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A KINETIC STUDY OF THE THERMAL REARRANGEMENT OF N-ARYL-N'-CYANOHYDRAZINE DERIVATIVES

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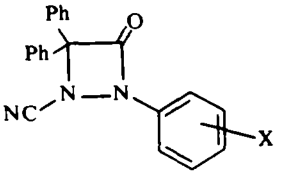
Abstract—The rates of rearrangement of 14 1-aryl-2-cyanodiazetidinones have been measured using differential scanning calorimetry and the entropies of activation thus obtained. In the case of the *para*-substituted compounds the rates can be correlated by either σ or σ^+ substituent constants. The rearrangement rates are independent of solvent polarity. These findings are discussed in relation to the sigmatropic pathway previously proposed for this rearrangement.

PREVIOUS papers[1-3] have described the facile thermal rearrangement of 1-aryl-2-cyanodiazetidin-4-ones (I) to imidazo [1.2-*a*] benzimidazoles (II) and its extension[4] to the conversion of 2-cyano-1-phenylpyrazoles such as III and V to IV and VI respectively. Two basically different mechanisms have been considered for this transformation.[2] The first of these entails an ortho-semidine rearrangement of I to VII. The intermediate (VII) might then undergo intramolecular cyclization to VIII followed by an N-to-N migration. Alternatively the intermediate (VII) could undergo rearrangement to the carbodiimide (IX), which on intramolecular cyclization would yield II. So far it has not proved possible to synthesize VII, but the dimethyl analogue is thermally stable at a temperature 100° higher than that at which the pyrazolidinone (III) rapidly rearranges.[4] This observation casts doubts on the foregoing mechanism and leaves as an alternative a [3.3]-sigmatropic rearrangement of X to the carbodiimide (XI) followed by intramolecular cyclization to XII. The present paper reports the results of a kinetic study of this transformation.

The essentially quantitative nature of these thermal rearrangements enabled us to study them by differential scanning calorimetry. Energies and entropies of activation, together with first order rate constants at 390°K are summarized in Table 1 for rearrangements of a range of diazetidinones in sulpholane. Rate constants at other temperatures are recorded in Table 3. Reproducibility of rate constants was usually within ±2% for duplicate runs, and the derived activation energies are probably reliable to within 1 to 2 Kcals.[5] No inflections were observed in the differential enthalpic curves implying that any intermediates formed enjoy only a transitory existence.

The first notable feature of these results is the magnitude of the entropies of activation. These range from −11 to +7 e.u. with an average value of about −2 e.u. This is consistent with a [3.3]-sigmatropic rearrangement mechanism since once the N-aryl and N-cyano groups assume a cisoid orientation all further processes necessitate only minimal variations in atomic positions. Recent studies[6] have indicated values of 2 ± 4 e.u. for the entropy of activation for nitrogen inversion in diazetidinones.



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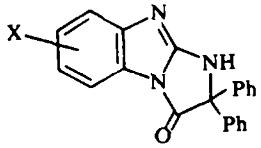

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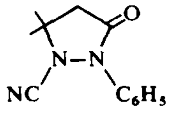

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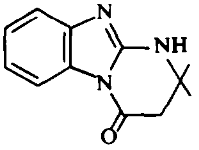

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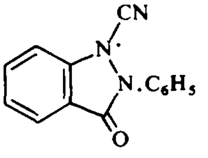
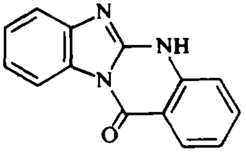


V



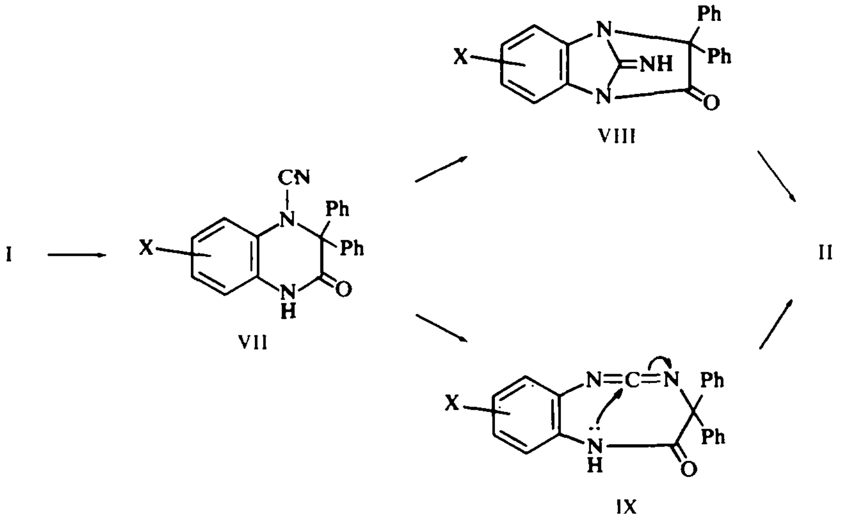
VI

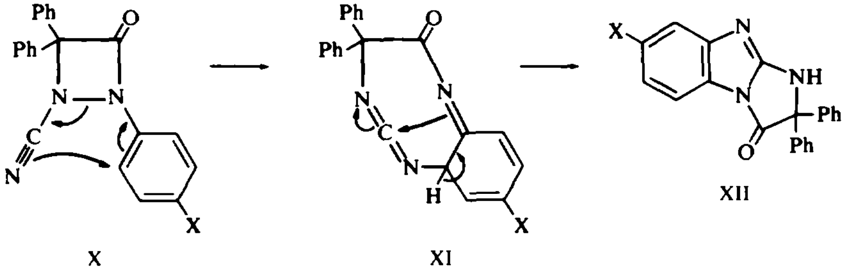
Equally satisfactory ($r = 1{\cdot}0$) linear correlations exist between log k and σ or σ^+ substituent constants, with ρ values of $-3{\cdot}5$ or $-2{\cdot}9$ respectively. It has been noted previously[7,8] that only σ^+ satisfactorily correlates the rates of rearrangement of *para*-substituted aryl allyl ethers, but it has not proved possible[2] to synthesize diazetidinones carrying electron releasing substituents on the N-aryl group, which

Table 1. Rate constant and activation parameters for rearrangement of 1-aryl-2-cyano-3.3-diphenyldiazetidin-4-one in sulfolane

$X.C_6H_4$	$k_{390} \times 10^4$ sec^{-1}	E_a Kcals/mole	† S‡ e.u.
X =			
p-F	501	20·7	−11
p-Cl	123	23·8	−5
p-Br	101	23·6	−5
p-PhCO	18·4	27·1	0
p-CN	3·35*	29·7	3
p-NO_2	1·62*	29·5	1
m-Cl	49·8	26·1	−1
m-Br	48·6	26·4	0
m-CF_3	13·4	26·3	−3
m-NO_2	10·8	26·4	−3
o-F	603	23·4	7
o-Cl	323*	21·2	−9
o-Br	519*	23·3	−4
o-NO_2	69·8	24·8	−3

* Extrapolated.
† Calculated for 390°K.





would have permitted a choice between σ and σ^+ in the present case. Although at first sight it might appear more appropriate to use an equation of the form[9]

$$\log(k/k_0) = \rho_p\sigma_p + \rho_m\sigma_m,$$

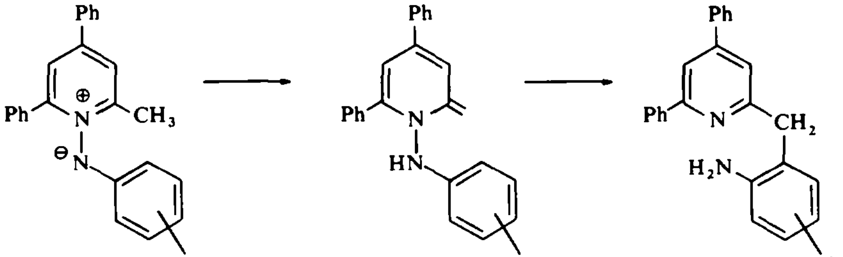
which takes into account the fact that a substituent is both *meta* and *para* to the reaction centres, a thorough analysis has shown[7] that linear correlations exist between appropriate solutions of this equation and σ or σ^+. In the case of the *meta*-substituted diazetidinones the observed rearrangement rates are far higher than

TABLE 2. RATES OF REARRANGEMENT OF 1-p-BROMOPHENYL-2-CYANO-3,3-DIPHENYLDIAZETIDINONE IN SOLVENTS OF VARYING DIELECTRIC CONSTANT ($k \times 10^3$ sec^{-1})

Solvent		$k_{380} \times 10^3$ sec^{-1}	$k_{390} \times 10^3$	$k_{400} \times 10^3$	E_a Kcal/mole
Quinoline	2·3	4·71	11·1	24·9	25·4
Diphenylmethane	2·5	4·45	9·82	20·1	23·0
Diphenylether	2·68	3·86	8·91	19·5	24·7
Dinonyl phthalate	—	2·68	6·08	12·6	23·6
Sulfolane	44	4·59	10·1	21·5	23·6
Ethylene carbonate	95	4·05	8·72	18·1	23·6
OS 124	—	3·97	8·99	18·2	23·2

predicted using σ_m or σ_m^+. An analogous situation arises with *meta*-substituted aryl allyl ethers.[7]

The value of $\rho(-2{\cdot}9)$ observed for the diazetidinone rearrangement lies between that (*ca* 0·5–0·6) reported for the rearrangement of allyl aryl ethers and the value of $-5{\cdot}8$ recently obtained[10] for rearrangement of the ylides XIII to XIV. The numerical value of ρ for the diazetidinone rearrangement suggests a polar transition state but the minimal solvent effect, *vide infra*, appears to exclude purely ionic intermediates.



XIII XIV

Alternatively the reaction could be envisaged as proceeding via cleavage of the N—N bond with formation of a pair of radicals and examples are known[11] of Cope rearrangements of hexa-1,5-dienes which proceed via dissociation to allyl radicals rather than following a concerted sigmatropic pathway. It has not proved possible to observe any of the conventional criteria for free-radical formation in the diazetidinone rearrangment though this does not exclude reaction within the solvent cage. A major objection to a mechanism proceeding by way of free radicals or free ions is that the rate-controlling step would presumably be the fission of the N—N bond, in which case the effect of both *para*- and *meta*-substituents should be correlated by one straight line in a Hammett plot, which is not the case.

TABLE 3. RATES OF REARRANGEMENT OF 1-ARYL-2-CYANO-3,3-DIPHENYLDIAZETIDIN-4-ONES IN SULFOLANE ($k \times 10^4$ sec^{-1})

	Temp °K										
Aryl group	352	361	371	380	390	400	410	420	430	440	450
p-F.C_6H_4	28·6	59·6	126	245	501						
p-Cl.C_6H_4	4·4	10·4	36·1	55·1	123	258					
p-Br.C_6H_4	4·4	10·1	21·8	45·9	101	215					
p-PhCO.C_6H_4				7·2	18·4	44·9	101	220			
p-NC.C_6H_4						8·51	21·5	52·0	116	239	
p-O_2N.C_6H_4						4·0	10·0	23·4	50·4	101	229
m-ClC_6H_4		3·2	8·7	21·2	49·8	112					
m-BrC_6H_4		3·0	8·35	20·9	48·6	109					
m-F_3C.C_6H_4					13·4	32·3	70·5	149	298		
m-O_2N.C_6H_4					10·8	26·1	58·4	125	252		
o-F.C_6H_4	22·4	56·2	129	257							
o-Cl.C_6H_4	18·6	39·8	86·5	177							
o-Br.C_6H_4	19·0	47·9	112	236							
o-O_2N.C_6H_4			13·0	29·7	69·8	150					

The kinetics of the rearrangement of 1-*p*-bromophenyl-2-cyano-3,3-diphenyldiazetidinone were examined in a variety of solvents covering a range of dielectric constants and ionizing power, Table 2. The hydrolytic lability of the compounds precluded the inclusion of protic solvents in this survey. The rearrangement is insensitive to solvent polarity. This may be partly due to the bulky diphenylmethylene group which would hinder access of solvent molecules to the immediate reaction site. The rearrangement of allyl *p*-tolyl ether shows[12] a rate increase of 3–4 times in going from tetradecane to solvents such as sulpholane and propylene carbonate. Much larger rate accelerations, up to 100 times, are only observed in hydroxylic solvents.

The role of relief of ring strain in promoting this rearrangement is illustrated by the results obtained for compounds (III: E_a = 36·7 Kcals/mole, S^{+} = 0 e.u.) and (V: E_a = 35·1 Kcals/mole, S^{+} = 1 e.u.), measured in *m*-bis (*m*-phenoxyphenoxy)benzene (OS 124). These indicate that the energy of activation increases by *ca* 15 Kcal/mole when the ring size is increased from four to five. This may be compared to a figure of 20 Kcals/mol derived from the difference between the thermodynamic strain energies of cyclobutane and cyclopentane.[13]

EXPERIMENTAL

1-*Aryl*-2-*cyano*-3,3-*diphenyldiazetidin*-4-*ones*. The following new 1-*aryl* derivatives were prepared by the method previously described:[2] p-*cyanophenyl*-, m.p. 133–34° (Found: C, 75·6: H, 4·1: N, 15·9. $C_{22}H_{14}N_4O$ requires: C, 75·4: H, 4·0: N, 16·0%): p-*fluorophenyl*-, 104–106°, 240–250° (Found: C, 73·5: H, 4·1: N, 11·8. $C_{21}H_{14}FN_3O$ requires: C, 73·5: H, 4·1: N, 12·2%): p-*benzoylphenyl*-, m.p. 125–7° (Found: C, 78·5: H, 4·5: N, 9·8. $C_{28}H_{19}N_3O_2$ requires: C, 78·3: H, 4·5: N, 9·8%): m-*trifluoromethylphenyl*-, m.p. 115–7°, 220–250° (Found: C, 67·5: H, 3·9: N, 10·6. $C_{22}H_{14}F_3N_3O$ requires: C, 67·2: H, 3·6: N, 10·7%): m-*nitrophenyl*-, m.p. 127–9°, *ca* 280° (Found: C, 67·9: H, 3·7: N, 14·9. $C_{21}H_{14}N_4O_3$ requires: C, 68·1: H, 3·8: N, 15·2%).

Preparative thermal rearrangements. The adduct in xylene was briefly heated under reflux and the product usually separated directly. In this way were prepared the following substituted 2,3-*dihydro*-3-*oxo*-2,2-*diphenyl*-1H-*imidazo*[1.2-a]*benzimidazoles*. 7-*Cyano*-, m.p. 255–259° (Found: C, 75·8: H, 4·3: N, 16·0. $C_{22}H_{14}N_4O$ requires: C, 75·4: H, 4·0: N, 16·0%): 7-*fluoro*-, m.p. 265–267° (Found: C, 73·6: H, 4·0: N, 12·5. $C_{21}H_{14}FN_3O$ requires: C, 73·5: H, 4·1: N, 12·2%): 7-*benzoyl*-, m.p. 239–241° (Found: C, 77·9: H, 4·5: N, 9·7. $C_{28}H_{19}N_3O_2$ requires: C, 78·3: H, 4·5: N, 9·8%).

Quantitative measurements. These were carried out following the method of Barrett[14] but using a Du Pont 900 Thermal Analyser equipped with a Differential Scanning Calorimeter Cell. All solvents were appropriately purified before use and compounds were of analytical purity. The rates of rearrangement thus determined are recorded in Table 3.

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REFERENCES

[1] C. W. Bird, *Chem. & Ind.* 1556 (1963)

[2] C. W. Bird, *J. Chem. Soc.* 5284 (1964)

[3] C. W. Bird, *Chem. Comm.* 1486 (1969)

[4] C. W. Bird, *Tetrahedron* **21**, 2179 (1965)

[5] L. L. Schaleger and F. A. Long, *Adv. Phys. Org. Chem.* **1**, 1 (1963)

[6] E. Fahr, W. Rohlfing, R. Thiedemann, A. Mannschreck, G. Rissmann and W. Seitz, *Tetrahedron Letters* 3605 (1970)

[7] H. L. Goehring and R. R. Jacobson, *J. Am. Chem. Soc.* **80**, 3277 (1958)
[8] W. N. White, D. Gwynn, R. Schlitt, C. Girard and W. Fife, *Ibid.* **80**, 3271 (1958)
[9] H. H. Jaffe, *Chem. Revs* **53**, 191 (1953)
[10] C. W. Bird and I. J. Partridge, in preparation
[11] G. S. Hammond and C. D. DeBoer, *J. Am. Chem. Soc.* **86**, 899 (1964); D. J. Trecker and J. P. Henry, *Ibid.* **86**, 902 (1964)
[12] W. N. White and E. F. Wolfarth, *J. Org. Chem.* **35**, 2196, 3585 (1970)
[13] S. Kaarsemaker and J. Coops, *Rec. Trav. Chim.* **71**, 261 (1952)
[14] K. E. Barrett, *J. Appl. Polymer Sci.* **11**, 1617 (1967)