Mononuclear Heterocyclic Rearrangements. Effect of the Structure of the Side Chain on the Reactivity. Part 2.[1] Rearrangement of Some *N*-(5-Phenyl-1,2,4-oxadiazol-3-yl)-*N'*-arylformamidines into 1-Aryl-3-benzoylamino-1,2,4-triazoles in Dioxane–Water at Various pS^+

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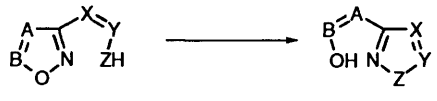
In the framework of studies concerning the effect of the structure of the side chain on the mechanism and the reactivity in mononuclear heterocyclic rearrangements, the reactivity of some *N*-(5-phenyl-1,2,4-oxadiazol-3-yl)-*N'*-arylformamidines **3** in dioxane–water in the pS^+-range 6.0–15.0 was studied and compared with that of arylhydrazones of 3-benzoyl-5-phenyl-1,2,4-oxadiazole **7** and of 3-arylureido-5-phenyl-1,2,4-oxadiazoles **5**. A plot of the logarithms of the rate constants *versus* pS^+ showed the occurrence of an uncatalysed (pS^+-independent) and of a catalysed (pS^+-dependent and then pS^+-independent) range. Kinetic data pointed out that the base catalysis is specific, in accord with the relatively high acidity of the formamidines used. The substituent effects on the reactivity were compared with those observed in other mononuclear heterocyclic rearrangements.

The synthesis of heterocyclic compounds continues to attract the interest of organic chemists, because of the relevance of heterocyclic derivatives such as pharmaceuticals, herbicides, and so forth[2] and as synthons especially as masked functionalities.[3] In this respect, a lot of interest has been addressed to reactivity studies of heterocycles containing side chains which could participate in a rearrangement reaction.[4] For a long time our research group has been active in the field of synthetic[5] and mechanistic[6] studies of heterocyclic rearrangements with particular regard to azole⟶azole interconversions (**1** ⟶ **2**, see Scheme 1) involving a side chain where the

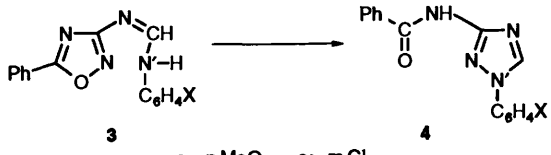


1 **2**

A,B = C or N
XYZ = CCN, CCO, CNN, CNO, NCC, NCN, NCO, NCS, NNN

reactive centre (usually a nucelophilic centre) is bound to the heterocyclic ring through a continuous system of conjugated electrons. Many mechanistic aspects of these reactions, named mononuclear heterocyclic rearrangements (MHRs),[4a] were examined and the relevance of the structure of the starting heterocycle and of the side chain as well as of the reaction conditions (reaction temperature, nature of the solvent and of the base used, and so on) as factors which make possible the reaction and determine the reactivity, was pointed out.[1,6]

Continuing our investigation of the mechanism of MHRs we addressed our attention to the effect of the structure of the side chain on the reactivity. In this respect we measured the rate constants for the rearrangement of some *N*-(5-phenyl-1,2,4-oxadiazol-3-yl)-*N'*-arylformamidines **3a–g** into 1-aryl-3-benzoylamino-1,2,4-triazoles **4a–g** in dioxane–water (DIOX–W) at various pS^+ (borate and citrate buffers; Tables A–H of

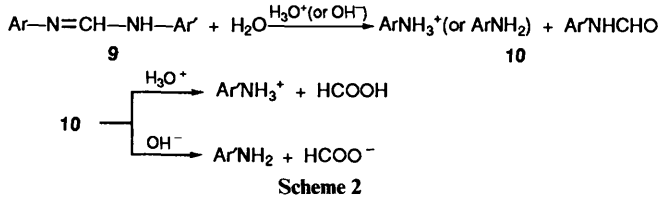


3 **4**

a; *p*-MeO **e**; *m*-Cl
b; *p*-Me **f**; *m*-NO_2
c; H **g**; *p*-NO_2
d; *p*-Cl

the Supplementary Publication).† The results obtained studying this rearrangement (**3** ⟶ **4**; NCN side chain: –N=CH–NH–Ar) can be compared with those previously obtained by studying the rearrangement of some (3-arylureido)-5-phenyl-1,2,4-oxadiazoles (**5** ⟶ **6**; NCN side chain: –NH–CO–NH–Ar)[1] and of some arylhydrazones of 3-benzoyl-5-phenyl-1,2,4-oxadiazole (**7** ⟶ **8**; CNN side chain: >C=N–NHAr).[6a–e]

It was known that *N*,*N'*-diarylformamidines **9** in the presence of both acids and bases could be hydrolysed to anilines and formanilides **10**, which in turn underwent a further hydrolysis to anilines and formic acid (Scheme 2).[8]



Scheme 2

On the other hand it was reported that **3b**, **c**, **g** rearranged into **4b**, **c**, **g** by melting as well as by treatment in ethanol with sodium hydroxide at room temperature.[9],‡

Under the experimental conditions used [DIOX–W (50:50 v/v)] we observed a clean rearrangement of **3a–g** into **4a–g** at p$S^+ \geq 6$; in contrast, at p$S^+ < 6$ the hydrolysis reaction became a more and more important competitive reaction (see the general behaviour of *N*,*N'*-diarylformamidines indicated in Scheme 2). Therefore the rearrangement of **3a–g** was studied in the pS^+ range 6–15.

† An operational pH scale, pS^+,[6a,c] was established in aqueous dioxane by employing the pK_a values of acids determined by interpolation from the data reported by Harned and Owen.[7] For Diox–W (1:1, v/v), the meter reading after calibration against buffers was not significantly different from pS^+; it was only necessary to apply a correction of +0.16 to the meter reading.

‡ The similar base- or heat-induced rearrangement of some *N*-(5-methylisoxazol-3-yl)-*N'*-arylformamidines into 1-aryl-3-acetonyl-1,2,4-triazoles was studies by Kano and Yamazaki.[10]

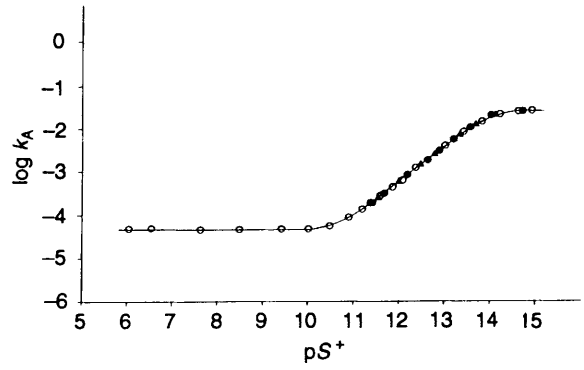
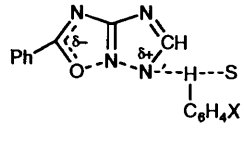


Fig. 1 Plot of log $(k_A)_{3c}$ in dioxane–water at 313.15 K *versus* pS^+ at different total borate concentrations: ○ [borate] 0.0125 mol dm^{-3}; ▲ [borate] 0.025 mol dm^{-3}; ● [borate] 0.050 mol dm^{-3}

Results and Discussion

Rearrangement of N-(5-*Phenyl*-1,2,4-*oxadiazol*-3-*yl*)-N′-*phenylformamidine* **3c** *in DIOX–W* (50:50 v/v) *in the Presence of Buffers.*—The experimental apparent pseudo-first-order rate constants (k)* for the title reaction have been measured (see Table C of the Supplementary Publication) in the temperature range 283.15–333.95 K in the pS^+ range 6.05–14.95 ([buffer] 0.0125 mol dm^{-3}, ionic strength 0.05 mol dm^{-3}). Calculated apparent pseudo-first-order rate constants (k_A) have been obtained from the activation parameters. Log k_A values (at 313.15 K) have been plotted in Fig. 1 (open circles) *versus* pS^+. A very large pS^+ range could be explored: on account of the relatively high reactivity in the pS^+-independent range, the rearrangement could be also studied at low pS^+ values (pS^+ range 6–10, but not at pS^+ < 6, because of the competitive hydrolysis reaction); on the other hand, due to the relatively low reactivity in the pS^+-independent catalysed range, the rearrangement could be studied at high pS^+ values (pS^+ range 14.3–15.0). The two pS^+-independent ranges [uncatalysed and catalysed: $(k_A)_{pS^+=15}/(k_A)_{pS^+=6}$ *ca.* 500] are separated by a pS^+-dependent range (pS^+ 10.0–14.2).

The kinetic results obtained allow the following comments to be made. At low pS^+ values the reactivity is not affected by the concentrations of the present acids or bases (*i.e.*, $k_A = k_u$) and the rearrangement occurs because of the high nucleophilicity of the N′ atom of the side chain; therefore, the corresponding transition state **11** can be depicted as below. As the base concentration increases (pS^+ > 10) a new reaction pathway becomes important because of the acidity of the hydrogen bonded to *N′* which makes operative a base-catalysed re-



S = solvent

11

$$AFH \xrightarrow{k_u} \text{products}$$

$$AFH + OH^- \underset{\text{(fast)}}{\overset{K_1}{\rightleftharpoons}} AF^- + H_2O$$

$$AF^- \xrightarrow[\text{(slow)}]{k_2} \text{products}$$

Scheme 3

arrangement. At very high pS^+ values (pS^+ > 14.3) a limiting rate constant was observed.

At any pS^+ value, the occurrence of the rearrangement (a S_Ni reaction)[6] is possible on account of: (*i*) the high nucleophilicity of N′ [at high pS^+ (> 10) enhanced by the conversion of the arylformamidine to its conjugated base (see Scheme 3)]; (*ii*) the weakness of the O_1–N_2 bond in the starting 1,2,4-oxadiazole ring, which has a low aromatic character; (*iii*) the presence of the electrophilic N_2 and the high nucleofugality of the leaving group (ABO = NCO) able to carry the incipient negative charge; and (*iv*) at low pS^+, the ability of the used solvent to favour the breaking of the N′–H bond.

As we pointed out by studying the rearrangement of some 3-arylureido-5-phenyl-1,2,4-oxadiazoles **5**,[1] the limiting rate constant observed is consistent with a reaction mechanism involving a specific base catalysis. Thus, in the presence of hydroxide ion, the high acidity of the hydrogen atom (N′–*H*) of **3c** causes a fast conversion of the substrate into its conjugated base followed by a slow rearrangement of the resulting anion: with reference to Scheme 3 (AFH represents the arylformamidine containing an acidic hydrogen atom),† this is expressed by eqn. (1).

$$k_A = (k_u + K_1k_2[OH^-])/(1 + K_1[OH^-]) \quad (1)$$

When $K_1[OH^-] \ll 1$, then

$$k_A = k_u + K_1k_2[OH^-] \quad (2)$$

and the reaction responds linearly to base catalysis; when $K_1[OH^-] \gg 1$ and since $k_u \ll k_2$, the reaction becomes insensitive to base catalysis and a plateau value is obtained [see

$$k_A = k_2 \quad (3)$$

eqn. (3)]. When neither approximation can be made k_A varies with [OH^-] in a curvilinear fashion.

Due to the high range of hydroxide ion concentrations spanned and the dominance of kinetic constants obtained at high pS^+ values, the regression parameters (k_u, k_2 and K_1) obtained by fitting our kinetic data to eqn. (1) by a least-squares method yielded, at low pS^+, calculated k_A values rather different from the experimental ones.

For this reason we used an alternative calculation method. Rearranging eqn. (1) gave eqn. (4).

$$(k_A - k_u)/(k_2 - k_A) = K_1(OH^-] \quad (4)$$

By giving k_2 trial values and by using an iterative calculation program, we obtained for k_2 and K_1 the 'best' values reported in Table 1, which correspond both to the best least-squares correlation and the minimum intercept [the straight line of eqn. (4) must cross the origin of axes].

Some K_1 and k_2 values obtained for the rearrangement of **3c** are shown in Table 1, where the corresponding quantities for the other substituted arylformamidines (**3a**, **b**, **d**–**g**) are also collected.

* k and k_A are, respectively, the experimental and the calculated apparent pseudo-first-order rate constants; k_u and k_2 (see Scheme 3) refer, respectively, to the uncatalysed and to the base-catalysed reaction pathways; K_1 is the equilibrium constant.

† The formation of the conjugate base of **3c** is consistent with the fact that the kinetic course of the alkaline hydrolysis of some *N*,*N*′-diarylformamidines was interpreted by taking into account their partial conversion into the corresponding conjugated bases.[8c] Moreover we observed that DIOX–W solutions of *N*-(5-phenyl-1,2,4-oxadiazol-3-yl)-*N*′-*p*-nitrophenylformamidine **3g** turned into a deep yellow colour by addition of bases.

Table 1 Equilibrium constants, K_1, catalysed rearrangement kinetic constants, k_2, and apparent pseudo-first-order kinetic constants, k_A, calculated at 313.15 K at some selected pS^+ values

Compd.	$10^4 k_A/s^{-1}$ [a]		$10^4 k_2/s^{-1}$ [b]	$K_1/dm^3 mol^{-1}$ [b]
	pS^+ 7.00	pS^+ 12.00		
3a	0.673	4.29	263	34.0
3b	0.567	4.38	272	37.4
3c	0.482	5.68	288	51.5
3d	0.421	14.4	394	103
3e	0.371	17.1	486	95.7
3f	0.284	46.8	634	245
3g	0.262	172	1070	649

[a] Values calculated from activation parameters. [b] Values calculated from eqn. (4).

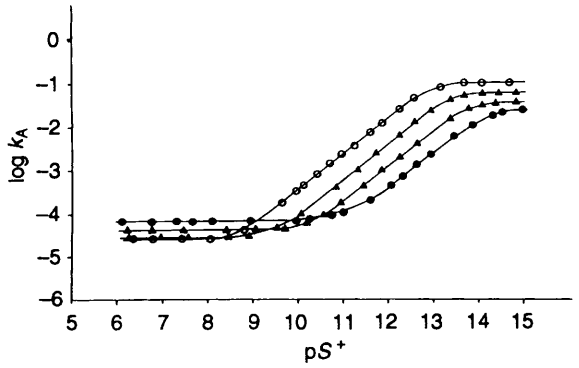


Fig. 2 Representative plot of log (k_A) [● (**3a**); △ (**3d**); ▲ (**3f**); ○ (**3g**)] in dioxane–water at 313.15 K *versus* pS^+ at total borate buffer concentration 0.0125 mol dm^{-3}

The nature of the catalysis (specific or general) appears clear from the examination of the rate profile (Fig. 1, open circles) and of the calculated K_1 and k_2 values (large and low, respectively: K_1/k_2 1.8 × 10^3), but we confirmed the occurrence of a specific catalysis by studying the rearrangement at two more buffer concentrations (0.0250 and 0.0500 mol dm^{-3} and at ionic strength 0.05 mol dm^{-3}, in Fig. 1 full triangles and circles, respectively; data in Table H of the Supplementary Publication). An inspection of the plot in Fig. 1 showed that the kinetic data calculated at different (higher) buffer concentrations fell on the curve obtained from the data collected at [buffer] 0.0125 mol dm^{-3}, so confirming that the catalysis is specific.

Effects of the Substituents Present in the Formamidine Moiety on the Rearrangement Reaction Rates.—The effect of the substituents on the course of the rearrangement was studied by examining a significant set of substituted *N'*-arylformamidines **3a–g**, containing both electron-donating and -withdrawing substituents. The experimental apparent pseudo-first-order rate constants (see Tables A–G of the Supplementary Publication) were used to calculate the apparent pseudo-first-order rate constants at 313.15 K (Table 1), as indicated above. Some representative kinetic data for the rearrangement are plotted in Fig. 2 *versus* pS^+.

As we have seen an examination of kinetic data for **3c** showed that in the uncatalysed pS^+-independent range the nucleophilic attack of the neutral N'-atom of the side chain on the N_2-atom of the 1,2,4-oxadiazole ring leads to the transition state **11**. Other things being equal electron-donating and -withdrawing substituents present in the formamidino moiety increase and decrease, respectively, the nucleophilicity of N' and at the same time affect the strength of the N'-*H* bond in an opposite way. Therefore the global effect arises from a balancing between the two opposite effects that every substituent can exert: so a low susceptibility constant for the linear free energy relationship (LFER) can be expected and its sign would indicate which is the prevailing effect. Only a little increase of the reactivity is observed on going from **3g** (substituent: *p*-nitro) to **3a** (substituent: *p*-methoxy) [at pS^+ 7.0, $(k_A)_{3g}/(k_A)_{3a}$ 0.4 at 313.15 K]. This fact indicates that the more important factor is the nucleophilicity of N'.

A Hammett plot of rate constants at pS^+ 7.0 *versus* substituent constants[11] (σ_m and σ_p) gave a good correlation with a *small negative* susceptibility constant (ρ −0.37 (±0.02), *i* 0.02 (±0.01), *n* 7, *r* 0.995].

Looking at Fig. 2 one can observe that there is a crossing of the rate profiles and at high pS^+ (*e.g.*, at pS^+ 12.0) the effect of the substituents is inverted with respect to the situation observed in the uncatalysed pS^+-independent range (*e.g.*, at pS^+ 7.0). The curves in Fig. 2 show that at pS^+ 12.0 the substituents have a large effect [$(k_A)_{3g}/(k_A)_{3a}$ 40], whereas at higher pS^+ values (*ca.* 15.0) a lower effect in the same direction is observed [$(k_2)_{3g}/(k_2)_{3a}$ 4.1]. These results indicate that the factors which determine the values of the rate constants are the acidity of the proton in the N'-H bond and the stabilization of the conjugated base by the electron-withdrawing substituents.

Thus at pS^+ 12.0 a *positive* susceptibility constant for the Hammett relationship *higher* than that concerning k_2 values was calculated [1.39 (±0.18) and 0.53 (±0.07), respectively], even though with poor statistical results (*n* 7, *r* 0.959 and 0.957, respectively). The results of the LFERs were largely improved by using σ^n substituent constants[12] for all the substituents but the *p*-nitro group (the only group which is electron-withdrawing by through-resonance) for which a σ_p^- constant[11] appeared to be required. The LFERs obtained were as follows.

at pS^+ 12.00	ρ 1.19 ± 0.03, *i* 0.02 ± 0.02, *n* 7, *r* 0.998
for k_2 values	ρ 0.45 ± 0.02, *i* 0.02 ± 0.01, *n* 7, *r* 0.995

An excellent LFER was also obtained for K_1 values (ρ 0.92 ± 0.05, *i* −0.03 ± 0.03, *n* 7, *r* 0.994) by using substituent constants as above. The correlation at pS^+ 12.0 is a function of both k_2 and K_1 values [see eqn. (2); the contribution of k_u can be neglected]. The susceptibility constants calculated for k_2 and K_1 values and for the rearrangement kinetic constants at pS^+ 12.0 agree with the observation deriving from eqn. (2) that in the pS^+-dependent range an equation like (5) should be followed.

$$(\rho)_{k_A} \simeq (\rho)_{K_1} + (\rho)_{k_2} \quad (5)$$

Because the susceptibility constants referring to both K_1 and k_2 values are *positive*, the susceptibility constant for the base catalysed range is *higher* in the pS^+-dependent range than in the pS^+-independent range. All the susceptibility constants calculated agree with the proposed mechanism. As already pointed out a higher effect of the substituents is expected[1] for the equilibrium reaction (ρ 0.92) than for the rearrangement step (ρ 0.45).

No LFER could be observed in the pS^+ range 8.0–11.0 and 13.0–14.5: in fact, the rate profiles showed that there is a substituent dependence in the change of mechanism (from uncatalysed to catalysed and then from the pS^+-dependent to the pS^+-independent catalysed mechanism), which takes place at a different pS^+ for each substituted formamidine. Thus we observed that for **3a** (which contains a strong electron-donating substituent) the uncatalysed pS^+-independent range extended to higher pS^+ than for **3g** (which contains a strong electron-withdrawing substituent); in contrast, the catalysed pS^+-

Table 2 Physical data of compounds **3** and **4**

Compd.	M.p./°C	UV λ_{max}/nm	UV log ε	IR (Nujol)/cm^{-1} $\nu_{C=N}$	IR (Nujol)/cm^{-1} ν_{CO}
3a	*a*	282	4.46	1665	
3b[b]	*a*	278	4.48	1655	
3c[b]	142–144	275	4.47	1662	
3d	*a*	280	4.51	1670	
3e	*a*	278	4.50	1665	
3f	*a*	278	4.50	1665	
3g[b]	*a*	340	4.40	1651	
4a	182–184[c]	264	4.22		1648
4b[b]	212–213[c]	260	4.29		1690
4c[b]	172–173[c]	250	4.38		1695
4d	246–248[c]	264	4.36		1645
4e	170–172[c]	262	4.28		1705
4f	210–211[c]	260	4.42		1635
4g[b]	274–276[c]	314	4.16		1648

[a] There is no m.p. because of rearrangement on heating; apparent m.p.s coincide with those of related compounds **4**.[5] [b] See also ref. 9. [c] From ethanol.

independent range was reached at lower pS^+ for **3g** than for **3a**.

Conclusions

The rearrangement in DIOX–W of *N*-(5-phenyl-1,2,4-oxadiazol-3-yl)*N'*-arylformamidines **3** gave at p$S^+ \geqslant 6$ the corresponding 1-aryl-3-benzoylamino-1,2,3-triazoles **4** (the hydrolysis reaction became competitive only at p$S^+ < 6$). In the large pS^+-range explored (pS^+ 6.0–15.0) firstly an uncatalysed (pS^+-independent) and then a catalysed range (pS^+-dependent and then pS^+-independent) were observed.

The reaction mechanism observed for **3a–g** in the first range was quite similar to that observed for some arylhydrazones of 3-benzoyl-5-phenyl-1,2,4-oxadiazole **7**:[6a,b] compounds **3a–g** rearranged faster than the corresponding compounds **7** [$(k_A)_3/(k_A)_7$ 35–320 as a function of the substituent], the rate ratios increasing with the electron-withdrawing effect of the substituents. This effect seems to indicate that the nucleophilicity of the nitrogen atom of arylformamidines is less affected by the electron-attracting substituents than that of arylhydrazones **7**. Thus for compounds **3** a lower susceptibility constant (ρ −0.37) is observed than for compounds **7** (ρ −1.31),[6b] and this fact agrees with the high ability to give internal conjugation that characterizes the arylformamidines (–N=CH–NH–Ar ⟷ $^-$N–CH=$^+$NH–Ar) and makes them only slightly susceptible to the effects of the substituent in the aryl moiety.

In contrast, in the catalysed range the reaction mechanism is strictly similar to that observed for some 3-arylureido-5-phenyl-1,2,4-oxadiazole **5**,[1] and completely different from that observed for some arylhydrazones of 3-benzoyl-5-phenyl-1,2,4-oxadiazole **7**.[6c,d] In fact a specific, not a general, catalysis is observed, and at high pS^+ values limit rate constants were found. This behaviour is strictly dependent on the high acidity of the hydrogen atom bonded to N' in arylureido derivatives **5**[1] and arylformamidines **3**, which in both cases causes at high pS^+ a fast conversion of the substrates in their conjugated bases which then slowly rearrange to **6** and **4**, respectively.

In the previously studied arylhydrazones of 3-benzoyl-5-phenyl-1,2,4-oxadiazole **7**[6] the low acidity of the hydrogen atom bonded to N' makes very low the concentration of the conjugated base and therefore the reaction rates depend on the concentration of each present base (general base catalysis).[6c]

Experimental

M.p.s were determined by a Kofler hot-stage apparatus. IR spectra were determined by a Perkin-Elmer 1310 instrument; UV spectra were recorded by a Beckman DU 6 spectrophotometer. pS^+ Measurements were made by a Radiometer PHM 82 digital pH-meter. Variation of pS^+ values before and after each run in buffered solutions of reaction were lower than 0.03 units. The mean value of pS^+ was used for calculations.

Synthesis and Purification of Compounds.—**3b**, **c**, **g** and **4b**, **c**, **g**[9] and dioxane[13] were synthesised and/or purified according to literature methods.

Compounds **3a**, **d–f** were synthesised[9] from 3-ethoxyformylamino-5-phenyl-1,2,4-oxadiazole and the appropriate aniline and then rearranged to **4a**, **d–f** according to the literature method.[9] All new compounds gave satisfactory elemental analytical data. Physical data are reported in Table 2.

As for other arylformamidines, the existence of geometric and/or tautomeric forms should be expected.[14,15] However we will consider this matter elsewhere.

Kinetic Measurements.—The kinetics (at ionic strength 0.05 mol dm^{-3}, KCl) were followed spectrophotometrically by measuring the disappearance of **3a–g**. The wavelengths and log ε values (ε_s and ε_p for substrates and rearrangement products, respectively) used for spectrophotometric determinations of kinetic constants are reported in Tables A–H of the Supplementary Publication, No. 56946 (8 pp),* together with the rate constants and the activation parameters calculated at each pS^+ value.

The values of hydroxide ion concentration were calculated by using 15.80 as the pK_w value in dioxane–water (1:1, v/v)[16] and 0.545 as the mean activity coefficient.[7]

Acknowledgements

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* For details of the Supplementary Publication Scheme see 'Instructions for Authors (1993)', *J. Chem. Soc., Perkin Trans. 2*, 1993, Issue 1.

References

1 Part 1, V. Frenna, D. Spinelli and G. Consiglio, *J. Chem. Soc., Perkin Trans. 2*, 1990, 1289.
2 *Nitroimidazoles, Chemistry, Pharmacology and Clinical Application*, eds. A. Breccia, B. Cavalleri and G. E. Adams, Plenum Press, London and New York, 1982; E. W. Flick, *Cosmetic and Toiletry Formulations*, Noyes Publications, Park Ridge, 1989; *QSAR in Drug Design and Toxicology*, eds. D. Hadzi and B. Jerman-Blazic, Elsevier, Amsterdam, 1987.
3 A. Dondoni and P. Marino, *J. Org. Chem.*, 1991, **56**, 5294; D. P. Curran and T. A. Heffner, *J. Org. Chem.*, 1990, **55**, 4585; S. I. Danishefsky and M. P. De Ninno, *Angew. Chem., Int. Ed. Engl.*, 1987, **26**, 15.
4 (*a*) M. Ruccia, N. Vivona and D. Spinelli, *Adv. Heterocycl. Chem.*, 1981, **29**, 141; (*b*) A. J. Boulton, A. R. Katritzky and A. M. Hamid, *J. Chem. Soc. C*, 1967, 2005; A. S. Afridi, A. R. Katritzky and C. A. Ramsden, *J. Chem. Soc., Perkin Trans. 1*, 1976, 315; A. J. Boulton, *Lectures in Heterocyclic Chemistry*, Hetero Corporation, Provo, 1973.
5 S. Buscemi and N. Vivona, *J. Chem. Soc., Perkin Trans. 2*, 1991, 187; S. Buscemi, V. Frenna and N. Vivona, *Heterocycles*, 1991, **32**, 1765.
6 (*a*) D. Spinelli, A. Corrao, V. Frenna, N. Vivona, M. Ruccia and G. Cusmano, *J. Heterocycl. Chem.*, 1976, **13**, 357; (*b*) D. Spinelli, V. Frenna, A. Corrao and N. Vivona, *J. Chem. Soc., Perkin Trans. 2*, 1978, 19; (*c*) V. Frenna, N. Vivona, G. Consiglio, A. Corrao and D. Spinelli, *J. Chem. Soc., Perkin Trans. 2*, 1981, 1325; (*d*) V. Frenna, N. Vivona, A. Corrao, G. Consiglio and D. Spinelli, *J. Chem. Res.*, 1981, (*S*) 308, (*M*) 3550; (*e*) V. Frenna, N. Vivona, L. Cannella, G. Consiglio and D. Spinelli, *J. Chem. Soc., Perkin Trans. 2*, 1986, 1183

and references therein; (*f*) V. Frenna, S. Buscemi and C. Arnone, *J. Chem. Soc., Perkin Trans. 2*, 1988, 1683 and references therein; (*g*) N. Vivona, G. Cusmano, M. Ruccia and D. Spinelli, *J. Heterocycl. Chem.*, 1975, **12**, 985.
7 H. S. Harned and B. B. Owen, *The Physical Chemistry of Electrolytic Solution*, ACS Monograph No. 137, 3rd edn., Reinhold, New York, 1958, pp. 716 and 755.
8 (*a*) R. H. De Wolfe and R. M. Roberts, *J. Am. Chem. Soc.*, 1953, **75**, 2942; (*b*) R. H. De Wolfe, *J. Am. Chem. Soc.*, 1960, **82**, 1585; (*c*) R. H. De Wolfe, *J. Am. Chem. Soc.*, 1964, **86**, 864.
9 M. Ruccia, N. Vivona and G. Cusmano, *J. Heterocycl. Chem.*, 1971, **8**, 137.
10 H. Kano and E. Yamazaki, *Tetrahedron*, 1964, **20**, 159.
11 (*a*) L. P. Hammett, *Physical Organic Chemistry*, McGraw-Hill, New York, 1970, 2nd edn., p. 355; (*b*) D. H. McDaniel and H. C. Brown, *J. Org. Chem.*, 1958, **23**, 420.
12 (*a*) B. M. Wepster, *J. Am. Chem. Soc.*, 1973, **95**, 102; (*b*) A. J. Hoefnagel, J. C. Monshouwer, E. C. G. Snorn and B. M. Wepster, *J. Am. Chem. Soc.*, 1973, **95**, 5350; (*c*) A. J. Hoefnagel and B. M. Wepster, *J. Am. Chem. Soc.*, 1973, **95**, 5358.
13 D. Weissberger, *Techniques of Organic Chemistry*, Wiley Interscience, New York, 1963, 2nd edn., vol. 7, p. 372.
14 M. Ruccia, N. Vivona, G. Cusmano and G. Macaluso, *J. Chem. Soc., Perkin Trans. 1*, 1977, 589.
15 S. Polanc, B. Vercek, B. Stanovnik and M. Tisler, *J. Heterocycl. Chem.*, 1974, **11**, 103.
16 E. M. Woolley, D. G. Hurkot and L. G. Hepler, *J. Phys. Chem.*, 1970, **74**, 3908.

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