Monatshefte für Chemie 115, 669—682 (1984)

Monatshefte für Chemie
Chemical Monthly

Kinetic Studies on the Formation of N-Nitroso Compounds IX. Nitrosyl Acetate as a Nitrosating Agent

Julio Casado*, Albino Castro, Manuel Mosquera, M. Flor Rodríguez Prieto, and **José Vázquez Tato**

Departamento de Química Física, Facultad de Química, Universidad, E-Santiago de Compostela, Spain

(Received 28 July 1983. Accepted 2 February 1984)

A study of the nitrosation of N-methylaniline and piperazine by nitrous acid in acetate buffer supports a mechanism covering both reactions, whose effective pathway depends on the relationship between the concentrations of nitrite ion, acetate ion, and nitrosatable substrate. In the case of N-methylaniline the only nitrosating agent is nitrosyl acetate, whereas in the nitrosation of piperazine the nitrous acidium ion and dinitrogen trioxide are also involved.

The results obtained seem to show that nitrosation by nitrosyl acetate is diffusion controlled. On this assumption, the equilibrium constant of the reaction $AcOH + HNO_2 \rightleftharpoons AcONO + H_2O$ has been estimated from kinetic measurements as approximately $1.4 \cdot 10^{-8} M^{-1}$. This means that the concentration of nitrosyl acetate in the medium must be extremely small, which explains the virtual impossibility of detecting it in aqueous solution except by kinetic methods.

(Keywords: Acetate buffer; Kinetics of nitrosation; Nitroso compounds; Nitrosyl acetate)

Kinetische Untersuchungen zur Bildung von N-Nitroso-Verbindungen, 9. Mitt.: Nitrosylacetat als Nitrosierungsreagens

Die Untersuchung der Nitrosierung von N-Methylanilin und Piperazin mit Salpetriger Säure in Acetat-Puffer unterstützt einen für beide Fälle geltenden Mechanismus, dessen effektiver Ablauf von den Konzentrationsverhältnissen des Nitritions, des Acetations und der nitrosierbaren Substanz abhängt. Im Fall des N-Methylanilins ist das einzige Nitrosierungsagens Nitrosylacetat, während bei der Nitrosierung von Piperazin das Nitrit-Acidium-Ion und Distickstofftrioxid ebenfalls beteiligt sind.

Die erhaltenen Resultate scheinen zu zeigen, daß die Nitrosierung durch Nitrosylacetat diffusionskontrolliert ist. Unter dieser Annahme kann die Gleichgewichtskonstante der Reaktion $AcOH + HNO_2 \rightleftharpoons AcONO + H_2O$ aus kinetischen Messungen zu etwa $1{,}4 \cdot 10^{-8} M^{-1}$ abgeschätzt werden. Das

bedeutet, daß die Konzentration von Nitrosylacetat im Medium extrem gering sein muß; das erklärt die praktische Undetektierbarkeit dieser Spezies in wäßriger Lösung, ausgenommen mit kinetischen Methoden.

Introduction

On a number of occasions it has been suggested that nitrosyl acetate acts as an intermediate in N-nitrosation reactions by nitrous acid in the presence of acetate buffer[1–4]. *Ac*ONO has been found to contribute to the formation of the effective nitrosating agent N_2O_3 by reacting with the NO_2^- ion[4], but hitherto its reaction with amines or other N-nitrosatable substrates has only been detected in the case of the N_3^- ion[3]. In order to investigate the reactivity of nitrosyl acetate as a nitrosating agent, we have studied the nitrosation of N-methylaniline (*MAN*) and piperazine (*PIP*) by nitrous acid in acetate buffer. These substrates were chosen because their acidity constants [$pK_a(MAN) = 4.85$, $pK_a(PIP) = 5.55$] facilitate the use of experimental conditions in which the concentration of free amine is at least as high as that of the nitrite ion, with which it may therefore compete with advantage for the nitrosyl acetate present.

Experimental

N-Methylaniline (Merck p.s.) was double-distilled at reduced pressure in a nitrogen atmosphere. Piperazine (Merck p.s.) was purified by sublimation. Dilute solutions of these compounds were slowly neutralized at 2 °C with dilute perchloric acid solution (Merck p.a.). All other chemicals used were Merck p.a. except the N-nitrosopiperazine, a solution with a known concentration of which was obtained by reacting nitrous acid with an excess of piperazine in conditions in which reaction was complete. The reaction was checked to ensure that it was fast enough for interference by the slow decomposition of nitrous acid to be negligible.

The stoichiometry of the reactions studied is well known:

$$R_2NH + HNO_2 \rightarrow R_2NNO + H_2O$$

The formation of N-nitroso-N-methylaniline (*NMAN*) was followed spectrophotometrically at a wavelength of 272 nm, at which the absorption of *MAN* and nitrite is minimal and that of *NMAN* a maximum. The formation of mononitrosopiperazine (*NPIP*) was followed at 249 nm, an isosbestic point of the nitrite ion/nitrous acid system, at which the coefficient of differential molar absorptivity between the nitroso compound and nitrite is a maximum, $4530 \pm 9\ M^{-1}\ cm^{-1}$. The absorption of piperazine at this wavelength is negligible.

All kinetic measurements were duplicated, and the results were reproducible to $\pm 2\%$. The experiments were carried out at 25 °C and an ionic strength of 0.2 *M* (ClO_4Na).

Acidity was measured using a Radiometer model 26 *pH*-meter equipped with a GK 2401 C combined electrode. The kinetic measurements were carried out in a Pye Unicam SP 8-200 and Uvikon 820 UV-VIS spectrophotometers.

Results and Discussion

The Nitrosation of N-Methylaniline in Acetate Buffer

This reaction was analysed by the integration method using conditions in which the concentration of *MAN* was greatly in excess of that of nitrite. In all cases at least 90% of the reaction was followed, and the data fitted an integrated first-order rate equation, as shown by the straight lines obtained on plotting $\ln (A_\infty - A_t)$ against time, A_∞ and A_t being the absorbance at infinity and time t respectively (Fig. 1). The slopes of these graphs are the first-order rate constants k_0. To avoid the problems involved in determining A_∞ experimentally in all cases (and the systematic errors that using an incorrect value would lead to), it was normally estimated by the unidimensional optimization algorithm of *Davies, Swann* and *Campey* using a program written for a Texas TI 59 calculator[5]. The accuracy of this method was checked by comparing this value with that obtained experimentally in various cases.

The influence of the concentration of buffer on k_0 was investigated at various concentrations of *MAN*. In all cases k_0 was found to depend linearly on the concentration of buffer, in whose absence the rate of reaction was negligible (Fig. 2), i.e.

$$k_0 = a\,[Buf] \tag{1}$$

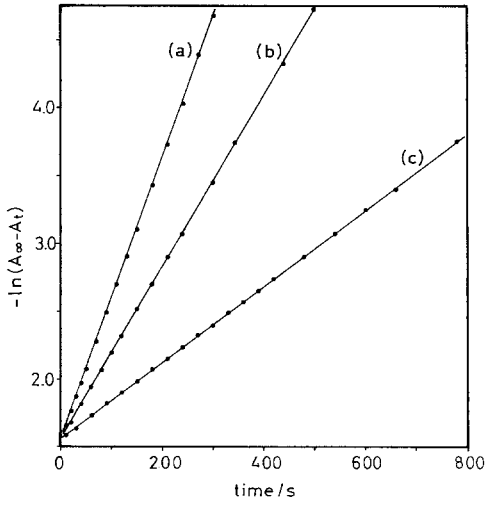


Fig. 1. Typical first-order plots for the nitrosation of *MAN* in acetate buffer at 25 °C, $\mu = 0.2\,M$, $[Buf] = 0.200\,M$, $pH = 4.37$, $[MAN]/M = (a)\ 6.07 \cdot 10^{-3}$, $(b)\ 3.03 \cdot 10^{-3}$, $(c)\ 1.011 \cdot 10^{-3}$ and $[Nit]_0 = 2.94 \cdot 10^{-5}\,M$

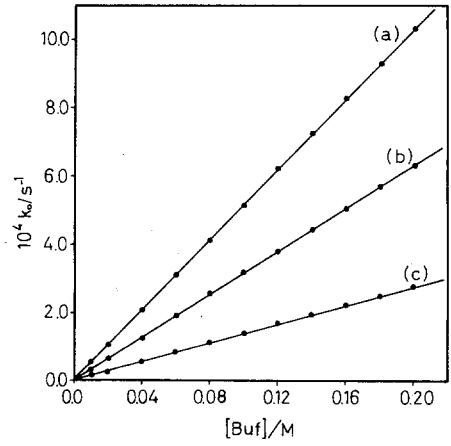


Fig. 2. Influence of the concentration of acetate buffer on the first-order rate constant for the nitrosation of *MAN* at 25 °C, $\mu = 0.2\,M$, $pH = 4.37$ and $[MAN]/M$ = (*a*) $6.07 \cdot 10^{-3}$, (*b*) $3.03 \cdot 10^{-3}$, (*c*) $1.011 \cdot 10^{-3}$

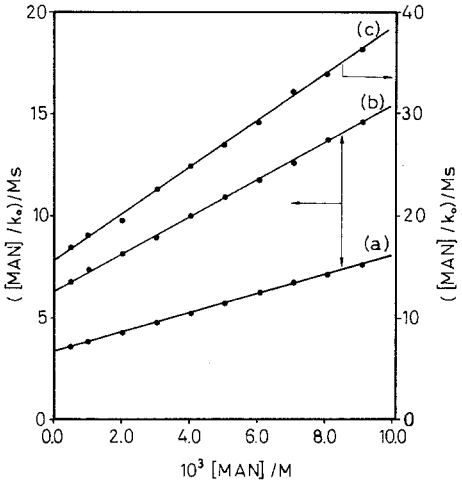


Fig. 3. Influence of the concentration of *MAN* on the first-order rate constant for the formation of *NMAN* at 25 °C, $\mu = 0.2\,M$, $pH = 4.37$ and $[Buf]/M$ = (*a*) 0.200, (*b*) 0.100, (*c*) 0.040

On studying the influence of the concentration of *MAN* on k_0 at various concentrations of buffer, the order of the reaction was found to be less than unity. Fig. 3 shows that the data could be linearized by plotting $[MAN]/k_0$ against $[MAN]$, so that

$$k_0 = \frac{[MAN]}{b + c[MAN]} \tag{2}$$

Together, the above results yield the following experimental rate equation at constant pH:

$$v = \frac{[Buf][MAN][Nit]}{d + e[MAN]} \tag{3}$$

The variation of k_0 with pH was also investigated, using various concentrations of MAN (Fig. 4). The resulting data are complex and difficult to linearize. They were therefore not used initially in deducing the reaction mechanism proposed below, but their agreement with the theoretical rate equation derived from the mechanism strongly supports the latter.

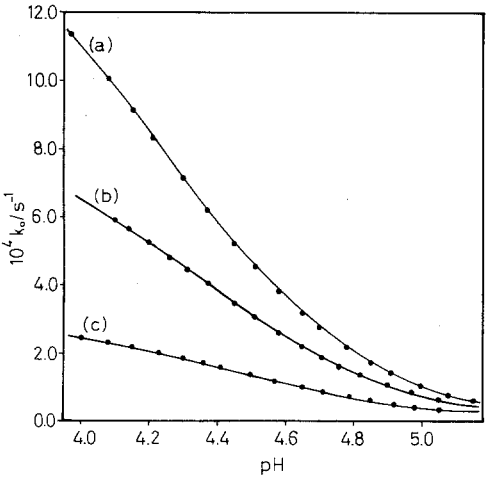


Fig. 4. Effect of pH on the first-order rate constant for the nitrosation of MAN at 25 °C, $\mu = 0.2\,M$, $[Buf] = 0.120\,M$ and $[MAN]/M$ = (*a*) $6.07 \cdot 10^{-3}$, (*b*) $3.03 \cdot 10^{-3}$, (*c*) $1.011 \cdot 10^{-3}$

The experimental rate equation found for this reaction, Eq. (3), shows that the rate determining step involves a molecule of each of the reactants nitrite, amine and acetate. The sum in the denominator implies that MAN reacts with an intermediate to which the steady-state approximation is applicable. This compound must be nitrosyl acetate formed by the reaction of the acetate ion with $H_2NO_2^+$ or NO^+ (which

are kinetically indistinguishable) in the same way as other nitrosyl compounds are formed from the corresponding ions[6,7]. On this basis, the following reaction mechanism is put forward (Scheme 1):

Scheme 1

$$
\begin{array}{rll}
PhNMeH_2^+ \rightleftharpoons PhNMeH + H^+ & K_1 & \left.\vphantom{\begin{array}{l}a\\b\\c\\d\end{array}}\right\} \\
HNO_2 \rightleftharpoons NO_2^- + H^+ & K_2 & \\
HNO_2 + H^+ \rightleftharpoons H_2NO_2^+ & K_3 & \\
AcOH \rightleftharpoons AcO^- + H^+ & K_4 & \left.\vphantom{\begin{array}{l}a\\b\\c\\d\end{array}}\right\} \text{fast} \\
H_2NO_2^+ + AcO^- \rightleftharpoons AcONO + H_2O & k_6,\ k_{-6} & \left.\vphantom{\begin{array}{l}a\\b\end{array}}\right\} \\
PhNMeH + AcONO \rightarrow PhNMeNO + AcOH & k_9 & \left.\vphantom{\begin{array}{l}a\\b\end{array}}\right\} \text{slow}
\end{array}
$$

According to this scheme, the rate of reaction will be given by

$$v = k_9 [PhNMeH] [AcONO] \tag{4}$$

The steady-state approximation may be applied to *Ac*ONO, whose concentration must be very low as it has not been detected spectrophotometrically in aqueous solution. Bearing this in mind, and also that $[Nit] = [HNO_2] + [NO_2^-]$ (the concentrations of $H_2NO_2^+$[8] and *Ac*ONO must be negligible with respect to that of nitrous acid), that $[Buf] = [AcOH] + [AcO^-]$, and that $[MAN] = [PhNMeH] + [PhNMeH_2^+]$, then Eq. (4) may be written

$$v = \frac{\alpha \dfrac{[Nit][H^+]^2}{K_2 + [H^+]} \cdot \dfrac{K_4 [Buf]}{K_4 + [H^+]} \cdot \dfrac{K_1 [MAN]}{K_1 + [H^+]}}{\beta + \dfrac{K_1 [MAN]}{K_1 + [H^+]}} \tag{5}$$

where $\alpha = K_3 k_6$ and $\beta = k_{-6}/k_9$. At constant pH this is of the same form as Eq. (3).

The values of the parameters that appear in Eq. (5) have been calculated by using *Marquardt*'s method of multidimensional optimization[9], which has been described in previous articles[4,10], to fit the equation to the results of the 113 experiments carried out. The weighting factor used was $w_i = 1/y_i^2$. The range of pH in which the reaction was studied did not allow the optimization of K_2, the acidity constant of nitrous acid, which was therefore fixed as $8.4 \cdot 10^{-4}\,M$, the value we had obtained in an earlier study[11] under the same conditions of temperature and ionic strength. The optimized values found for the other parameters are

$$\alpha = (1.66 \pm 0.08) \cdot 10^4\, M^{-2}\, s^{-1} \qquad K_1 = (1.6 \pm 0.2) \cdot 10^{-5}\, M$$
$$\beta = (1.91 \pm 0.17) \cdot 10^{-3}\, M \qquad K_4 = (2.02 \pm 0.16) \cdot 10^{-5}\, M$$

The standard deviation of the fit, as defined elsewhere[4], is 0.029.

The values obtained for the acidity constants of *MAN* and acetic acid, K_1 and K_4, agree reasonably well with the published values $K_1 = 1.41 \cdot 10^{-5} M$[12] and $K_4 = 3.06 \cdot 10^{-5} M$[13], which supports the proposed reaction mechanism. The value of the parameter α, which is the rate constant for the formation of nitrosyl acetate from nitrous acid, also agrees quite well with those obtained by other authors[1,3,14] or by ourselves when studying the nitrosation of morpholine[4] (where it was called k', see Table 1).

From the value found for β, $k_9/k_{-6} = 524$, i.e. N-methylaniline reacts with nitrosyl acetate at a specific rate some 500 times faster than that of the latter's hydrolysis. This figure is very close to that obtained[4] for the ratio of the rate constants of the reactions of *Ac*ONO with NO_2^- and H_2O. This means that the nitrite ion and *MAN* react with nitrosyl acetate at approximately the same rate, notwithstanding that only the reaction with *MAN* is observed in the present study, in which the concentration of NO_2^- is much smaller than that of the free amine.

The results presented above seem to show that nitrosyl acetate must be an effective nitrosating agent under conditions in which the concentration of nitrosatable substrate is at least as great as that of the nitrite ion and the reactivities of the two are comparable. In the second part of the present study we have found further support for this hypothesis by investigating the nitrosation of piperazine, whose pK_a of 5.55 allows the use of similar concentrations of the two substrates.

The Nitrosation of Piperazine in Acetate Buffer

In this case the complexity of the kinetic results did not fit any simple function, therefore their analysis by the integration method was impossible. The initial rate method was therefore employed, and the linearity of the absorbance-time data ensured by generally following no more than 1% of the reaction.

The influence of the concentration of nitrite on the rate of reaction was studied at various concentrations of buffer (Fig. 5). In the absence of buffer the reaction was found to have both first and second order terms with respect to nitrite:

$$v_0 = f[Nit]_0 + g[Nit]_0^2 \qquad (6)$$

As the concentration of buffer rose, however, the kinetic behaviour became more complex, though the overall order of the reaction remained between one and two.

Figs. 6 and 7 show the results of some of the series of experiments

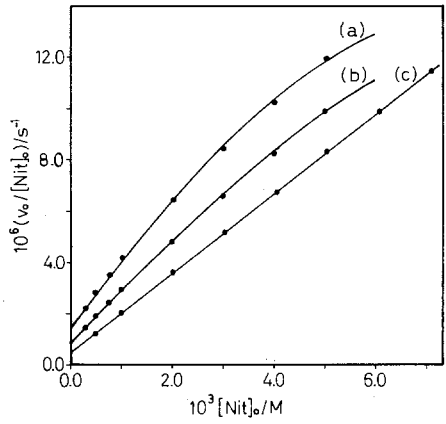


Fig. 5. Influence of the concentration of nitrite on the initial rate of nitrosation of *PIP* at 25 °C, $\mu = 0.2\,M$, $pH = 4.97$, $[PIP]_0 = 9.12 \cdot 10^{-3}\,M$ and $[Buf]/M =$ (*a*) $1.00 \cdot 10^{-2}$, (*b*) $4.26 \cdot 10^{-3}$, (*c*) 0.00

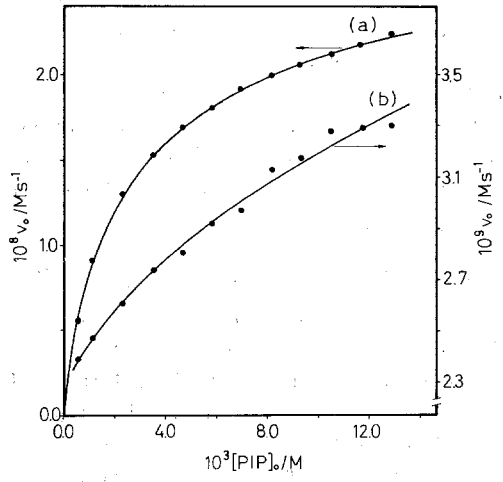


Fig. 6. Influence of the concentration of *PIP* on the initial rate of formation of *NPIP* at 25 °C, $\mu = 0.2\,M$, $[Nit]_0 = 1.09 \cdot 10^{-3}\,M$, $pH = 4.98$ and $[Buf]/M =$ (*a*) $8.50 \cdot 10^{-2}$, (*b*) $4.12 \cdot 10^{-3}$

undertaken to investigate the dependence of the initial rate of reaction on the concentration of piperazine at various concentrations of buffer and nitrite. The order of the reaction with respect to piperazine was found to be between zero and one, as for *MAN*, but in this case the data could not be linearized by plotting $[PIP]_0/v_0$ against $[PIP]_0$. It may be observed, however, that the order of the reaction with respect to

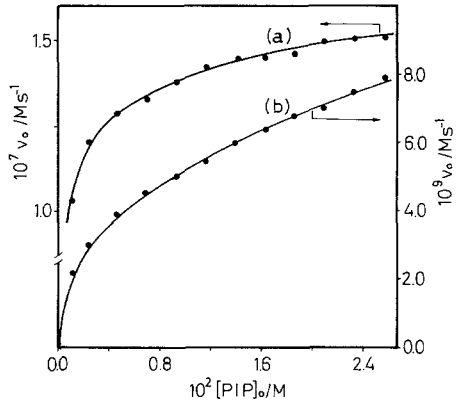


Fig. 7. Influence of the concentration of *PIP* on the initial rate of formation of *NPIP* at 25 °C, $\mu = 0.2\,M$, $[Buf] = 5.02 \cdot 10^{-2}\,M$, $pH = 4.96$ and $[Nit]_0/M =$ (*a*) $5.12 \cdot 10^{-3}$, (*b*) $5.46 \cdot 10^{-4}$

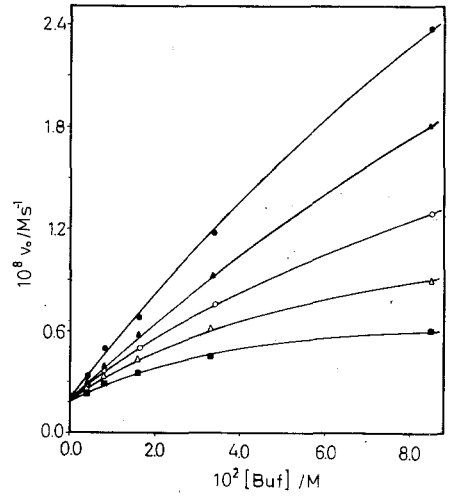


Fig. 8. Influence of the concentration of buffer on the initial rate of nitrosation of *PIP* at 25 °C, $\mu = 0.2\,M$, $pH = 4.98$, $[Nit]_0 = 1.09 \cdot 10^{-3}\,M$ and $[PIP]_0/M =$ (●) $1.29 \cdot 10^{-2}$, (▲) $5.84 \cdot 10^{-3}$, (○) $2.34 \cdot 10^{-3}$, (△) $1.17 \cdot 10^{-3}$, (■) $5.85 \cdot 10^{-4}$

piperazine approaches zero as the concentration of nitrite rises and the concentration of buffer falls.

At various concentrations of piperazine the rate of reaction was found to depend non-linearly on the concentration of buffer (Fig. 8). The lower the concentration of piperazine, the less linear was the behaviour observed.

To arrive at a possible mechanism for this reaction on the basis of the experimental results obtained and the conclusions of our studies of the nitrosation of *MAN* and morpholine[4], the following points should be kept in mind.

1. The fact that the order of the reaction with respect to piperazine is less than one shows that the rate limiting steps include not only the reactions of the nitrosating agents with the amine, but also the formation of the nitrosating agents themselves.

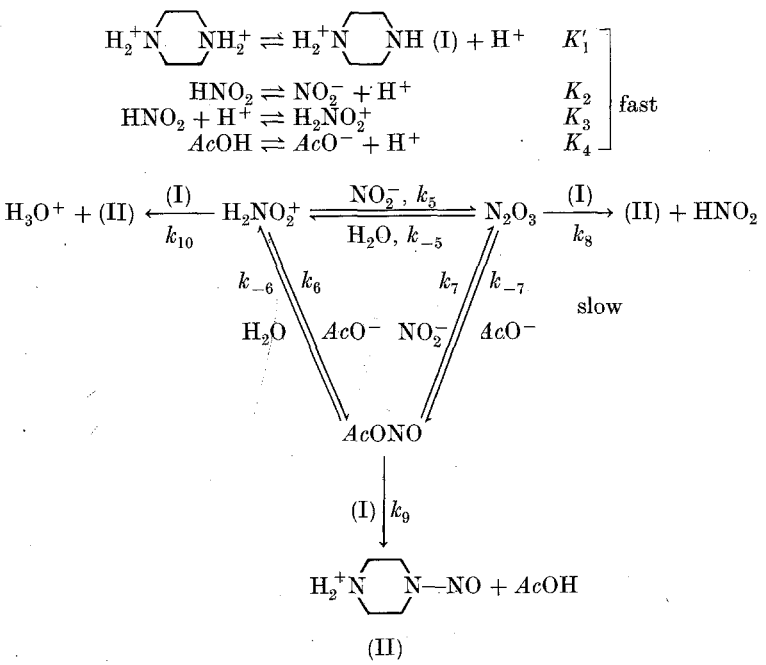
2. Since the concentrations of nitrite ion and free amine are comparable in the experimental conditions employed, both may be expected to react with nitrosyl acetate.

3. That Eq. (6) involves both first and second order terms with respect to nitrite means that both N_2O_3 and $H_2NO_2^+$ must act as nitrosating agents.

In accordance with these considerations, the following reaction mechanism is proposed (Scheme 2).

It should be pointed out that in the above scheme only one of the protonation equilibria of piperazine has been included, because the value of the other pK_a (9.72) means that under the working conditions

Scheme 2



used the concentration of unprotonated piperazine is smaller by several orders of magnitude than that of (I), which is therefore the form that reacts with the nitrosating agents.

The rate of reaction will be given by

$$v = (k_8[N_2O_3] + k_9[AcONO] + k_{10}[H_2NO_2^+])\ [I] \qquad (7)$$

However, the known values of k_{-7}, k_8 and k_{-5}[4, 15] imply that the rates of reaction of dinitrogen trioxide with the acetate ion and piperazine must be similar, and much faster than its rate of hydrolysis, so that

$$k_{-5} \ll k_8[I] + k_{-7}[AcO^-]$$

Moreover, the steady-state approximation may be applied to both $AcONO$ and N_2O_3. Eq. (7) may therefore be written

$$v = \eta[H^+]^2[NO_2^-][I] \cdot \left[\frac{\chi[AcO^-]}{A} + \frac{A[NO_2^-] + \chi\delta[NO_2^-][AcO^-]}{A[I] + \varepsilon[AcO^-](\gamma + [I])}\left(1 + \frac{\varepsilon[AcO^-]}{A}\right) + \Phi\right] \qquad (8)$$

where

$$\eta = K_3 k_5/K_2 \qquad \gamma = k_{-6}/k_9 \qquad \varepsilon = k_{-7}/k_8$$
$$\chi = k_6/k_5 \qquad \delta = k_7/k_9 \qquad \Phi = k_{10}/k_5$$

and $A = \gamma + \delta[NO_2^-] + [I]$.

The consistency of Eq. (8) with the experimental results has been checked by fitting it to the data obtained in the 188 experiments carried out, taking into account that in the experimental conditions employed $[NO_2^-] = [Nit]$, $[AcO^-] = [Buf]\,K_4/(K_4 + [H^+])$ and $[I] = [PIP]\,K_1'/(K_1' + [H^+])$. The published value $2.5 \cdot 10^{-6}\,M$[16] was used for K_1', and for K_4 the value obtained when studying the nitrosation of MAN under the same experimental conditions. Using the same multidimensional optimization algorithm as before, the values of the constants appearing in Eq. (8) were calculated as

$$\eta = (1.37 \pm 0.02) \cdot 10^7\,M^{-3}\,s^{-1} \qquad \delta = 6.9 \pm 0.7$$
$$\chi = 0.469 \pm 0.013 \qquad \varepsilon = (1.02 \pm 0.07) \cdot 10^{-2}$$
$$\gamma = (1.00 \pm 0.06) \cdot 10^{-2}\,M \qquad \Phi = 0.164 \pm 0.010$$

The standard deviation of the fit, as defined elsewhere[4], is 0.041, showing that the data agree well with the function calculated. Moreover, no systematic discrepancy between the experimental and calculated values was detected. Further support for the proposed mechanism is provided by the agreement (Table 1) between the values calculated in

Table 1. *Values of the rate constants and ratios between constants obtained in studies of the nitrosation of morpholine*[4], *N-methylaniline and piperazine at 25 °C*

Rate constant[a]	Morpholine	N-Methylaniline	Piperazine
$k/M^{-1}s^{-1}$	17.4	—	9.67
$10^{-4}k'/M^{-2}s^{-1}$	0.88	1.66	0.54
$10^{-3}K_3k_{10}/M^{-2}s^{-1}$	—	—	1.89
$10^{-8}k_8/M^{-1}s^{-1}$	2.2	—	1.08
$10^{-3}k_{-5}/s^{-1}$	5.7	—	3.3
$10^{-6}k_{-7}/M^{-1}s^{-1}$	1.5	—	1.1
k_6/k_5	0.54	—	0.47
$(10^{-2}k_7/k_{-6})/M^{-1}$	4.9	—	6.9
$(10^{-2}k_9/k_{-6})/M^{-1}$	—	5.2	1.00

[a] The constants k and k' are the rate constants for the formation of N_2O_3 and $AcONO$ respectively, $k = K_2K_3k_5$ and $k' = K_3k_6$.

the present and previous studies for those parameters which appear both in Eq. (8) and in the nitrosation of morpholine and MAN (in calculating some of these constants the published value $3.03 \cdot 10^{-3}M$[17] has been used for the equilibrium constant for the formation of N_2O_3, $K_{N_2O_3} = K_2K_3K_5$).

The values shown in Table 1 imply that the nitrite ion, N-methylaniline and piperazine all react at approximately the same rate with nitrosyl acetate, and on the basis of the data published by *Stedman*[3] for the azide-nitrite reaction we have deduced[18] that N_3^- also reacts at roughly the same rate as NO_2^-. Moreover, analysis of the experimental conditions used in our earlier study of the nitrosation of morpholine shows that the rate constant for the reaction between morpholine and nitrosyl acetate must be at most of the same order of magnitude as that for the nitrosyl acetate-nitrite ion reaction, for if it were greater the reaction with morpholine would have been observed experimentally, which was not the case. It appears therefore that the rate constants for the reaction of $AcONO$ with substrates whose pK_a cover a range of almost three units [$pK_a(HNO_2) = 3.08$, $pK_a(PIP) = 5.55$] are all comparable, and are no greater even for compounds of considerably greater pK_a such as morpholine ($pK_a = 8.7$). This invariance of the rate constants for reactions with substrates of very different nucleophilicities seems to show that the factors controlling the rate of attack by $AcONO$ must be physical rather than chemical, as has already been found for various nitrosating agents[15,19]. If the reactions of nitrosyl acetate with the substrates studied here are accepted as being diffusion controlled, the equilibrium constant for the formation of nitrosyl acetate may be

estimated by taking for k_7 or k_9 the value of the specific rate of encounter at 25 °C, $7.4 \cdot 10^9\, M^{-1}\, s^{-1}$ [19]; then the values shown in Table 1 imply for the hydrolysis of nitrosyl acetate

$$k_{-6} \simeq 1.5 \cdot 10^7\, s^{-1},$$

so that

$$K = K_3 K_4 K_6 = k' K_4 / k_{-6} \simeq 1.4 \cdot 10^{-8}\, M^{-1}$$

K being the equilibrium constant of the reaction

$$AcOH + HNO_2 \rightleftharpoons AcONO + H_2O$$

This estimate for K means that the concentration of nitrosyl acetate present in the medium must be extremely small, which explains the virtual impossibility of detecting it in aqueous solution except by kinetic methods of analysis.

The mechanism shown in Scheme 2, and the values of the kinetic constants involved (Table 1), allow a unified interpretation of the results we have obtained in our studies of the nitrosation of morpholine[4], N-methylaniline, and piperazine if the differences between the experimental conditions employed in each case are taken into account. Thus the concentrations of free amine used to study the nitrosation of morpholine were some 1 000 times lower than those of the acetate and nitrite ions, so that the reactions of NO^+ and $AcONO$ with the amine were undetectable. In the study of the nitrosation of N-methylaniline, on the other hand, the concentration of nitrite ion used was of the order of 100 times smaller than those of the free amine or acetate ion, and it was accordingly the reactions of $H_2NO_2^+$ and $AcONO$ with NO_2^- that were not observed. Moreover, since the concentration of AcO^- was twenty times greater than that of the free amine, nitrosation was only observed to be effected by $AcONO$. The mechanism we propose also explains the results obtained by other authors for the diazotization of aniline and the reactions of nitrous acid with hydroxylamine and azide ions[1—3,18]. In all these cases the observed kinetic behaviour may be said to depend fundamentally on the relationship between the concentrations of nitrite ion, acetate ion and nitrosatable substrate.

Acknowledgement

One of the authors (*J. C.*) whishes to thank the Spanish Comisión Asesora de Investigación Científica y Técnica for subsidising the research reported in this article as part of an investigation into the mechanism of formation of carcinogenic N-nitroso compounds.

References

[1] *Döring C., Gehlen H.*, Z. anorg. allg. Chem. **312**, 32 (1961).
[2] *Hughes E. D., Ridd J. H.*, J. Chem. Soc. **1958**, 70.
[3] *Stedman G.*, J. Chem. Soc. **1960**, 1702.
[4] *Casado J., Castro A., López Quintela M. A., Mosquera M., Rodríguez Prieto M. F.*, Monatsh. Chem. **114**, 647 (1983).
[5] *Casado J., Mosquera M., Rivas A., Rodríguez Prieto M. F., Santaballa J. A.*, Computers & Chemistry **7**, 209 (1983).
[6] *Schmid H., Maschka A.*, Z. Phys. Chem. **49**, 171 (1941).
[7] *Stedman G., Whincup P. A. E.*, J. Chem. Soc. **1963**, 5796.
[8] *Bayliss N. S., Dingle R., Watts D. W., Wilkie R. J.*, Aust. J. Chem. **16**, 933 (1963).
[9] *Adby P. R., Dempster M. A. H.*, Introduction to Optimization Methods. London: Chapman and Hall. 1974.
[10] *Casado J., Castro A., López Quintela M. A.*, Monatsh. Chem. **112**, 1221 (1981).
[11] *Casado J., Castro A., Mosquera M., Rodríguez Prieto M. F., Vázquez Tato J.*, Ber. Bunsenges. Phys. Chem. **87**, 1211 (1983).
[12] *Robert C. W.*, ed., Handbook of Chemistry and Physics. Florida: CRC Press. 1980.
[13] *Kilpi S., Lindell E.*, Ann. Acad. Sci. Fennicae AII, **136**, 3 (1967).
[14] *Bunton C. A., Masui M.*, J. Chem. Soc. **1960**, 304.
[15] *Casado J., Castro A., López Quintela M. A., Leis J. R., Mosquera M.*, Monatsh. Chem. **114**, 639 (1983).
[16] *Christensen J. J., Izatt R. M., Wrathall D. P., Hansen L. D.*, J. Chem. Soc. (A) **1969**, 1212.
[17] *Markovits G. Y., Schwartz S. E., Newman L.*, Inorg. Chem. **20**, 445 (1981).
[18] *Casado J., Castro A., López Quintela M. A., Mosquera M., Rodríguez Prieto M. F.*, Acta Cient. Comp. **19**, 93 (1982).
[19] *Ridd J. H.*, Adv. Phys. Org. Chem. **16**, 1 (1978).