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CYCLOADDITIONS—XIX[1]*

KINETICS OF THE THERMAL DECOMPOSITION OF 2,5-DIARYLTETRAZOLES

SOON-YUNG HONG† and J. E. BALDWIN‡

Department of Chemistry and Chemical Engineering of the University of Illinois, Urbana, Illinois 61801, U.S.A.

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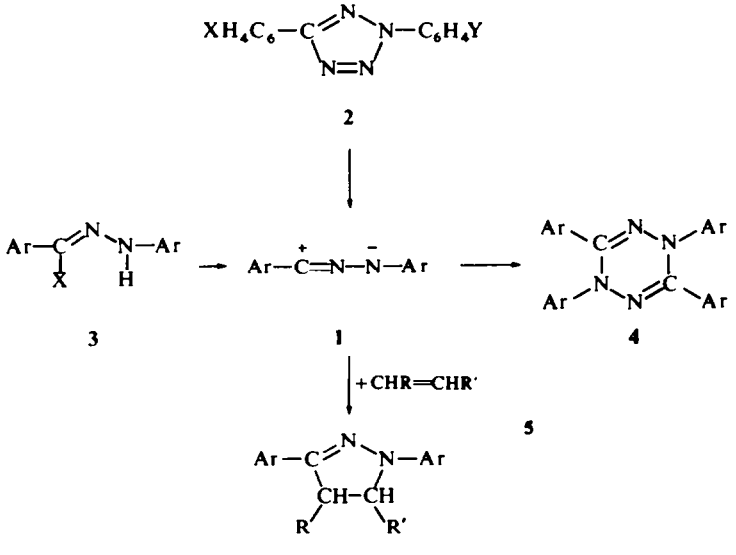
Abstract—The kinetics of the thermal decomposition of nine 2,5-diaryltetrazoles at 165·8° have been determined manometrically. For 2-aryl-5-phenyltetrazoles, a plot of log k against the Hammett substituent constants gives a good straight line with slope $\rho = 1{\cdot}16$. For 2-phenyl-5-aryltetrazoles, $\rho = -0{\cdot}23$. The pertinence of these results to the mechanism of the cycloadditions of 1,3-diarylnitrile imines is discussed.

1,3-DIARYLNITRILE IMINES (**1**) are among the most thoroughly investigated[2–15] short-lived 1,3-dipolar systems.[16] These reactive chemical intermediates may be generated from the thermal or photolytic decomposition of 2,5-diaryltetrazoles[9] (**2**) or through elimination of HX (X = Cl, NO_2) from α-chloro- or α-nitrobenzylidene phenylhydrazines (**3**). In the absence of suitable reaction partners, they dimerize forming dihydrotetrazines (**4**).[8] They add to reactive multiple bonds giving 5-membered heterocyclic adducts[2–15] (**6**).



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3 **1** **4**

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† Fulbright Fellow, 1965–1966; present address, Department of Chemistry, Kyungpook University, Taegu, Korea.

‡ Alfred P. Sloan Research Fellow.

TABLE 1. 2,5-

Compound	Substituents		Appearance[a]	M.p. (°C)	Yield (%)	UV absorption	
	2-Y-Phenyl	5-X-Phenyl				λ_{max} (mμ)	ε (× 10^{-4})
2a	H	H	white needles	99·5–100°[b]	42·9	271	1·62
2b	H	*p*-MeO	yellow needles	105–105·5	22·8	278	2·04
	H	*p*-Me	olive plates	92–93	16·4	273·5	1·90
	H	*p*-Cl	green plates	108–108·5	34·3	274·5	2·24
	H	*m*-Br	white needles	95·5–96·5	48·3	270	1·75
	H	*p*-CN	yellow plates	152–154	5·7	277·5	2·73
	p-Me	H	yellow needles	103–104	19·2	272·5	1·96
	m-MeO	H	violet powder	89·5–90	36·2	271	1·57
	p-Cl	H	brown plates	120·5–121·5	46·5	272·5	2·22

[a] The colors were pale, not vivid.
[b] Lit.[3,17] m.p. 101·5–102°, 101–103°.

In the cases studied to date, the 1,3-cycloadditions of 1,3-diarylnitrile imines have been found to be highly stereoselective. With *cis* or *trans* olefins (**5**; R = R′), adducts retaining the original *cis* or *trans* disposition of R and R′ are obtained.[10] Sterically unsymmetrical olefins (e.g. **5**, R = H, R′ = Me or CO_2Me) add to give only the corresponding 3-substituted adducts (**6**), regardless of the electronic character of R′.[10,12,13] From electronically unsymmetrical olefins (e.g. **5**, R, R′ = Me and CO_2Me), two adducts are obtained in comparable amounts.[9,12,13] These observations derived from product studies, and relative rate data obtained from competition experiments involving pairs of olefins and 1,3-diphenylnitrile imine,[15] have been interpreted through a phenomenological generalization: stereochemistry and relative rates of formation in these 1,3-cycloadditions of 1,3-diarylnitrile imines seem to be controlled predominantly by the steric rather than the electronic characteristic of the dipolarophile. With enamines, however, electronic effects may dominate.[13]

RESULTS AND DISCUSSION

In the present work, quantitative information on the sensitivity of such reactions to the electronic characteristics of the 1,3-dipolar system was sought through measuring the rates of thermal decomposition of 2,5-diaryltetrazoles. The tetrazoles used in this kinetic study, prepared by the method of Dimroth and Merzbacher,[3,17] are listed with some of their properties in Table 1. Their rates of nitrogen evolution in 1-chloronaphthalene at 165·8° are given in Table 2. The two Hammett plots based on these data are shown in Fig. 1; the σ-constants employed were taken from the summary in Hine.[18] Temperature dependent kinetic data for the decomposition of 2,5-diphenyltetrazole are summarized in Table 3. The calculated activation parameters for this decomposition are E_a = 32·4 kcal/mole and $\Delta S^{\ddagger}_{25^\circ}$ = −2·6 eu.

The ρ-values in Fig. 1 are of different sign and magnitude: they indicate that substituents on the 2-phenyl (N-Ph) group which can stabilize negative charge speed the decomposition (ρ = 1·16) while 5-phenyl (C-Ph) substituents able to delocalize positive charge facilitate the 1,3-cycloelimination (ρ = −0·23).

DIARYLTETRAZOLES (2)

Formula	Elemental analysis						Compound
	Calc			Found			
	C	H	N	C	H	N	
$C_{13}H_{10}N_4$	70·25	4·54	25·21	70·50	4·54	25·34	**2a**
$C_{14}H_{12}N_4O$	66·65	4·80	22·21	66·78	4·82	21·97	**2b**
$C_{14}H_{12}N_4$	71·16	5·12	23·71	71·12	5·01	23·60	
$C_{13}H_9ClN_4$	60·83	3·53	21·83	60·57	3·40	21·89	
$C_{13}H_7BrN_4$[c]	51·84	3·01	18·61	52·04	3·16	18·72	
$C_{14}H_9N_5$	68·00	3·67	28·33	67·79	3·84	28·29	
$C_{14}H_{12}N_4$	71·16	5·12	23·71	70·79	5·08	23·55	
$C_{14}H_{12}N_4O$	66·65	4·80	22·21	66·91	4·79	22·09	
$C_{13}H_9ClN_4$[d]	60·83	3·53	21·83	60·85	3·68	21·92	

[c] Bromine analysis: Calc, 26·54; Found, 26·35.
[d] Chlorine analysis: Calc, 13·81; Found, 13·95.

These tetrazole decompositions may be viewed as 1,3-cycloeliminations; such an elimination and the reverse reaction, the 1,3-cycloaddition of the corresponding 1,3-diarylnitrile imine with the symmetrical dipolarophile nitrogen, must share a common rate-determining transition state region. If the aryl substituent in a mono-substituted 2,5-diaryltetrazole effects the decomposition rate primarily through

TABLE 2. KINETIC DATA FOR THE THERMAL DECOMPOSITION OF 2,5-DIARYLTETRAZOLES (2) IN 1-CHLORONAPHTHALENE AT 165·8°

Compound	Substituents		First-order rate constants for N_2 evolution ($\times 10^4$ sec^{-1})	
	2-Y-Phenyl	5-X-Phenyl	Run 1	Run 2
2a	H	H	2·71	2·81
2b	H	*p*-MeO	3·29	3·17
2c	H	*p*-Me	3·06	2·93
2d	H	*p*-Cl	2·02	2·04
2e	H	*m*-Br	2·35	2·31
2f	H	*p*-CN	1·87	1·97
2g	*p*-Me	H	1·77	1·83
2h	*m*-MeO	H	3·44	3·20
2i	*p*-Cl	H	5·32	5·60

stabilizing or destabilizing the activated complex rather than the tetrazole, the rate data provide a quantitative measure of the electronic demands of the activated complex for the 1,3-cycloeliminations or corresponding 1,3-cycloadditions. The subsequent discussion posits this assumption.

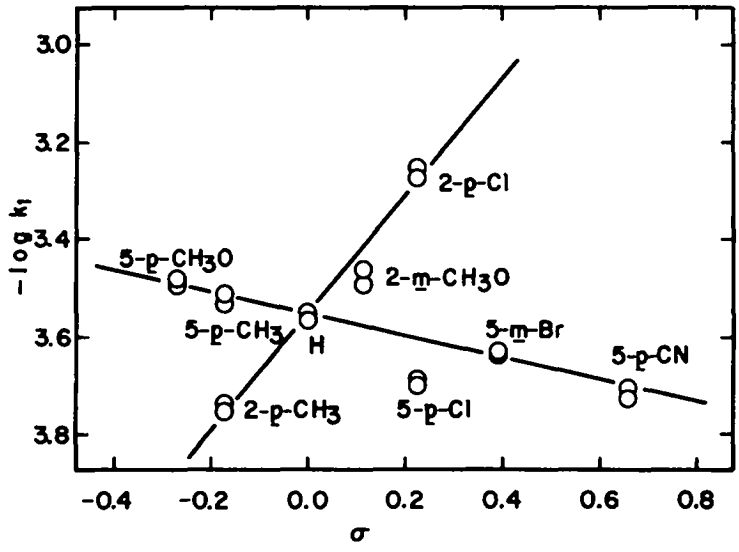


FIG. 1 Hammett plot for the rates of nitrogen evolution from 2,5-diaryltetrazoles in 1-chloronaphthalene at 165·8°.

1,3-Diarylnitrile imines (1) are representative of the octet-stabilized 1,3-dipolar systems with a double bond. The molecular orbital correlation diagram for the reaction of such a system with an olefin indicates that the thermal 1,3-cycloaddition process may be concerted.[19]

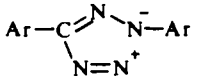
The measured ρ-values are not directly informative as to the concerted or non-concerted character of 1,3-cycloadditions of 1,3-diarylnitrile imines with symmetrical olefins or the 1,3-cycloeliminations of nitrogen from 2,5-diaryltetrazoles, for the 1,3-dipolar system is not completely symmetrical. One may not rigorously ascribe

TABLE 3. KINETIC DATA FOR THE THERMAL DECOMPOSITION OF 2,5-DIPHENYLTETRAZOLE IN 1-CHLORONAPHTHALENE

Point	k_1 ($\times 10^4$ sec^{-1})	Temp (°C)
1	2·81	165·8
2	2·71	165·8
3	2·65	165·1
4	2·50	165·1
5	1·06	155·4
6	0·93	155·4
7	0·92	154·0
8	0·82	154·0
9	0·51	145·8
10	0·46	145·8

the differences in the measured ρ-values either to a non-concertedness in the 1,3-cycloelimination process or to a slightly dissymmetric transition state species in a concerted reaction.

The $\Delta S^{\ddagger}$ for the cycloelimination of nitrogen from the 2,5-diaryltetrazoles implies a geometry for the activated complex very close to that of the tetrazole. The ρ-values for the cycloelimination are most easily rationalized in terms of an activated complex such as 7 in which the N_2—N_3 bond has suffered more extensive heterolytic cleavage than the N_4—C_5 bond.



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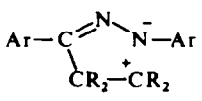
In structure 7 and in other dipolar formulations below, the "plus" and "minus" signs do not necessarily stand for full 1*e* charges; they are meant to encompass both this possibility and an alternative one in which less extensive separation of charge obtains and the atoms bearing the formal "plus" and "minus" charges are linked by a highly polar valence bond.

In terms of the simplest possibilities for the reactions of 1,3-diarylnitrile imines (1) with olefins, a concerted addition or a non-concerted 1,3-cycloaddition proceeding *via* a dipolar intermediate, and if one assumes that the C—C bond would be the first formed if indeed one bond-making step precedes the other, which seems plausible in light of the available stereochemical evidence, then three transition state species may be considered (**8**, **9**, **10**).



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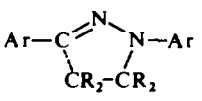

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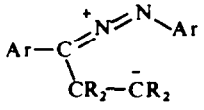

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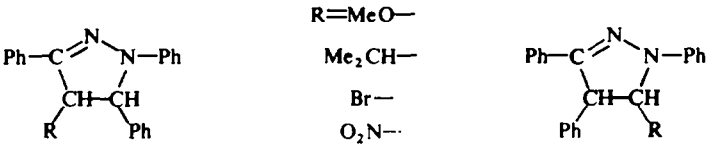
The often-invoked continuum of mechanistic possibilities for cycloaddition reactions extending from a perfectly concerted process to a two-step pathway involving a bifunctional intermediate places the purely concerted process at the center of the continuum rather than at one extremum.

If such a mechanistic continuum obtains, then one would *not* expect the ρ-values determined for the cycloelimination of a completely symmetrical "dipolarophile" such as nitrogen to reflect accurately the electronic demands in the transition state for cycloeliminations or cycloadditions involving a highly unsymmetrical dipolarophile.

The recently published product ratios from β-substituted styrenes and 1,3-diphenylnitrile imine provide an intriguing though indecisive test for these ideas. The product ratios (**11**/**12**) for methoxy, isopropyl, bromo, and nitro β-substituted styrenes were found to be 0·54, 2·23, 5·67, and 0·45, respectively.[12] These data for the

isomer distributions in the product mixtures were seen to exhibit no simple relationship to the van der Waals radii of the β-substituents.[12]



11 12

If these are the kinetically controlled product ratios,[12,15] the logarithms of the ratios are proportional to differences in free energy between two activated complexes. The electronic contributions to these free energy differences should depend on the ability of the β-substituent relative to phenyl to stabilize charge in the transition state. Indeed, the logarithms of the product ratios for the first three β-substituted styrenes do correlate reasonably well with the σ_p^+-constants (Fig. 2) appropriate in situations where the substituent may exert a direct resonance effect.[20]

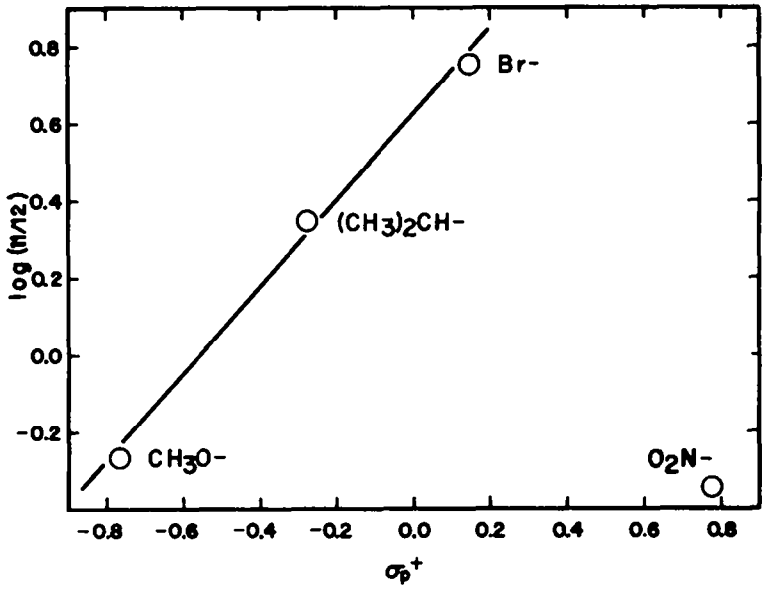
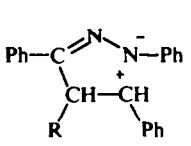


FIG. 2 Plot of log (11/12) against σ_p^+, correlating the product distributions in the 1,3-cycloadditions of diphenylnitrile imine with the electronic properties of β-substituted styrenes.

The point for β-nitrostyrene falls well off the line, presumably because it reacts by a different mechanism. The two activated complexes controlling the product ratios are no longer, say, **13** and **14**, but **13** and **15**. One could also insist that, since the product ratio from β-nitrostyrene and the 1,3-diphenylnitrile imine was determined

under different reaction conditions, no comparison should be made with the other product ratios.



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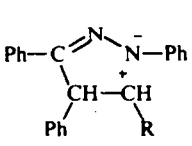

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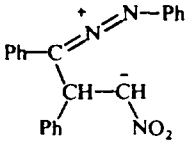

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This interpretation of the product ratios from β-substituted styrenes and 1,3-diphenylnitrile imine, based as it is on only four data points and some assumptions, must be viewed as speculative. It has value, nevertheless, as a stimulus to further reflection on the timing of chemical changes and the consequences of the amphoteric nature of 1,3-dipolar systems. It also serves as a predictive model: the ρ-values for the two cycloadditions of N-aryl–C-phenylnitrile imines with olefins like β-methoxystyrene should both be positive; those for reactions with olefins like β-nitrostyrene should be, according to the suggested model, of opposite sign, with additions giving a 4-phenyl-5-nitroadduct having ρ negative. Further work designed to test these predictions is in progress.

Part of the fascination of cycloaddition chemistry is the delicate balance between structure and mechanism, and the frequency with which the mechanistic course of a reaction type can be fundamentally altered through structural changes in the reactants without changing the type of product eventually formed. The present experimental indications and speculation suggest such mechanistic complexity and subtle interplay between steric and electronic effects in the 1,3-cycloadditions of 1,3-diarylnitrile imines.

EXPERIMENTAL

UV absorption spectra were determined in 95% EtOH with a Perkin–Elmer Model 202 Spectrometer. M.ps are uncorrected. Elemental analyses were obtained by J. Nemeth and associates, Urbana, Illinois.

Preparation of 2,5-*diaryltetrazoles* (2). A mixture of 1·96 g (8·5 mmole) benzaldehyde *p*-chlorophenylhydrazone, 1·05 g (8·8 mmole) phenyl azide, and 9·1 ml of a soln of 0·46 g metallic Na in methyl cellosolve (2-methoxyethanol) was refluxed at 110–115° for 7 hr. The mixture was cooled in an ice bath and 15 ml 2N HCl was added. The product was dried at 2 mm for 21 hr and had m.p. 120·5–121·5°; 1·01 g (46·5% yield). The other 2,5-diaryltetrazoles listed in Table 1 were prepared in a similar manner.

Kinetics. The high temp kinetic apparatus utilized for the rate studies of the 2,5-diaryltetrazoles has been described in detail.[21] It is composed of a high temp oil bath, an automatic press adjuster, and a strip-chart recorder. The bath temp was maintained to ±0·1°: the temps of the kinetic runs were determined with a thermometer certified by the National Bureau of Standards. A long-necked flask containing 30 ± 0·1 mg 2,5-diaryltetrazole and 5 ml reagent-grade 1-chloronaphthalene (b.p. 120–121° (17 mm)) was immersed in the oil bath. A magnetic stirring bar was placed in the flask. A syringe needle, connected to the press adjuster with polyethylene tubing, was inserted in the cap of the flask. The magnetic stirrer was started and after allowing 3 min for thermal equilibration, N_2 evolution was recorded. The calculations to obtain the first-order rate constants were done by an IBM 7094 digital computer. The data obtained are given in Tables 2 and 3.

For 2-phenyl-5-*m*-bromophenyltetrazole (2e), 40 mg was used for each kinetic run.

REFERENCES

[1] Paper XVII in this series: J. A. Kapecki, J. E. Baldwin and I. C. Paul, *Tetrahedron Letters* 5307 (1967); paper XVIII, J. E. Baldwin and S. Y. Hong, *Chem. Commun.* 1136 (1967).

[2] R. Huisgen, M. Seidel, J. Sauer, J. W. McFarland and G. Wallbillich, *J. Org. Chem.* **24**, 892 (1959).
[3] R. Huisgen, J. Sauer and M. Seidel, *Chem. Ber.* **94**, 2503 (1961).
[4] R. Huisgen, M. Seidel, G. Wallbillich and H. Knupfer, *Tetrahedron* **17**, 3 (1962).
[5] R. Huisgen, R. Grashey, M. Seidel, G. Wallbillich, H. Knupfer and R. Schmidt, *Liebigs Ann.* **653**, 105 (1962).
[6] R. Huisgen, R. Grashey, H. Knupfer, R. Kunz and M. Seidel, *Chem. Ber.* **97**, 1085 (1964).
[7] R. Huisgen, R. Grashey, E. Aufderhaar and R. Kunz, *Ibid.* **98**, 642 (1965).
[8] R. Huisgen, E. Aufderhaar and G. Wallbillich, *Ibid.* **98**, 1476 (1965).
[9] J. S. Clovis, A. Eckell, R. Huisgen and R. Sustmann, *Ibid.* **100**, 60 (1967).
[10] R. Huisgen and V. Weberndörfer, *Ibid.* **100**, 71 (1967).
[11] R. Huisgen, H. Knupfer, R. Sustmann, G. Wallbillich and V. Weberndörfer, *Ibid.* **100**, 1580 (1967).
[12] J. S. Clovis, A. Eckell, R. Huisgen, R. Sustmann, G. Wallbillich and V. Weberndörfer, *Ibid.* **100**, 1593 (1967).
[13] R. Huisgen, R. Sustmann and G. Wallbillich, *Ibid.* **100**, 1786 (1967).
[14] R. Sustmann, R. Huisgen and H. Huber, *Ibid.* **100**, 1802 (1967).
[15] A. Eckell, R. Huisgen, R. Sustmann, G. Wallbillich, D. Grashey and E. Spindler, *Ibid.* **100**, 2192 (1967).
[16] R. Huisgen, *Angew. Chem.* **75**, 604, 742 (1963); *Angew. Chem.* (Internat. Edit.) **2**, 565, 633 (1963).
[17] O. Dimroth and S. Merzbacher, *Chem. Ber.* **40**, 2402 (1907).
[18] J. Hine, *Physical Organic Chemistry* (2nd Edition) p. 87. McGraw-Hill, New York, N.Y. (1962).
[19] R. Hoffmann and R. B. Woodward, *J. Am. Chem. Soc.* **87**, 2045 (1965); R. Hoffmann and R. B. Woodward, unpublished.
[20] Y. Okamoto and H. C. Brown, *J. Org. Chem.* **22**, 485 (1957).
[21] J. E. Baldwin, *J. Org. Chem.* **32**, 2438 (1967).