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THE MECHANISM OF THE BENZIDINE REARRANGEMENT - IV

EVIDENCE FOR A METASTABLE INTERMEDIATE [1]

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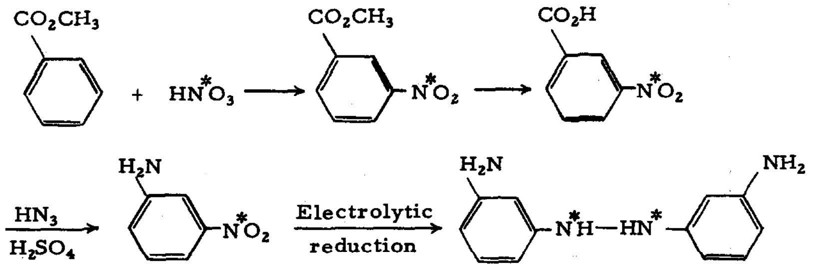
THE rate of rearrangement of m-hydrazoaniline to o,o'-diaminobenzidine is inversely proportional to the concentration of strong acid in 95 per cent alcoholic solutions over the range of acidities 0.0067-0.04 M. The result indicates that the rate-determining step involves some transformation of a first conjugate acid of the substrate; the inverse dependence of rate on acid concentration arises from the fact that the substrate is a fairly strong diacid base.

Various mechanisms proposed for the benzidine and related transformations predict differences in the extent to which symmetrization of the two halves of the hydrazoaniline molecule will occur during the rearrangement. Therefore, we have prepared the substrate with N^{15} specifically located in the hydrazo linkage by the following reactions:



I

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[1] Part III is G.S. Hammond and W. Grundemeier, J. Amer. Chem. Soc. 77, 2444 (1955).

[2] National Institutes of Health Predoctoral Fellow, 1961-2.

TABLE 1

Rearrangement of Labeled Hydrazoaniline

Expt. No.	Source of starting material	Total acid concentration[a]	Total hydrazoaniline	Corrected $[H^+]$[b]	N^{15} Atoms per molecule		Percent *ortho* coupling
					~~-NHNH-group~~ of substrate [c]	Diamino-carbazole	
1	A	0.002	1.12×10^{-3}	1.7×10^{-4}	0.974	0.804 ± 0.006	35.7
2	C	0.002	1.14×10^{-3}	1.7×10^{-4}	0.936	0.807 ± 0.009	33.9
3	A	0.01	1.17×10^{-3}	7.7×10^{-3}	0.974	0.795 ± 0.0005	37.6
4	A	0.01	1.10×10^{-3}	7.8×10^{-3}	0.974	0.795 ± 0.002	37.6
5	C	0.02	1.12×10^{-3}	1.78×10^{-2}	0.936	0.783 ± 0.009	39.2
6	C	0.02	1.13×10^{-3}	1.77×10^{-2}	0.936	0.783 ± 0.000	39.2
7	A	0.04	1.17×10^{-3}	3.77×10^{-2}	0.974	0.768 ± 0.006	43.2
8	B	0.04	1.09×10^{-3}	3.78×10^{-2}	0.952	0.759 ± 0.000	44.8

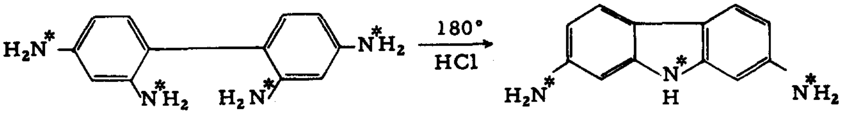
[a] Calculated from amount of HCl added to the reaction mixture;

[b] Calculated for experiments 1 and 2 using estimated values of 5×10^4 and 10^4 for the first and second basicity constants of hydrazoaniline ($K = [BH^+]/[B][H^+]$.

[c] The related azo compound was deaminated and the N^{15} content of the azobenzene was measured. The azo-aniline was prepared from *m*-$NO_2C_6H_4NH_2$ containing 0.490 atoms N^{15} per molecule.

[d] Calculated on the assumption that N^{15} from *m*-$NO_2C_6H_4NH_2$ is in the amino groups of hydrazoaniline if it does not appear in the hydrazo group.

The reaction product was converted to 2,7-diaminocarbazole by cyclization in the presence of aqueous hydrochloric acid at 180°.



II III

The difference between the N^{15} content of III and that of I measures the N^{15} in the *ortho* amino groups of II. If II were formed exclusively by coupling in positions originally *para* to the hydrazo linkage of I, all of the N^{15} would be retained and if *ortho* coupling were observed exclusively half of the N^{15} would be lost. The data presented in Table 1 show that the results actually lie between these extremes.

The most startling result is the fact that *the N^{15} distribution varies as the acidity of the reaction mixture is varied*. Since the dependence of the reaction rate on acid concentration is invariant over the range of acidities involved,[3] the result shows that a metastable intermediate is produced in the rate-determining step. The intermediate may either collapse to products with predominant, but not exclusive, *para* coupling or it may react with another proton to give products in which the relative amounts of *ortho* and *para* coupling are more nearly equal. In fact, the results are entirely compatible with the view that addition of a second proton produces a system in which the four nitrogen atoms become equivalent.

The results exclude a "cart wheel" mechanism[4] with V as an intermediate. Except for nitrogen labeling V, VI, and other intermediates of the same type are identical if shuffling of protons among nitrogen sites is faster than

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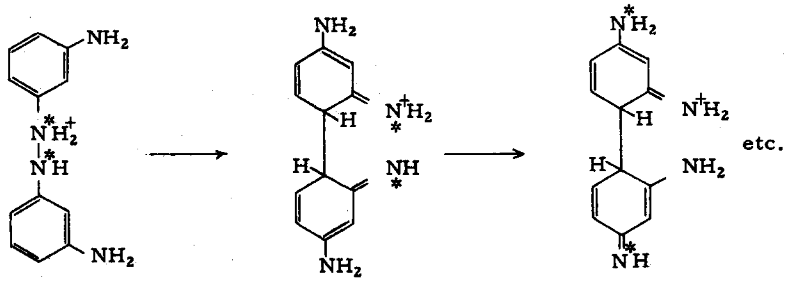
[3] This assertion can not be rigorously defended for Runs 1 and 2 in which the concentration of acid was so low that the hydrogen ion concentration can not be known without a knowledge of the basicity constants of I.

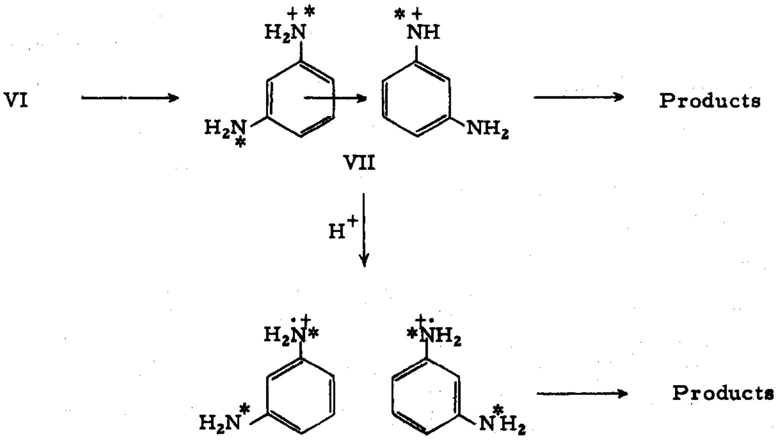
[4] S. Brownstein, C.A. Bunton and E.D. Hughes, *Chem. & Ind.* 981 (1956).

C-C bond breaking; since V would be formed first, reaction by this path would give a minimum of 50 per cent ortho coupling.



IV V VI

The following dissociative mechanism fits the data and interestingly, contains features which are found in two previously suggested mechanisms.



VII

VIII

If rotation in intermediate VII is faster than collapse to products, the intermediate contains a symmetrical part and an unsymmetrical part. Coupling reactions of the symmetrical part would involve positions originally ortho and para to the labeled nitrogen atoms with equal probability. Coupling would involve the ortho and para positions of the unsymmetrical part in some unknown ratio. Because the results of runs 1 and 2 are not in very good agreement, we do not know the limiting value for the fraction of the coupling which occurs at ortho positions. The results do indicate that the value is above the lower limit of 25 per cent predicted by the suggested mechanism. The mechanism also predicts that ortho coupling will never exceed 50 per cent. The data are compatible with this prediction but it is not feasible to test the expected limit by carrying out experiments at very high acidities, since the reaction rates become prohibitively slow.

Although the suggested mechanism is actually largely dictated by experimental facts, it is a remarkably even compromise between two commonly considered mechanisms, the Dewar[5] mechanism and a mechanism involving formation of a pair of cation radicals by homolysis of the second conjugate acid of a hydrazo compound. We accept Dewar's suggestion that the first step is heterolysis of a first conjugate acid and append the specific suggestion that the second step involves addition of a second proton to form a symmetrical system that may well be described as a pair of cation radicals. There is no direct evidence as to the electron spin state of VIII; however, analogy to the π-dimer of the Wurster Blue cation described by Hausser and Murrell[6] suggests that the complex may be a spin-paired, singlet state.

Since the rate of rearrangement of hydrazoaniline shows a different dependence on acidity than does the rate of rearrangement of hydrazobenzene,[7] it is possible that the reactions involve entirely different mechanisms. However, the mechanism suggested for hydrazoaniline may be adapted smoothly to fit all of the available data relating to hydrazobenzene and many of its derivatives if we assume, as Dewar has done, that reversal of the initial cleavage reaction may be rapid in comparison with product-forming steps in many cases.

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[5] M.J.S. Dewar, Kekule Symposium on Theoretical Organic Chemistry p. 198 ff. Butterworths Scientific Publications, London (1958).

[6] K.H. Hausser and J.N. Murrell, J. Chem. Phys. 27, 500 (1957).

[7] G.S. Hammond and H.J. Shine, J. Amer. Chem. Soc. 72, 220 (1950).