, 6·6; N, 11·5%). It gives a red colour with aqueous mineral acids and with mercuric chloride, with acetyl chloride and with benzyl chloride, and its solution in ethyl alcohol absorbs atmospheric oxygen, yielding 2 : 2′-dimethoxyazobenzene. 2 : 2′-Diethoxy-hydrazobenzene was prepared in like manner, using ethyl in place of methyl alcohol. It was colourless and had m. p. 90° (lit. 89°) (Found: C, 70·8; H, 7·4; N, 10·4. Calc.: C, 70·6; H, 7·4; N, 10·3%), and its properties were otherwise similar to those of the lower homologue.

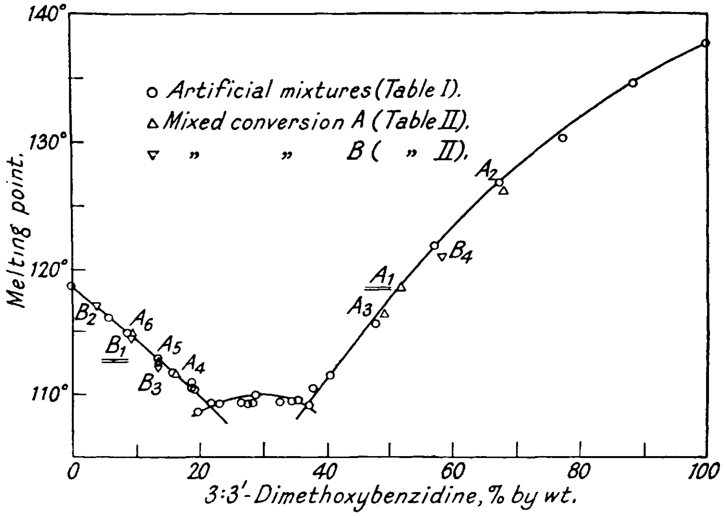
Conversion of Hydrazo-compounds into 3 : 3′-*Dimethoxy- and* 3 : 3′-*Diethoxy-benzidine*.—Hydrogen chloride was passed into an ethyl-alcoholic solution of either hydrazo-compound contained in a vessel, from which the air had been displaced by hydrogen or nitrogen. The dihydrochlorides of the dimethoxy- and diethoxy-benzidines were precipitated from the orange solution by ether as colourless crystals, which, after being washed with ether containing a small proportion of alcohol, had m. p. 272° (decomp.) and 254° (decomp.) (Found: for the ethoxy-compound: C, 55·3; H, 6·6; N, 7·7; Cl, 20·4. Calc.: C, 55·7; H, 6·4; N, 8·1; Cl, 20·6%), and on basification with ammonia gave 3 : 3′-dimethoxybenzidine, m. p. 138°, m. p. after crystallisation from alcohol containing a little ammonium sulphide 138° (Found: C, 68·9; H, 6·6; N, 11·6. Calc.: C, 68·9; H, 6·6; N, 11·5%), and 3 : 3′-diethoxybenzidine, m. p. 119°, m. p. after crystallisation from the same solvent 119° (Found: C, 70·9; H, 7·4; N, 10·5. Calc.: C, 70·6; H, 7·4; N, 10·3%). These compounds have been described as becoming coloured in air, but our preparations were completely stable in air in the absence of acids, and their m. p.'s are appreciably higher than those previously recorded (131·5° and 117° respectively). In both cases the yield was 73% and the mother-liquors yielded 12 mols. % of 2 : 2′-dimethoxy- or 2 : 2′-diethoxy-azobenzene and a quantity of *o*-anisidine or *o*-phenetidine. The 2 : 2′-dimethoxyazobenzene, m. p. 154—155° (Found : C, 69·8; H, 5·9. Calc. : C, 69·4; H, 5·8%), and 2 : 2′-diethoxyazobenzene, m. p. 130—131° (Found : C, 71·2; H, 6·7. Calc. : C, 71·1; H, 6·6%), were each identified by mixed m. p.'s with authentic specimens. The efficiency of the method of isolation of the benzidines was checked by repeating the manipulation of conversion and separation, after combining the isolated benzidines with their by-products or with artificial mixtures corresponding to their by-products. Yields of 97—98% of either original benzidine were recovered.

Fusion Diagram of 3 : 3′-*Dimethoxy- and* 3 : 3′-*Diethoxy-benzidine.*—The ordinary method of plotting this diagram was not available, as the substances undergo some decomposition on fusion, becoming coloured. The samples of the components were therefore weighed and ground together for 15 mins., which was found sufficient to ensure consistent m. p.'s. The m. p.'s were taken in a capillary tube with continuous stirring both of the material and of the bath. The temperature at which the melt became clear could be read and reproduced to 0·1°. The data tabulated below and shown in the fig. are each the result of concordant triplicate determinations. The temperatures are uncorrected, but were measured with the thermometer and under the conditions used for the experiments on simultaneous isomerisation and for those on the relative velocities of the two interconversions. The percentages tabulated represent proportions by weight of the dimethoxybenzidine.

TABLE I.

Percentage.	M. p.	Percentage.	M. p.	Percentage.	M. p.	Percentage.	M. p.
0·0	118·6°	28·8	109·9°	19·0	110·4°	47·9	115·6°
5·5	116·1	32·6	109·4	19·7	108·5	57·1	121·8
9·2	114·6	34·5	109·4	21·8	109·3	67·5	126·7
13·2	112·8	35·4	109·5	23·1	109·2	77·3	130·2
15·7	111·7	37·2	109·1	26·6	109·3	88·4	134·5
18·5	110·9	37·9	110·5	27·4	109·2	100·0	137·7
18·6	110·5	40·5	111·5	28·2	109·3		

Simultaneous Conversion of 2 : 2′-*Dimethoxy- and* 2 : 2′-*Diethoxy-hydrazobenzene into Mixture of Benzidines.*—A mixture of the two hydrazo-compounds in known proportion was converted into benzidines by the method used in the cases of the separate isomerides. In the first experiment the composition of the original mixture was chosen to give a mixture of benzidines having an m. p. at *A* 1 on the dimethoxybenzidine branch of the fusion diagram (see fig.). The point was proved to be located on the correct branch by the addition of dimethoxybenzidine in quantities sufficient to change the composition from that corresponding to the point *A* 1 to a new composition, which, together with the new m. p., is represented by the point *A* 2. The original mixture corresponding to point *A* 1 was then mixed with successively increasing quantities of the diethoxybenzidine; the compositions calculated for each of these mixtures together with their freezing points yielded a succession of points *A* 3, *A* 4, *A* 5, *A* 6, the last three of which lie



on the diethoxybenzidine branch of the diagram, thus establishing the binary character of mixture *A*1. In the second experiment the original mixture of hydrazo-compounds was so chosen that the resulting mixture of benzidines had an m. p. lying at *B*1 on the diethoxy-branch of the diagram. The correct location of the point on this branch was proved by the addition of a further quantity of the diethoxy-component, the point *B*2 being thus determined. The addition of successively increasing quantities of the dimethoxy-component yielded the points *B*3 and *B*4, of which the last lies on the dimethoxybenzidine branch of the diagram. The data are shown in the fig. and also in the following table, in which col. 2 records the percentages by weight of 2 : 2′-dimethoxyhydrazobenzene in the mixture of hydrazobenzenes isomerised, col. 4 records the percentages by weight of 3 : 3′-dimethoxybenzidine calculated from the m. p.'s of the products of conversion and the proportions of pure components added thereto, and col. 5 contains the corresponding percentages as deduced from the m. p.'s of the various mixtures.

TABLE II.

	Hydrazo-mixture.	Benzidine mixture, composition %.				Hydrazo-mixture.	Benzidine mixture, composition %.		
Expt.	Composition, %.	M. p.	Calc.	Found.	Expt.	Composition, %.	M. p.	Calc.	Found.
*A*1	55·0	118·5°	—	52·0	*B*1	12·1	114·5°	—	9·0
*A*2	—	126·2	68·0	67·4	*B*2	—	116·9	3·7	3·3
*A*3	—	116·3	49·2	48·5	*B*3	—	112·2	13·5	14·0
*A*4	—	111·7	16·0	15·9	*B*4	—	120·9	58·4	56·4
*A*5	—	112·6	13·3	13·3					
*A*6	—	114·9	9·3	8·3					

Relative Velocities of Isomerisation of 2 : 2′-*Dimethoxy- and* 2 : 2′-*Diethoxy-hydrazobenzene*.—The principle of the method was to act on a mixture of the hydrazo-compounds in known proportion with an amount of hydrogen chloride sufficient to convert only a small proportion of the less plentiful constituent, and to determine by means of the fusion diagram the composition of the mixture of benzidines produced. The conditions of these experiments were the same as those applying to the experiments of the preceding section, except with regard to the quantity of hydrogen chloride. The amount of conversion catalysed by a given quantity of the acid under the conditions employed is limited by the circumstance that the product of the change unites with 2 mols. of acid and destroys the catalytic activity of the reagent to that extent. The hydrochlorides of dimethoxy- and diethoxy-benzidine are not of themselves catalytically effective, and do not by alcoholysis give hydrogen chloride in quantities sufficient to exhibit detectable catalytic activity. These preliminary points were established by isomerising either hydrazo-compound in ethyl alcohol with varying measured quantities of standard hydrogen chloride in that solvent, weighing the derived benzidine hydrochlorides, and measuring the residual unconverted hydrazo-compounds gravimetrically by the reduction of Fehling's solution. Comparison of the weights of the benzidine hydrochlorides with the quantities of hydrogen chloride used showed also that the relative extents of isomerisation and of the side reaction remain substantially the same as when the acid was used in excess. The results of the experiments on the simultaneous conversion of the two hydrazo-compounds in the presence of small amounts of hydrogen chloride are shown in the following table, the headings of the first five columns of which are self-explanatory. The last column gives the calculated velocity of isomerisation of the dimethoxy-compound relatively to that of the diethoxy-derivative taken as unity. These figures are not corrected for the change with time in the ratios of the concentrations of the hydrazo-compounds, since, with the small conversions obtaining, this correction is unimportant. The observational error is evidently considerable; but the object of the experiments was merely to show that the two reactions have comparable velocities.

		Benzidines.			
Hydrazo-compounds (mols.).		Yield	Composition, mols. %.		Velocity
Dimethoxy-.	Diethoxy-.	(mols.).	Dimethoxy-.	Diethoxy-.	ratio.
1·00	0·90	0·090	88	12	6·6
1·00	1·50	0·075	79	21	5·7
1·00	1·00	0·090	86	14	6·2

UNIVERSITY COLLEGE, LONDON.

[*Received, June* 16*th*, 1933.]