181. Diazotisations in Highly Concentrated Mineral Acids: The Nitrosation Mechanism of Anilinium and Hydroxylammonium Ions through Proton Loss from the Ammonio Group

by **Heinrich Zollinger**

Technisch-Chemisches Laboratorium, Eidgenössische Technische Hochschule, CH-8092 Zürich

(18. VIII. 88)

It is shown that the acidity dependence of the rate of nitrosation of aromatic amines and of hydroxylamine in strongly acidic aqueous solutions does not necessarily involve the rearrangement of a charge transfer complex (consisting of the NO^+ ion and the substrate with an NH_3^+ group) in concert with a proton loss at the NH_3^+ group. More likely, proton loss of the charge complex preceeds the $\pi \rightarrow N$ rearrangement of the NO^+ ion.

Introduction. – The influence of the acidity of the aqueous medium on diazotisations has been an object of investigation since the pioneering work of *Ridd* and coworkers in 1958 [1]: in the low acidity region (normally in the pH range of 1 to 3), the rate of diazotisation decreases with increasing concentration of hydrogen ions. In an intermediate region, corresponding to h_0 of *ca.* 10^{-1} to 10^3, the rate increases linearly with acidity, and finally, in high acidity media ($h_0 > 10^4$), the rate decreases again with acidity.

For all three regions, *Ridd* [2] [3] proposed mechanisms which are consistent with the kinetic results. In this paper, we discuss only the mechanisms in the intermediate and high-acidity regions.

The marked acid catalysis in the intermediate region indicates that the new nitrosating reagent is the (solvated) nitrosyl cation (NO^+) formed in the overall *Equilibrium 1.*

$$H_2SO_4 + HNO_2 \rightleftarrows NO^+ + HSO_4^- + H_2O \qquad (1)$$

The linear correlation between the concentration of the effective nitrosating reagent and the rate of diazotisation implies, however, as postulated by *Challis* and *Ridd* [4], that the anilinium ion and not aniline must enter the substitution proper, forming a dicationic charge-transfer complex of NO^+ with the anilinium ion. For the rate-limiting step, a $\pi \rightarrow N$ rearrangement, concerted with *N*-deprotonation, forming the *N*-nitrosoanilinium monocation was postulated [5]. This conclusion is supported by some other unusual features, notably in the pattern of substituent effects in the aniline ring; the influence of *p*-substituents is the reverse of that observed in the low-acidity range.

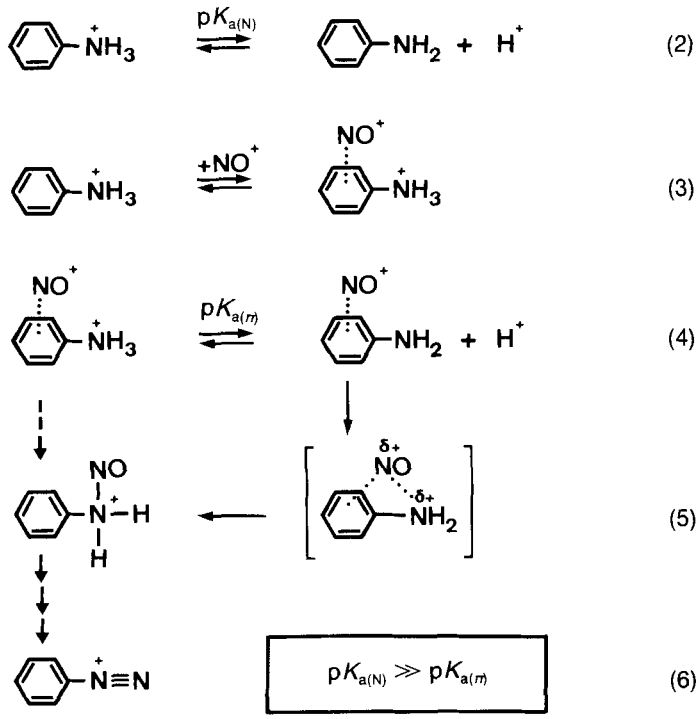
Ridd [2] explained the anewed rate decrease at high acidities by assuming that the rate-limiting step at high acidities is the deprotonation of the *N*-nitrosoanilinium ion.

In the present communication, we intend to present a mechanism which involves also the anilinium ion, but which offers a reasonable explanation for the reactivity of this relatively weak nucleophile.

Discussion. – Since the 1960's, a large amount of data with several completely different probes indicate that the Me_3N^+ group, along with the unsubstituted ammonio group NH_3^+, is a modest π donor with a resonance effect similar to that of the isoelectronic Me_3C group. The donor activity of the NH_3^+ substituent, however, is much smaller than that of the NH_2 group.

It is, therefore, not trivial to ask, if the NH_3^+ group of the anilinium ion is really not changed in the course of the formation of the covalent N–N bond yielding the *N*-nitroso-anilinium ion.

The fundamental issue of our present communication is based on the postulate that the pK_a value of the dicationic charge-transfer complex must be significantly lower than that of the anilinium ion: electrophilic complexation of any benzene derivative bearing a *Brönsted*-acid group such as NH_3^+ will increase the acidity constant of that group. Incorporating this consideration into the reaction mechanism of diazotisation, the *Ridd* mechanism is modified as shown in *Eqns. 2–6*.



(2)

(3)

(4)

(5)

(6)

The essential basis of this mechanism, therefore, is the deprotonation of the charge-transfer complex *(Eqn. 4)*. That equilibrium is situated more on the right side than that of the uncomplexed anilinium ion *(Eqn. 2)*: $pK_{a(N)} \gg pK_{a(\pi)}$. This facilitates the rearrangement of the NO^+ group from the charge-transfer position to an NH_2 group and not anymore to an NH_3^+ group. Comparing our mechanism *(Eqns. 2–6)* with the original *Ridd* mechanism, one realizes that *Ridd* combined the steps of *Eqns. 4* and *5* in a concerted

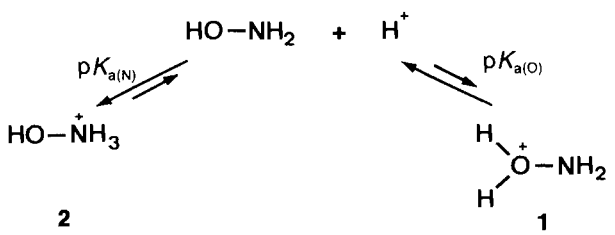
rearrangement-deprotonation step. This is indicated in *Eqns. 4* and *5* by the dashed-arrow 'short-cut' between the charge-transfer complex and the *N*-nitrosoanilinium ion.

Our mechanism *(Eqns. 2–6)* is of course also applicable to strongly acidic conditions. The only difference is the deprotonation of *N*-nitrosoanilinium ion, *i.e.* the first step of the steps summarized in *Eqn. 6* becoming rate-limiting.

In that context the diazotisation of heteroaromatic amines in highly acidic media is interesting. Recently *Diener* [6] demonstrated that the rates of diazotisation of 2-aminothiazole in 65 to 75% H_2SO_4 solution show a dependence on acidity and a kinetic deuterium isotope effect which is significantly lower than the corresponding figures for the diazotisation of aniline [7] in the same medium (2-aminothiazole: rate proportional to $h_o^{-0.69}$, $k_H/k_D = 5.8$; aniline: $h_o^{-2.4}$, $k_H/k_D = 10$). This comparison shows clearly that the rate-determining part of the diazotisation of 2-aminothiazole contains only one deprotonation, whereas that of aniline contains two.

2-Aminothiazole is protonated first at the heterocyclic N-atom ($pK_a = 5.28$, [6]), but does not add a second proton up to solutions in 90% H_2SO_4 (see [8]). It is, therefore, possible, but less likely that, in nitrosations of 2-aminothiazole, a π-complex of NO^+ with the heteroaromatic thiazolium system is formed first. Direct *N*-nitrosation is easier, however, for that heterocyclic amine than for the anilinium ion, because it contains an NH_2 and not an NH_3^+ group.

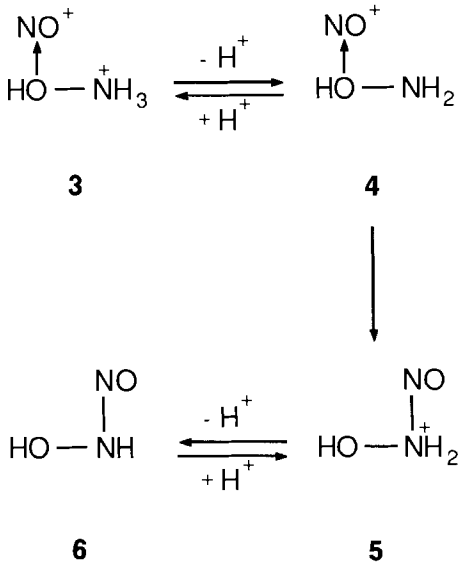
In the nitrosation of an inorganic amino compound, namely hydroxylamine, dinitrogenoxide (N_2O) is the final reaction product. As shown by *Hughes* and *Stedman* [9], the kinetics of that reaction in acidic solution are very similar to the diazotisation of aniline. They showed that the overall reaction rate is too great to involve the *O*-protonated hydroxylamine (**1**) which is present only in an extremely small concentration in the acidic media used by *Hughes* and *Stedman* (aqueous $HClO_4$). The equilibrium between the two protonated isomers of hydroxylamine *(Eqn. 7)* is very much in favour of the *N*-protonated isomer **2**. Therefore, *Hughes* and *Stedman* suggested that the nitrosating agent replaces a proton of the hydroxylammonium ion **2**.



(7)

$pK_{a(N)} \gg pK_{a(O)}$

In analogy to *Ridd*'s work with aromatic amines, it is possible that the O-atom of the hydroxylammonium ion **2** provides electrons for the formation of a charge-transfer complex **3** with the NO^+ ion *(Eqn. 8)*. For obvious reasons, the NH_3^+ group of complex **3** is much more acidic than the NH_3^+ group in non-complexed hydroxylammonium ion **2**: $pK_{a(3)} \gg pK_{a(N)}$. Complex **3** will, therefore, loose a proton of the NH_2 group relatively



(8)

easily[1]). *Afterwards,* the NO^+ group of the complex **4** can rearrange to the hydroxy-nitroso-ammonium ion **5** which, in turn, will loose another proton yielding *N*-nitroso-hydroxylamine **6**.

The essence of the mechanism which we postulate is a separation of the *concerted* rearrangement and the deprotonation into *two* steps, namely *de*protonation of the NH_3^+ ion complex *followed* by rearrangement of NO^+ to the NH_2 group. In a review of nitrosation published more than 10 years after his original work on diazotisations in relatively strong acid asolutions, *Ridd* [10] points out in a footnote that in such reactions 'the interaction of NO^+ with the protonated amine appears to facilitate the proton loss'. This statement is almost in agreement with our mechanism *(Eqns. 2–6)* !

I am grateful to Prof. *J. H. Ridd,* University College, London, for valuable discussions.

REFERENCES

[1] E. D. Hughes, C. K. Ingold, J. H. Ridd, *J. Chem. Soc.* **1958,** 65.
[2] J. H. Ridd, *Quart. Revs.* **1961,** *15,* 418.
[3] J. H. Ridd, *J. Soc. Dyers Colourists* **1965,** *81,* 355.
[4] B. C. Challis, J. H. Ridd, *J. Chem. Soc.* **1962,** 52.
[5] E. C. R. de Fabrizio, E. Kalatzis, J. H. Ridd, *J. Chem. Soc. (B)* **1966,** 533.
[6] H. Diener, Ph. D. Thesis, ETH Zürich, 1984.
[7] B. C. Challis, J. H. Ridd, *Proc. Chem. Soc.* **1960,** 245.
[8] G. Tóth, B. Podányi, *J. Chem. Soc., Perkin Trans. 2* **1984,** 91.
[9] M. N. Hughes, G. Stedman, *J. Chem. Soc.* **1963,** 2824.
[10] J. H. Ridd, Adv. *Phys. Org. Chem.* **1978,** *16,* 1.

[1]) *O*-Deprotonation of **3** is, of course, possible too. It is even more dominant than *N*-deprotonation for obvious reasons. It can be neglected, however, in this context, because *O*-deprotonation is a side-equilibrium which does not lead to the reaction product N_2O.