Furazans and Furazan Oxides. Part IV.[1,2] The Structures and Tautomerism of Some Unsymmetrically Substituted Furoxans

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The furoxan equilibration reaction [(*A*) $\rightleftharpoons$ (*B*)] has been studied for a range of derivatives in the monomethyl series. Activation energies are similar to those determined by other workers for dialkyl and aryl(alkyl) (R = Et or Ph) derivatives, and equilibrium constants are close to unity, except for the ether and amine derivatives, in which the isomerisation is more rapid, and the 3-methyl isomers (*A*) are strongly preferred. Carbonyl stretching frequencies of some carboxy-derivatives, and rotational barriers of *NN*-dimethylamides, are also investigated.

THE isomerisation, or tautomerism, of a furoxan (furazan oxide), (*A*) $\rightleftharpoons$ (*B*), provides two parameters for study: the rate of the reaction, controlled by $\Delta G^{\ddagger}$ or the Arrhenius parameters, and the equilibrium constant, determined by the free energy difference ΔG^0 between the isomers. Previous work on this reaction has been summarised earlier, when the isomerisation of some cyclic acyl furoxans was described.[3] Here we report on a range of variously substituted furoxans (*1—16*; see Table 1 for specification of R) with a methyl group in position 3 or 4.

(*A*) (*B*) (*C*)

(*1*) — (*16*); for R see Table 1

Structural Assignments.—The structures of the isomers were assigned on the basis of the chemical shifts of the protons α to the heterocyclic ring. Thus, when the methyl group is in position 3, adjacent to the *N*-oxide [isomer (*A*)], its ^{1}H n.m.r. absorption is to high field of the signal when it is in position 4. This criterion, which was first proposed by Mallory and Cammarata,[4] has been discussed in Part I of both series.[5,6] Although some cases in which the α-proton is rigidly held with the C–H bond nearly parallel to the plane of the furoxan ring appear to be exceptional,[5] in the time-averaged environment of a proton on a methyl group the distinction is quite clear-cut, and *X*-ray and n.m.r. measurements on two compound pairs [(*A*), (*B*), R = p-C_6H_4Br,[7] and compounds (*5A*), (*5B*) [8]] have confirmed the assignment. Table 1 gives the chemical shift differences between the methyl groups of each pair of tautomers, in tetrachloroethane. Concentration and solvent effects were sometimes appreciable, but in the only instance where the effect was of magnitude comparable with the shift $\Delta\tau$ recorded in the Table [compounds (*16*), in benzene] the peak separation was increased.

DISCUSSION

Equilibrium Constants.—The equilibrium constants between the isomer pairs, measured at the temperatures indicated, are listed in Table 1. In most cases the equilibrium was approached from both sides.

Carboxylic acid derivatives (*1*)—(*7*). The equilibria for the esters (*1*), acid chlorides (*2*), and dimethylamides (*3*) lie appreciably in favour of the isomers (*A*), with the *N*-oxide group out of conjugation with the substituent R. This was an unexpected result, because benzofuroxans (*17*) with acid and ester groups, and other electron-withdrawing substituents, as R favour tautomer (*B*), in which the substituent is conjugated with the *N*-oxide function.[9] Furthermore, the acyl derivative (*18B*) is strongly favoured (ΔG^0 −6·3 kJ mol^{-1}) over its isomer (*18A*).[3] The amides (*4*) and hydrazides (*5*), on the other hand, do show a preference for form (*B*); presumably hydrogen bonding plays a role in stabilising this structure. An *X*-ray determination of the crystal structure of the hydrazide (*5B*) shows that, in the solid phase, the α-hydrogen atom of the hydrazine group is 2·16 Å from the *N*-oxide oxygen atom, with only a slight deviation of the CO–NH(α) atoms from coplanarity with the ring.[8b] The nitriles (*6*) also exist at equilibrium predominantly in form (*B*), but the preference is small. In this case, we assume that steric effects are not important. We are therefore forced to the conclusion that the substituents of these acid derivatives do not conjugate at all strongly with the *N*-oxide function. Further evidence on this point will be given in later sections of this paper.

The equilibrium between the acids (*7*) could not be measured directly; the compounds decomposed rapidly on heating, with only a slight degree of concurrent isomerisation. I.r. spectroscopy (see later) indicates the

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[1] Part III, A. J. Boulton and S. S. Mathur, *J. Org. Chem.*, 1973, **38**, 1054.

[2] This paper is also Part IV of the series 'Synthesis and Structure of Some Asymmetrically Substituted Furoxans'; for Part III see A. Gasco, V. Mortarini, G. Ruà, and A. Serafino, *J. Heterocyclic Chem.*, 1973, **10**, in the press.

[3] J. Ackrell and A. J. Boulton, *J.C.S. Perkin I*, 1973, 351.

[4] F. B. Mallory and A. Cammarata, *J. Amer. Chem. Soc.*, 1966, **88**, 61.

[5] J. Ackrell, M. Altaf-ur-Rahman, A. J. Boulton, and R. C. Brown, *J.C.S. Perkin I*, 1972, 1587.

[6] A. Gasco, V. Mortarini, G. Ruà, G. M. Nano, and E. Menziani, *J. Heterocyclic Chem.*, 1972, **9**, 577.

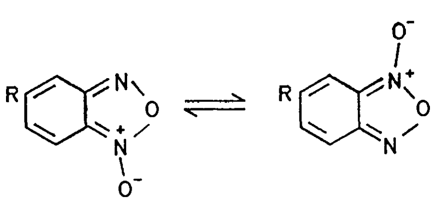
[7] M. Calleri, G. Ferraris, and D. Viterbo, *Acta Cryst.*, 1969, **B25**, (*a*) p. 1133; (*b*) p. 1126. The n.m.r. spectra were compared in this laboratory (M. Altaf-ur-Rahman and A. J. Boulton, unpublished work).

[8] (*a*) G. Germain and D. Viterbo, *Cryst. Struct. Comm.*, 1972, **1**, 411; (*b*) M. Calleri, G. Chiari, and D. Viterbo, *ibid.*, p. 407.

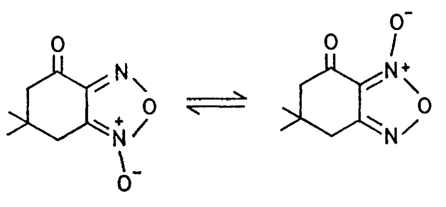
[9] (*a*) A. J. Boulton, A. R. Katritzky, M. J. Sewell, and B. Wallis, *J. Chem. Soc.* (*B*), 1967, 914; (*b*) for related compounds, see review by A. J. Boulton and P. B. Ghosh, *Adv. Heterocyclic Chem.*, 1969, **10**, 1.

presence of internal hydrogen bonding (*19*) in isomer (*7B*), which may therefore be thermodynamically more stable than (*7A*).

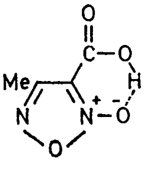
Amine derivatives (*8*) *and* (*9*). The urethanes (*8*) show a strong preference for form (*A*). Heating of the pyrrolidinofuroxan (*9*) produced a rapid decomposition at temperatures above 120°, but no isomerisation was found. Gagneux and Meier[10] succeeded in isolating a number of amino(aryl)furoxans in both tautomeric forms, and showed that thermal equilibration (at *ca.* 80°) gave only the 4-amino-isomer, no 3-amino-form (*B*) being detectable. Also, the chemical shift of the methyl group of the amine (*9*) was 0·09 p.p.m. to high field of that of the corresponding furazan (*9C*).[2] Therefore we assume that the pyrrolidinofuroxan has the structure (*9A*). Gagneux and Meier were able partly to isomerise their stable isomers into the unstable ones, by u.v. irradiation;[10b] we were not so successful in the present case.



(*A*) (*17*) (*B*)



(*A*) (*18*) (*B*)



(*19*)

TABLE 1

Equilibria between furoxan isomers

Compound pair no.	R	T/°C	$K = \frac{[(B)]}{[(A)]}$	ΔG^0/kJ mol^{-1}	From[a] (*A*)	(*B*)	$\tau_{CH_3(A)} - \tau_{CH_3(B)}$ (p.p.m.)
(*1*)	CO_2Et	125	$0·80 \pm 0·05$	$0·73 \pm 0·2$	+	+	0·17
(*2*)	COCl	125[b]	$0·60 \pm 0·03$	$1·68 \pm 0·15$	+	+	0·24
(*3*)	$CONMe_2$	125	$0·59 \pm 0·03$	$1·73 \pm 0·15$	+	+	0·14
(*4*)	$CONH_2$	135	$2·22 \pm 0·1$	$-2·69 \pm 0·15$	+	+	0·20
(*5*)	$CONHNH_2$	125[c]	$2·5 \pm 0·5$	$-3·0 \pm 0·6$	+	+	0·21
(*6*)	CN	100[c]	$1·4 \pm 0·3$	$-1·04 \pm 0·6$	+		0·19
(*7*)	CO_2H	*d*			+	+	0·19
(*8*)	$NHCOOCH_2Ph$	85	$0·04 \pm 0·01$	$9·5 \pm 0·8$	+	+	0·20
(*9*)	$N[CH_2]_4$	125[e]	$<0·02$	>13	+		
(*10*)	SO_2Ph	125	$0·50 \pm 0·03$	$2·28 \pm 0·2$	+	+	0·26
(*11*)	SO_2Et	125	$0·45 \pm 0·03$	$2·63 \pm 0·2$	+		0·18
(*12*)	SPh	95	$0·66 \pm 0·04$	$1·26 \pm 0·2$	+	+	0·30
(*13*)	SEt	95	$0·32 \pm 0·02$	$3·46 \pm 0·2$	+		0·26
(*14*)	OPh	78	$<0·02$	>13	+	+	0·11[f]
(*15*)	OEt	78	$<0·02$	>13	+	+	0·12[f]
(*16*)	NO_2	135[d]			+		0·21

The solvent was tetrachloroethane, unless otherwise stated.

[a] Equilibrium approached from side indicated. [b] Slight decomposition on heating. [c] Moderate decomposition on heating, introducing some imprecision into *K*. [d] Extensive decomposition; equilibrium not reached. [e] Extensive decomposition. By analogy with urethane (*8*), and the amino(aryl)furoxans,[13] 80° should be sufficient to induce equilibration. At 80° no decomposition or equilibration was observed. We conclude that the equilibrium concentration of (*B*) is undetectably small. [f] In dichloromethane.

Sulphides and sulphones (*10*)—(*13*). Isomers (*A*) are slightly favoured, both in the sulphides and the sulphones, and there is no obvious difference between the two types. In fact, the order of ΔG^0 difference between the forms (*A*) and (*B*) is given by R = SEt > SO_2Et > SO_2Ph > SPh. In the light of the present and previous results with other substituents, it is perhaps to be expected that forms (*A*) are favoured by the sulphones for steric reasons, and by the sulphides for electronic reasons, and that, in view of the generally-recognised reluctance of sulphur to form *p*–*p* π-bonds to carbon,* the smallness of the electronic effect in the sulphides is also not surprising.

Ethers (*14*) *and* (*15*). The phenoxy- and ethoxy-derivatives were isolated in their forms (*A*), and their n.m.r. spectra were unchanged after heating, even to 125° for several hours. Irradiation (Hanovia medium pressure Hg arc) in dichloromethane caused a second peak to appear, downfield of the first, and reaching 10—20% of its intensity. The second peak is assigned to isomers (*B*). (The isomerisation was accompanied by decomposition, a white solid being deposited, and prolonged irradiation produced a loss of intensity of both the methyl peaks.) Heating of the irradiated solution for 2 h at 78° resulted in complete reversion to the original spectrum. Evidently, like the amines, the ethers prefer

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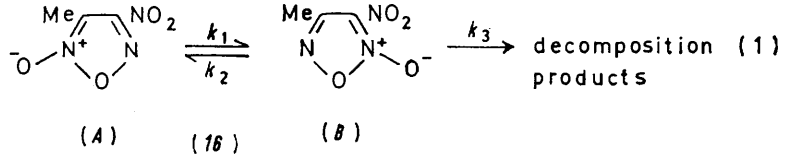
* A qualitative indication is provided by the greater reactivity, and tendency to polymerise, of thiones, compared with ketones, and the increased energy barriers to rotation about the C–N bond of thioamides, compared with amides.[11]

[10] (*a*) A. R. Gagneux and R. Meier, *Helv. Chim. Acta*, 1970, **53**, 1883; (*b*) lecture to the Second International Congress of Heterocyclic Chemistry, Montpellier, 1969.

[11] R. C. Neuman and L. B. Young, *J. Phys. Chem.*, 1965, **69**, 2570; R. C. Neuman, D. N. Roark, and V. Jonas, *J. Amer. Chem. Soc.*, 1967, **89**, 3412; W. Walter and E. Schaumann, *Chem. Ber.*, 1971, **104**, 3361. See also discussion by M. J. Janssen, Ph.D. Thesis, University of Utrecht, 1959.

form (*A*), with the proportion of (*B*) at equilibrium being undetectable by n.m.r.

Methylnitrofuroxan (*16*). On heating of this compound to 135° in tetrachloroethane nitrogen oxides were slowly evolved and a small peak (*ca.* 5%) appeared to low field of the methyl signal of the starting material. Irradiation (3 h) produced a mixture containing *ca.* 25% of the compound absorbing to low field. When this mixture was heated to 125° a rapid evolution of oxides of nitrogen was seen, and after 10 min the n.m.r. spectrum resembled that obtained after heating alone, with the addition of a number of small and broad peaks due to decomposition products. Although superficially, therefore, the nitro-compound behaves rather like the ethers on irradiation and heating, it appears that in this case isomer (*16B*), the probable origin of the low-field methyl peak, does not reach its thermodynamic equilibrium concentration on heating, but rather a steady state controlled by the relative rates of its formation (k_1) and decomposition ($k_2 + k_3$) [equation (1)]. No evidence was obtained for the thermal reconversion of (*16B*) into (*16A*), which would provide firmer ground for its identification. However, of the anions of the acids (*7*), isoelectronic with the nitro-compounds, isomer (*B*) is considerably less stable than isomer (*A*) to thermal decomposition; the potassium salt of (*7B*) explodes above 115°.[6]



Equilibration Rates.—For five of the compounds (see Table 2) the rates of the equilibration, approached from one side, were determined at three or more temperatures, and from these the Arrhenius and Eyring parameters for the reaction were derived (Table 3). We have followed the recommendation of Harris [12a] in computing these two sets of parameters independently, since their usual derivations are based on different (and, rigorously, mutually incompatible) assumptions. The form of the Eyring equation used is given in equation (2), where *k* is

$$\log\frac{k}{T} = \log\frac{\kappa \mathbf{k}}{h} - \frac{\Delta G^\ddagger}{2{\cdot}303RT} = \log\kappa + 10{\cdot}319 + \frac{\Delta S^\ddagger}{19{\cdot}12} - \frac{\Delta H^\ddagger}{19{\cdot}12T} \qquad (2)$$

the rate constant at temperature T, $\mathbf{k}$ and h are Boltzmann's and Plank's constants, and κ is the ' transmission coefficient '. There is some doubt as to what value to give to κ, and 1 has been used, by ourselves [9a] and others;[4] see discussion in ref. 4. We continue to use this value, not through confidence in its correctness, but because we are unable to justify the use of any other.

Mallory and Cammarata were the first to obtain reliable rate measurements on the furoxan isomerisation reaction.[4] Their results, for the ethyl(methyl) and methyl(phenyl) compounds, are included in Table 3 for comparison. In addition to the five compounds which we studied in detail, the temperatures of isomerisation of Table 1 can be used to give a rough indication of the relative ease of the reaction in the remaining compounds, except for those cases [(*7*), (*16*)] where decomposition proceeds faster than rearrangement.

The activation energies vary over a fairly narrow range, and it is clear that substitution affects the rate of the reaction far less profoundly than does aromatic ring fusion (the activation energy $\Delta G^\ddagger$ for benzofuroxan [13] is 80 kJ mol^{-1} lower than those for the simple derivatives of ref. 4). The urethane (*8*), and (qualitatively) the ethers (*14*) and (*15*) show the most significant decrease in activation energy. This can be accounted for by stabilisation of the transition state [which may be identical with the dinitroso-olefin (*20*); see discussion in ref. 4] relative to the initial furoxan. The sulphides (thioethers) (*12*) and (*13*) also show some lowering of the energy barrier, suggesting that the C–S conjugation in (*20*) is greater than in the furoxan (in which, as pointed out in the discussion on the equilibria, its importance seems to be small). However, the sulphone (*10*), and, qualitatively, the nitrile (*6*), also isomerise appreciably faster than the ethyl and phenyl derivatives. Stabilisation of type (*20*) does not account for these cases, and

TABLE 2

Rate constants for furoxan equilibration

Reaction	T/K	10^5k/s^{-1}
(*1A*) ⟶ (*1B*)	398·9	2·96 ± 0·08
(CO_2Et)	403·8	5·14 ± 0·07
	404·1	5·39 ± 0·24
	408·8	8·71 ± 0·21
	412·8	13·7 ± 0·8
(*2A*) ⟶ (*2B*)	397·8	2·37 ± 0·06
(COCl)	401·7	3·80 ± 0·07
	405·7	5·78 ± 0·14
(*8B*) ⟶ (*8A*)	353·8	5·17 ± 0·16
($NHCOOCH_2Ph$)	358·6	9·13 ± 0·15
	363·2	16·0 ± 0·7
(*10A*) ⟶ (*10B*)	388·0	1·84 ± 0·06
(SO_2Ph)	391·3	2·65 ± 0·09
	396·8	4·59 ± 0·04
	400·8	7·17 ± 0·20
(*12A*) ⟶ (*12B*)	367·1	2·80 ± 0·03
(SPh)	371·1	4·43 ± 0·09
	375·5	7·39 ± 0·23

Solvent: 1,1,2,2-tetrachloroethane. The errors are standard deviations on a least-squares analysis; systematic errors are not included.

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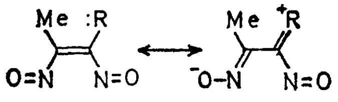
[12] R. K. Harris, ' Specialist Periodical Report on Nuclear Magnetic Resonance,' The Chemical Society, London, (*a*) 1973, vol. 2, ch. 6; (*b*) 1972, vol. 1.

[13] K.-I. Dahlqvist and S. Forsen, *J. Magnetic Resonance*, 1970, **2**, 61.

therefore we are inclined to be cautious in the drawing of quantitative conclusions from any of these figures, even when they fall in line with expectation.



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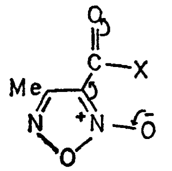

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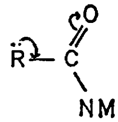

(22)

I.r. Spectroscopy.—We thought that it might be possible to observe the effect of electron donation from the *N*-oxide group, as shown in (*21*), by comparing the carbonyl stretching frequencies of the pairs of isomers (*A*) and (*B*). Such an effect had earlier been found in the cyclic ketones (*18*) and some of their derivatives.[3] The i.r. spectra of several furoxans (see Table 4) were studied. The results fail to show any convincing effect; the slight positive indication from the esters (*1*) is contradicted by the dimethylamides (*3*). It is in most cases not clear what is the ' true ' value of the carbonyl frequency, because of the multiplicity of peaks observed (caused, presumably, by rotational isomerism and/or Fermi resonance). Steric hindrance to coplanarity of the ring and side-chain grouping is another factor undermining the reliability of this approach.

TABLE 3

Activation parameters for furoxan equilibration

Reaction	E_a/ kJ mol^{-1}	log (A/s^{-1})	$\Delta H^\ddagger$/ kJ mol^{-1}	$\Delta S^\ddagger$/ J K^{-1} mol^{-1}	$\Delta G^\ddagger_{373\,K}$/ kJ mol^{-1}
(*1A*) ⟶ (*1B*)	148 ± 3	15·0 ± 0·3	146 ± 3	+32 ± 7	134 ± 4
(*2A*) ⟶ (*2B*)	150 ± 6	15·3 ± 0·5	148 ± 6	+36 ± 10	135 ± 7
(*8B*) ⟶ (*8A*)	127 ± 4	14·6 ± 0·3	125 ± 4	+27 ± 7	116 ± 4
(*10A*) ⟶ (*10B*)	135 ± 3	13·6 ± 0·3	132 ± 3	+5 ± 7	131 ± 4
(*12A*) ⟶ (*12B*)	131 ± 4	14·3 ± 0·3	129 ± 4	+18 ± 5	122 ± 5
[(*A*) ⟶ (*B*); R = Ph] [a]	143 ± 1	14·2 ± 0·2	140 ± 1	+16 (±5)	133 ± 2
[(*A*) ⟶ (*B*); R = Et] [a]	147 ± 2	14·8 ± 0·2	147 ± 2	+34 (±5)	134 ± 2

[a] From ref. 9. Entries in the last three columns are calculated from the data given.

TABLE 4

I.r. data of carbonyl compounds

Compd.	$\nu_{C=O}$/cm^{-1}	$\nu_{furoxan}$/cm^{-1}		Solvent
(*1A*)	1757, 1735	1616	1470	CCl_4
	1750, 1738	1615		MeCN
(*1B*)	1748, 1721	1613	1478	CCl_4
	1744, 1725	1606		MeCN
(*1C*)	1756, 1733			CCl_4
	1747, 1736			MeCN
(*2A*)	1765	1625	1470	CCl_4
(*2B*)	1776,[a] 1751, 1720 [a]	1611	1450	CCl_4
(*2C*)	1775, 1763			CCl_4
(*3A*)	1656	1610	1465	CCl_4
(*3B*)	1658	1601	1498	CCl_4
(*3C*)	1655			CCl_4
(*7A*)	1756,[b] 1736 [c]	1610	1472	$CHCl_3$
	1736 [c]	1605, 1588		Nujol [d]
(*7B*)	1761,[e] 1736,[b,f] 1723 [c]	1605	1478 [a]	$CHCl_3$
	1721 [c]	1595		Nujol [d]
(*7C*)	1755,[b] 1730 [c]			$CHCl_3$
	1747 [c]			Nujol [d]

All bands are of ' strong ' or ' very strong ' intensity, unless otherwise stated. ' Weak ' bands are not listed.

[a] ' Medium ' intensity. [b] *syn*-Monomer. [c] Dimer. [d] Solid phase, in mull. [e] *anti*-Monomer (*19*). [f] Shoulder.

The carboxylic acid isomer (*7B*) shows evidence of internal hydrogen bonding: the high frequency carbonyl band (1761 cm^{-1}) is assigned to form (*19*). In agreement with this monomeric formulation, the intensity of the band increases with dilution, relative to that of the (dimer) band at 1723 cm^{-1}.

Restricted Rotation in Dimethylamides.—Electron donation from R to the carbonyl group of a dimethylamide (*22*) is expected to reduce the extent to which the amide nitrogen interacts in the same fashion (' competitive delocalisation '[14]), and therefore should reduce the free energy of activation for rotation about the C–N bond. The effect, however, is not large, even in urethanes [*e.g.* (*22*; R = OCH_2Ph),[15] where $\Delta G^\ddagger = 67$ kJ mol^{-1}; *cf.* 75·5 kJ mol^{-1} for dimethylacetamide [14]], and there is a fairly wide range of activation energies reported, even for dimethylamides with apparently similar electron availability in R.[12,14]

Table 5 gives the activation energies at the coalescence temperatures for the C(O)–N bond rotation of the three dimethylamides (*3A*—*C*). It can be seen that the activation energy ($\Delta G^\ddagger$) is greatest, not least, for the amine (*3B*), but within experimental error all three values are the same.

TABLE 5

Rotation in dimethylamides

Compound	T_c/K	δ/Hz [a]	$\Delta G^\ddagger$/kJ mol^{-1} [b]
(*3A*)	359	16·8	78
(*3B*)	356	5·5	80
(*3C*)	353	7·2	79

The solvent was 1,1,2,2-tetrachloroethane throughout.

[a] Chemical shift difference between methyl signals (extrapolated to T_c). [b] At T_c. ±3 kJ mol^{-1}.

EXPERIMENTAL

N.m.r. spectra, with integration, were measured with a Perkin-Elmer R12 instrument, and variable temperature spectra were obtained on a Varian HA 100 machine, with

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[14] W. E. Stewart and T. H. Siddall, *Chem. Rev.*, 1970, **70**, 517.

[15] B. J. Price, R. V. Smallman, and I. O. Sutherland, *Chem. Comm.*, 1966, 319.

V 4313 variable temperature control. I.r. spectra were of *ca.* 0·05M solutions in 0·1 mm NaCl cells, measured on a Perkin-Elmer 125 grating spectrometer. U.v. irradiation was performed with a Hanovia medium pressure ' 1 litre photochemical reactor ' lamp, illuminating the n.m.r. tubes directly.

Preparation of Compounds.—The preparation of most of the compounds examined is described in Parts I—III of the Italian series.[2,6,16] Compounds (*1*)—(*5*) and (*8*) were formed from the carboxylic acids (*7*).[6,16] The nitriles (6) were prepared according to Ponzio and Bertini[17] as a mixture of isomers, with (*6A*) predominating. The availability of the derivatives (*9*)—(*15*) is a result of the ready nucleophilic displacement of the nitro-group from 3-methyl-4-nitrofurazan 2-oxide.[2]

TABLE 6

M.p. and analytical data for compounds (3)

Compound no.	M.p. (°C) (form)	Recryst. solvent	Required (%)			Found (%)		
			C	H	N	C	H	N
(*3A*)	71—72 (Needles)	Light petroleum	42·1	5·3	24·5	41·9	5·3	24·5
(*3B*)	109—110 (Prisms)	Isopropyl ether	42·1	5·3	24·5	42·2	5·3	24·6
(*3C*)	53—54 (Needles)	Light petroleum	46·4	5·9	27·1	46·3	6·0	27·6

4-*Methylfurazan*-3-NN-*dimethylcarboxamide* (*3C*) *and its* N-*Oxides* (*3A and B*).—Dimethylamine (0·02 mol) in dry ether (20 ml) was added dropwise, with vigorous shaking, to the ice-cooled acid chloride (*2*)[18] (0·01 mol) in dry ether (30 ml). The ether was removed *in vacuo* and the residue was washed with ice-cold water (5 ml). The remaining solid was dried and recrystallised, giving the dimethylamides (*3*) (90—95%).

Measurement of Kinetics and Equilibria.—Tubes containing solutions (0·5—1M) of the furoxan in 1,1,2,2-tetrachloroethane were immersed in a bath at the temperatures indicated in the Tables. At intervals they were withdrawn and the n.m.r. spectra were measured. Isomerisation was followed by electronic integration of the methyl peaks: each measurement was repeated 20 times, and after rejection of obviously deviant values caused by instrument noise, field drift, and so on, the relative proportions of the isomers were found. The r.m.s. deviations of the means of each set of ratios were within 2% of the determined value of the means, but other instrument settings (avoiding saturation of the signals) gave other values for the ratios which were considerably outside this range (±5%). The equilibrium constants of Table 1, and the log A and $\Delta S^{\ddagger}$ values of Table 3, together with the rate constants from which they are derived, are subject to this larger error, which was introduced at an appropriate stage into the calculations.

For the determination of the equilibrium constants, the temperatures quoted in Table 1 were maintained to an accuracy of ±2°. For the rate constants, ±0·2° was achieved, except in the case of the urethane (*8*), when a water-bath accurate to ±0·05° was used.

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