and the second using 0.5 mmol of each of the reagents. Once the synthesis was completed, the protected nonapeptide from above was obtained in the usual manner[27,32] to give 650 mg of the nonapeptide. A 320-mg (0.25 mmol) sample was treated with Na in liquid ammonia, oxidized to the disulfide products, and then purified by partition chromatography on Sephadex G-25 using 1-butanol–H_2O (containing 3.5% HOAc in 1.5% pyridine) (1:1) to give the purified, specifically labeled all-L- and D-Tyr[2] diastereoisomers with R_f values of 0.23 and 0.41, respectively. Each diastereoisomer was further purified by gel filtration on Sephadex G-25 using 20% aqueous HOAc as eluent solvent. There was obtained 71 mg of [2-D-[3′,5′-$^{13}C_2$]tyrosine]oxytocin as a white powder. Amino acid analysis gave the following molar ratios: Asp, 1.0; Glu, 1.0; Pro, 1.0; Gly, 1.0; half-Cys, 1.8; Ile, 1.0; Leu, 1.0; Tyr, 0.90. TLC in solvent systems A, B, and C gave single uniform spots, identical with those of authentic [2-D-tyrosine]oxytocin.[32] HPLC gave a single uniform spot in the position previously reported[29,30] and no observable (<0.5%) all-L diastereoisomer. There also was obtained 60 mg of [2-[3′,5′-$^{13}C_2$]tyrosine]oxytocin as a white powder. Amino acid analysis gave the following molar ratios: Asp, 1.0; Glu, 1.0; Pro, 1.0; Gly, 1.0; half-Cys, 1.9; Ile, 1.0; Leu, 1.0; Tyr, 0.93. TLC in solvent systems A, B, and C gave single uniform spots with R_f values identical with those of authentic oxytocin. HPLC gave a single uniform peak identical with that of oxytocin[29,30] with no trace (<0.5%) of the D diastereoisomer. We have previously shown the 2-diastereoisomers to be separated by over 20 min under the HPLC conditions used here.[29,30]

Milk ejecting activities were determined[31] for each diastereoisomer and [2-[3′,5′-$^{13}C_2$]tyrosine]oxytocin had about 450 U/mg of activity, identical with that of authentic oxytocin.[31] Interestingly, [2-D-[3′,5′-$^{13}C_2$]tyrosine]oxytocin had nearly 400 U/mg of activity, identical with that of authentic [D-Tyr[2]]oxytocin.

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Registry No. **1**, 7217-25-6; **2**, 70479-88-8; **3**, 70479-89-9; **4**, 70479-90-2; **5**, 70479-91-3; **6**, 70479-92-4; **7**, 70479-93-5; **8**, 70479-94-6; **9**, 70479-95-7; **10**, 70479-96-8; **11**, 70479-97-9; **11a**, 70479-98-0; **11b**, 70479-99-1; sodium nitromalonaldehyde, 34461-00-2; [(3,5-$^{13}C_2$)-*p*-methoxyphenyl]diazonium fluoborate, 70480-01-2; diethyl acetamidomalonate, 1068-90-2; [2-DL-[3′,5′-$^{13}C_2$]tyrosine 8-arginine]vasopressin, 70480-02-3; H-Cys(DMB)-DL-[3′,5′-$^{13}C_2$]Tyr-Phe-Gln-Asn-Cys(DMB)-Pro-Arg(Tos)-Gly-NH_2, 70513-46-1; [2-D-[3′,5′-$^{13}C_2$]tyrosine, 8-arginine]vasopressin, 70480-03-4; [2-[3′,5′-$^{13}C_2$]tyrosine, 8-arginine]vasopressin, 70480-04-5; 2-DL-[3′,5′-$^{13}C_2$]tyrosine]oxytocin, 70480-05-6; H-Cys(DMB)-DL-[3′,5′-$^{13}C_2$]Tyr-Ile-Gln-Asn-Cys-(DMB)-Pro-Leu-Gly-NH_2, 70513-47-2; [2-D-[3′,5′-$^{13}C_2$]tyrosine]-oxytocin, 70480-07-8; [2-[3′,5′-$^{13}C_2$]tyrosine]oxytocin, 70480-06-7; *N*-trifluoroacetyl-DL-[3′,5′-$^{13}C_2$]tyrosine, 70479-87-7.

Acid- and Base-Catalyzed Isomerization of *cis*-1,2-Diarylacrylonitriles

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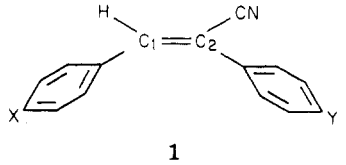
The isomerization kinetics of *cis*-1,2-*p*-substituted-diphenylacrylonitriles and *cis*-1-aryl-2-phenylacrylonitriles (Ar = 2-furyl, 2-thienyl, 2-selenophenyl) have been studied in a solution of decahydronaphthalene with methanesulfonic acid and potassium *tert*-butoxide as catalysts. The acidic isomerization is slower than the basic one and is characterized by highly positive entropy changes. The substituents produce similar effects in both reactions. The general scheme of the isomerization includes (i) nucleophilic addition of the catalyst to the double bond, (ii) free rotation around the formed single bond, and (iii) elimination of the catalyst from the trans rotamer. In the acid isomerization, the heterocycle-containing acrylonitriles react faster than the phenyl derivative owing to the greater inductive effects and the lesser steric congestion of heterocycles. A satisfactory correlation of the reactivities with a combination of polar and steric effects is observed by an appropriate two-parameter equation. In the base-catalyzed isomerization a correlation with mesomeric constants of heterocycles is found.

In previous work we have studied the isomerization kinetics of *cis*-1,2-diarylethylenes[1] and *cis*-1,2-diarylacrylonitriles,[2] in decahydronaphthalene with selenium as catalyst. It has been ascertained that the cis–trans conversion proceeds through a stepwise radical mechanism initiated by the paramagnetic biatomic selenium.[2]

Our interest is now devoted to the study of this isomerization process by other catalysts in order to measure kinetic effects and suggest plausible reaction schemes. Thus, in this paper we report the rate constants and the activation parameters for the acid- and base-catalyzed isomerizations of *cis*-1,2-*p*-substituted-diphenylacrylonitriles (1) in decahydronaphthalene.



1

X = OCH_3, CH_3, H, Cl, NO_2; Y = H
X = H; Y = OCH_3, CH_3, Cl, NO_2

Several cis-substituted ethylenes, for example, stilbenes, unsaturated acids, chalcones, and so on, have been isomerized in aqueous or organic solutions of acids[3–5] and

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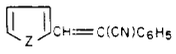
Table I. Rate Constants at 170 °C for the Acid- and Base-Catalyzed Isomerization of *cis*-1,2-Diphenylacrylonitrile (DPA) and of *cis*-1-(2-Thienyl)-2-phenylacrylonitrile (TPA)

	acid-catalyzed isomerization			base-catalyzed isomerization		
	$10^2[CH_3SO_3H]$, M	DPA 10^7k_1, s^{-1}	TPA 10^6k_1, s^{-1}	$10^2[(CH_3)_3COK]$, M	DPA 10^5k_1, s^{-1}	TPA 10^4k_1, s^{-1}
	0.5		1.67	0.5		0.472
	1.0	2.32	3.25	1.0	1.15	0.875
	1.5		4.35	1.5	1.68	1.30
	2.0	4.57	6.47	2.0	2.25	1.68
	2.5		7.78	2.5	2.87	
	3.0	6.38				
k_2,[a] M^{-1} s^{-1}		2.03×10^{-5}	3.09×10^{-4}		1.15×10^{-3}	8.10×10^{-3}

[a] Obtained by the least-squares method between k_1 values and catalyst concentrations.

Table II. Second-Order Rate Constants and Activation Parameters for the Acid-Catalyzed Isomerization of *cis*-1,2-Diarylacrylonitriles (1 and 2) in Decahydronaphthalene

	10^5k_2, M^{-1} s^{-1}			$\Delta H^{\ddagger}$,[a]	$\Delta S^{\ddagger}$,[a]	$\Delta G^{\ddagger}$,
	150 °C	170 °C	190 °C	kcal mol^{-1}	cal mol^{-1} K^{-1}	kcal mol^{-1}
$XC_6H_4CH{=}C(CN)C_6H_4Y$						
X = OCH_3 Y = H	0.172	1.68	18.0	44.4 (1.9)	19.1 (4.1)	35.9
X = CH_3 Y = H	0.177	1.93	24.3	47.1 (2.2)	25.4 (4.8)	35.8
X = H Y = H	0.209	2.03	32.6	48.2 (4.2)	28.4 (9.5)	35.6
X = Cl Y = H	0.532	3.86	42.7	41.7 (3.5)	15.0 (8.0)	35.0
X = NO_2 Y = H	2.68	14.1	103	34.6 (2.9)	1.4 (6.4)	34.0
X = H Y = OCH_3	0.543	4.46	54.5	43.9 (3.5)	20.2 (8.1)	34.9
X = H Y = CH_3	0.284	3.20	40.1	47.3 (2.0)	27.0 (4.4)	35.3
X = H Y = Cl	0.202	2.09	24.2	45.7 (2.0)	22.6 (4.4)	35.7
X = H Y = NO_2	0.103	0.908	11.8	45.2 (3.5)	20.0 (7.9)	36.3
						
Z = O	21.3	52.6	157	18.5 (1.6)	−32.3 (3.7)	32.8
Z = S	11.1	30.9	113	21.7 (2.2)	−26.2 (4.9)	33.3
Z = Se	19.2	43.5	126	17.4 (1.6)	−35.2 (4.2)	33.0

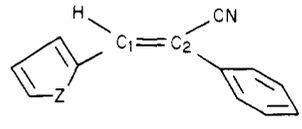
[a] Standard deviation in parentheses.

bases.[5,6] The proposed isomerization pathways seem to be enough clarified but cannot be generalized because the experimental conditions of isomerization are different from each other, the solvent participation, in most cases, involving specific features. In order to obtain homogeneous data for both acid- and base-catalyzed isomerization for a useful mechanistic comparison, we have chosen decahydronaphthalene as a solvent, since it behaves as an inert reaction medium. In fact this solvent does not show solute–solvent interactions because of its low dielectric constant and its extremely poor capability of electrophilic and nucleophilic solvations.[7]

On the other hand, an aqueous solvent cannot be used as reaction medium for base-catalyzed isomerizations because cleavage of diarylacrylonitriles occurs.[8]

Methanesulfonic acid and potassium *tert*-butoxide have been chosen as catalysts not only for their high acidity[9] and basicity,[10] respectively, but also for their good solubilities in the reaction medium at the reaction temperatures (150–190 °C).

Furthermore, in connection with recent studies on the side-chain reactivity of five-membered heterocyclic compounds,[11] we have investigated the acid- and base-catalyzed isomerizations of *cis*-1-aryl-2-phenylacrylonitriles (2) to provide an additional contribution to the knowledge of the electrical effects in the heteroaromatic ring systems.



2
Z = O, S, Se

Results

The thermal isomerization of *cis*-1,2-diarylacrylonitriles in decahydronaphthalene at 150–190 °C is negligible, but catalytic amounts of methanesulfonic acid and potassium *tert*-butoxide yield quantitatively trans isomers; on the other hand, the reverse catalyzed isomerization of authentic samples of *trans*-1,2-diarylacrylonitriles is not detectable under the same experimental conditions.

Kinetics of isomerization, followed by GLC analysis of both isomers, are consistent with a first-order rate law to at least 90% completion; pseudo-first-order rate constants (k_1) increase linearly on increasing catalyst concentrations, as shown in Table I. The reaction is also first order with respect to catalyst. Second-order rate constants (k_2) were calculated from the slopes of the plots of k_1 against catalyst

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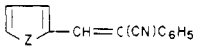
Table III. Second-Order Rate Constants and Activation Parameters for the Base-Catalyzed Isomerization of *cis*-1,2-Diarylacrylonitriles (1 and 2) in Decahydronaphthalene

	10^4k_2, M^{-1} s^{-1}			$\Delta H^{\ddagger}$,[a]	$\Delta S^{\ddagger}$,[a]	$\Delta G^{\ddagger}$,
	150 °C	170 °C	190 °C	kcal mol^{-1}	cal mol^{-1} K^{-1}	kcal mol^{-1}
$XC_6H_4CH=C(CN)C_6H_4Y$						
X = OCH_3 Y = H	5.88	8.03	11.1	5.3 (0.2)	−61.5 (0.6)	32.5
X = CH_3 Y = H	6.87	9.05	12.7	5.1 (0.5)	−61.7 (1.2)	32.4
X = H Y = H	8.53	11.5	16.3	5.4 (0.4)	−60.5 (1.0)	32.2
X = Cl Y = H	9.18	14.6	28.2	10.0 (1.4)	−49.6 (3.2)	32.0
X = NO_2 Y = H	20.0	36.3	135	17.6 (4.6)	−30.2 (10)	31.0
X = H Y = OCH_3	26.8	52.7	141	15.2 (2.1)	−35.1 (4.9)	30.8
X = H Y = CH_3	17.5	31.5	35.2	6.0 (2.5)	−57.5 (6.4)	31.5
X = H Y = Cl	2.32	4.20	5.48	7.6 (2.7)	−57.8 (5.1)	33.2
X = H Y = NO_2	0.265	0.385	0.420	3.6 (1.4)	−71.5 (3.5)	35.3
						
Z = O	11.7	18.7	31.5	8.7 (0.5)	−52.0 (1.3)	31.7
Z = S	35.2	81.0	183	15.2 (0.3)	−34.6 (0.8)	30.5
Z = Se	17.1	36.5	102	16.5 (2.8)	−33.1 (4.6)	31.1

[a] Standard deviation in parentheses.

Table IV. Application of the Hammett Equation

	$XC_6H_4CH=C(CN)C_6H_5$					$H_5C_6CH=C(CN)C_6H_4Y$				
T, °C	R	ρ_X	log k_0	s_{ρ_X}	$s_{\log k_0}$	R	ρ_Y	log k_0	s_{ρ_Y}	$s_{\log k_0}$
				Acid Isomerization						
150	0.985	1.20	−5.55	0.12	0.05	0.993[a]	−0.45	−5.65	0.03	0.02
170	0.985	0.90	−4.59	0.09	0.04	0.991[a]	−0.45	−4.67	0.03	0.02
190	0.995	0.69	−3.52	0.04	0.02	0.983[a]	−0.43	−3.55	0.05	0.02
				Base Isomerization						
150	0.988	0.49	−3.10	0.04	0.02	0.998	−1.93	−3.10	0.07	0.03
170	0.997	0.62	−2.94	0.03	0.01	0.998	−2.02	−2.87	0.07	0.03
190	0.992	1.05	−2.73	0.08	0.03	0.987	−2.25	−2.69	0.21	0.08

[a] In this correlation σ^+ values have been used.

concentrations. The *zero* intercept of the obtained straight lines confirms that thermal isomerization, in the absence of catalyst, does not proceed spontaneously with noticeable rates.

Tables II and III report k_2 values determined at 150, 170, and 190 °C for the acid- and base-catalyzed isomerizations, respectively, together with the activation parameters calculated at 170 °C.

Base-catalyzed isomerization is faster than the acid-catalyzed one: for *cis*-1,2-diphenylacrylonitrile the rate constant in basic medium at 150 °C is about 400 times faster than in the acidic medium, but the reactivity ratio becomes about 5 at 190 °C. The activation parameters show special features: the acid-catalyzed isomerizations are characterized by highly positive $\Delta H^{\ddagger}$ and $\Delta S^{\ddagger}$ values, while the base-catalyzed reactions show lower $\Delta H^{\ddagger}$ and negative $\Delta S^{\ddagger}$ values.

The substituents produce similar effects in both reactions, being favored by electron-withdrawing groups in the X-substituted phenyl ring and by electron-donating groups in the Y-substituted one. Table IV reports the results of the correlations by the Hammett equation.

Heterocycle-containing acrylonitriles react faster than the phenyl derivative; in the acid-catalyzed isomerization the reactivity order is *2-furyl* > *2-selenophenyl* > *2-thienyl* > *phenyl*, while the sequence *2-thienyl* > *2-selenophenyl* > *2-furyl* > *phenyl* is found in the base-catalyzed isomerization. Higher $\Delta H^{\ddagger}$ and less negative $\Delta S^{\ddagger}$ values are associated with the acid-catalyzed isomerization, in comparison with the base-catalyzed one.

Discussion

Isomerization by Methanesulfonic Acid. Electrophilic addition in ethylene derivatives is favored by the presence of π electrons; nevertheless, when an electron-withdrawing group is α linked to the double bond, the electron availability for electrophilic attack is drastically reduced since a partial positive charge is present at the β-carbon atom; thus, nucleophilic addition in the latter position occurs easily.[12]

This general trend can be applied to the interaction of methanesulfonic acid with *cis*-1,2-diarylacrylonitriles. In fact, electrophilic attack is strongly inhibited by the presence of the electron-withdrawing CN group and owing to the negligible dissociation of methanesulfonic acid in decahydronaphthalene; nucleophilic attack is also unfavored owing to the weak nucleophilicity of the methanesulfonic group.[13]

Simultaneous addition of nucleophilic and electrophilic parts of undissociated $MeSO_3H$ to the double bond is then probable, with formation of a tetraatomic complex in which the rate-limiting step (RLS), represented by the OH bond breaking, occurs after addition (Figure 1). Then, the free fast rotation around the single C_1–C_2 bond and the departure of the leaving methanesulfonic acid from the trans rotamer yield the energetically more favored trans olefin which is sterically less hindered than the starting cis olefin.

The methanesulfonate ion is an excellent leaving group and can easily abstract a proton from the C_2 atom; in fact, alkylsulfonic groups are quoted among the most mobile groups in saturated aliphatic S_N reactions,[14] as well as in

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(14) J. Hine, "Physical Organic Chemistry", 2nd ed., McGraw-Hill, New York, 1962, p 182.

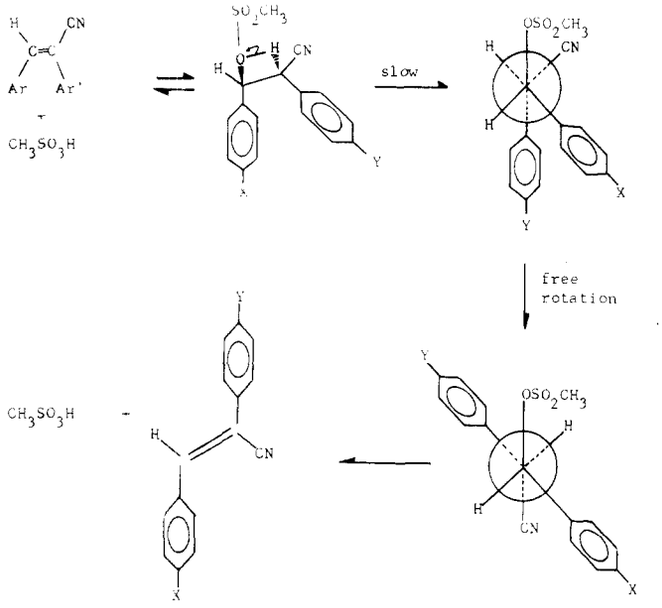

Figure 1. Scheme of the acid-catalyzed isomerization of *cis*-1,2-diarylacrylonitriles.

activated (addition–elimination) aromatic S_N reactions.[15]

This mechanism is supported by the observed substituent effects (Table II): electron-withdrawing groups in X and electron-releasing groups in Y, increasing positive and negative charges at C_1 and C_2 atoms, respectively, accelerate the reaction rate.

Positive $\Delta S^{\ddagger}$ values argue against simultaneous addition as the rate-determining step since the formation of a cyclic transition state would involve negative $\Delta S^{\ddagger}$ by loss of translational freedom; however, if the rate-limiting step occurs after addition, as postulated, the increase of rotational degrees of freedom by bulky groups with high inertial moment and low rotation energy would provide a remarkable positive contribution to $\Delta S^{\ddagger}$ values.

An alternative mechanism could be represented by the initial protonation of the N atom of a cyano group, followed by addition of $MeSO_3^-$, as the rate-limiting step. Since $MeSO_3H$ is weakly dissociated in BuCN and MeCN,[16] postulating proton transfer to the N atom is not unreasonable.

However, the kinetic evidence (substituent effect, and $\Delta S^{\ddagger}$ values) is better explained in terms of the former mechanism. In fact, if a carbenium ion was formed on the C_1 atom, one would expect a correlation with σ^+ values of the X substituents and a rate acceleration higher than that observed; moreover, the formation of a polar transition state is not consistent with the observed positive $\Delta S^{\ddagger}$ values.

Another possible mechanism is the free radical addition which is also consistent with the small substituent effect and the positive entropy. However, this mechanistic hypothesis was ruled out because no kinetic effects were observed in the acid isomerizations carried out in the presence of benzoyl peroxide or hydroquinone, as radical initiator or inhibitor, respectively.

Isomerization by Potassium *tert*-Butoxide. The above argument concerning acid-catalyzed isomerization can be applied to the base-catalyzed one, apart from some quantitative differences. In fact, the higher reaction rates (Table III) originate from a greater nucleophilicity of the potassium *tert*-butoxide, bearing a localized charge on the oxygen atom, and by an additional delocalization of the negative charge in the resultant carbanion intermediate; of course, the energetic gap for the syn-adduct formation is lowered, as the activation parameters well indicate. The overall isomerization scheme is depicted in Figure 2.

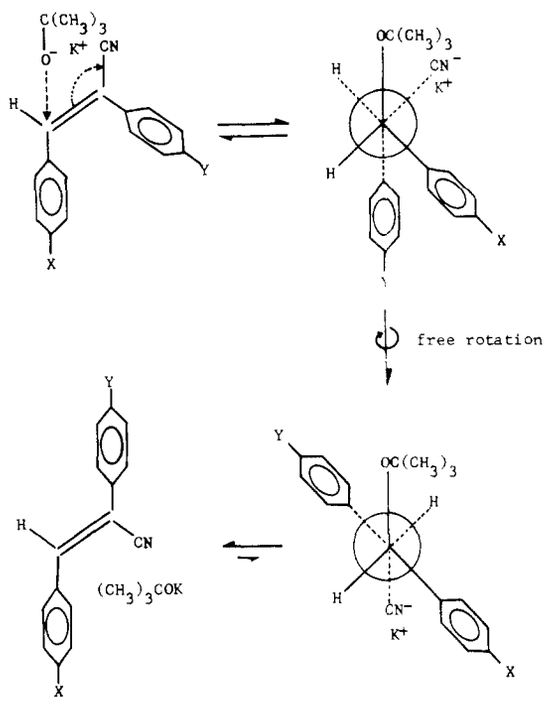

Figure 2. Scheme of the base-catalyzed isomerization of *cis*-1,2-diarylacrylonitriles.

Nucleophilic attack of the alkoxide group at the most positive C_1 atom has already been indicated by Kroeger and Stewart, who used *trans*-1,2-diarylacrylonitriles as Lewis acids to establish the basicity scale H_R-.[17]

In the base-catalyzed isomerization the creation of a pair of unit charges is known to give negative contributions to $\Delta S^{\ddagger}$, since the delocalization of charges decreases the freedom degrees. Moreover, the most negative entropy change is associated with the isomerization of the *p*-nitro (Y) derivative where a supplementary charge separation is possible.

Substituent effects in both rings indicate that the rate-determining step is the nucleophilic attack of the catalyst to the olefinic double bond. The values of ρ_X^B and ρ_Y^B (Table IV) are positive and negative, respectively, as the corresponding ρ^A values in the acid-catalyzed isomerization.

Although potassium *tert*-butoxide is a more active catalyst with respect to methanesulfonic acid, the ρ_Y^B values are greater than ρ_Y^A ones, in apparent contrast with the reactivity–selectivity principle (RSP).[18]

This is not surprising, because Hammett ρ values are misleading indexes of selectivity.[19] In fact, these constants mainly reflect the ability of a system to transmit the substituent effects to the reaction center; but this ability is variable, since it depends on the charge development in the transition state.

In the acid-catalyzed isomerization, a neutral intermediate is formed, while a carbanionic transition state is present in the base-catalyzed isomerization. Therefore, a comparison of ρ values, as a measure of selectivity, appears to be unreliable.

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Table V. Statistical Results from the Application of Equation 2 for the Acid-Catalyzed Isomerization of *cis*-X-Substituted-1,2-diphenylacrylonitriles and *cis*-1-Aryl-2-phenylacrylonitriles in Decahydronaphthalene[a]

T, °C	variables	FD[b]	% EV[c]	R[d]	F test[e]	ρ	ψ	log k_0 calcd	log k_0 exptl	s_ρ[f]	s_ψ[f]
150	σ	6	84.6	0.920	32.9	1.78		-5.44	-5.68	0.31	
	σ, ϑ	5	97.0	0.985	81.8	1.07	-0.104	-5.53		0.21	0.023
170	σ	6	87.5	0.935	42.0	1.25		-4.53	-4.69	0.19	
	σ, ϑ	5	97.2	0.986	88.9	0.819	-0.0639	-4.58		0.143	0.0151
190	σ	6	95.6	0.978	129	0.741		-3.50	-3.49	0.065	
	σ, ϑ	5	97.3	0.986	91.0	0.636	-0.0153	-3.51		0.08	0.0084

[a] Number of observations = 8. [b] Freedom degrees. [c] Percent of explained variation. [d] Correlation coefficient. [e] Significant above 99% confidence level. [f] Standard error of the estimated ρ or ψ values.

Reactivity of Heterocycle-Containing Acrylonitriles. Five-membered heterocycles can delocalize positive charge by release of p electrons from the heteroatom; they can also accept electrons by inductive effects, as in the furan ring, or by accommodation into free d orbitals of sulfur and selenium in thiophene and selenophene, respectively.[20-22] In addition, steric effects due to different bond angles among the furan, thiophene, selenophene, and benzene rings can act together with electrical effects.[23,24]

In the acid-catalyzed isomerizations the greater reactivity of heterocyclic derivatives with respect to the X-substituted diphenylacrylonitriles could be ascribed to the stronger electron-withdrawing effects of five-membered heterocycles in the ground state, as indicated by the strength of arylcarboxylic acids[25] and by polar σ* values.[26] The capability of electron release from the heteroatom to the side chain bearing a partial positive charge is inhibited by the noncoplanarity of the heteroaryl ring with the ethylenic fragment, as dipole moments and conformations of the parent *cis*-2-styrylfurans and *cis*-2-styrylthiophenes have pointed out.[27] Thus, only polar effects can be transmitted at the adjacent ethylenic carbon atom.

A satisfactory Hammett plot, including heterocyclic and X-substituted phenyl derivatives, is found in the isomerization at 190 °C (Figure 3).[28] But analogous plots at lower temperatures show remarkable positive deviations for heterocyclic derivatives. This can be ascribed to a minor steric congestion on these compounds, due to a smaller internal angle,[29] in comparison with the benzene ring. On increasing temperature, differences in steric barriers are leveled, so that the Hammett plot appears to be linear.

To verify this interpretation by a quantitative method, we tested the two-parameter (polar and steric) equation (1), where the ρσ term refers to the contribution of

$$\log k_2 = \rho\sigma + \psi\vartheta + \text{constant} \quad (1)$$

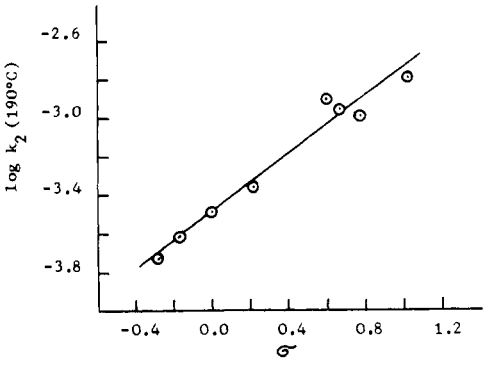

Figure 3. Hammett plot for the acid-catalyzed isomerization of X-substituted diphenylacrylonitriles and 1-(2-heteroaryl)-2-phenylacrylonitriles.

electrical effects (Hammett equation, at constant steric effects), ψ is the susceptivity of the reaction to steric effects, and ϑ represents the difference between the internal angle Z–C_α–C_β in the heterocycle[29] and the 120° of the phenyl ring. In such a manner the value of the constant term affords the calculated log k_0 of the benzene derivative, whose σ and ϑ are zero.

We have not taken into account the Taft–Pavelich equation[30] (2)to separate polar and steric effects, since a

$$\log k_2 = \rho^*\sigma^* + \delta E_s + \text{constant} \quad (2)$$

recent examination has criticized the σ* values.[31] Furthermore, it is well-known that E_s values for aromatic and unsaturated groups do not represent a good measure of steric effects, because a remarkable contribution of resonance effects is involved.[32]

The results of the correlations with eq 2 (Table V) are statistically more satisfactory with respect to the single-parameter (σ) correlations. The signs of the ρ and ψ values, positive and negative, respectively, are consistent with the proposed hypothesis, since the increase of polar effects and the decrease of steric ones favor the kinetics. The contribution of the steric effects (ψ) strongly decreases on increasing temperature, becoming negligible at 190 °C.[33]

In the base-catalyzed isomerizations, the step of adduct formation (Figure 2) is accelerated not only by the greater electrophilic character of heterocyclic substrates but also by the powerful nucleophilicity of the catalyst, so that the elimination of *tert*-butoxide probably occurs at comparable rate.[34]

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(29) The internal Z–C_α–C_β angles in furan, thiophene, and selenophene are 110.68, 111.47, and 111.56°, respectively: F. Fringuelli, G. Marino, and A. Taticchi, *Adv. Heterocycl. Chem.*, **21**, 121 (1977), and references therein.
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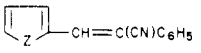
(33) A criticism of these results could arise from the limited range of the employed ϑ values; a more extended interval would assure us about the "chemical" significance of the correlation better than does the found "statistical" goodness.

Table VI. Spectroscopic Properties of *cis*-1,2-Diarylacrylonitriles[a]

		UV spectra[b] λ, nm/log ε	IR frequencies,[c] cm^{-1} C=C	IR frequencies,[c] cm^{-1} C=N	mp or bp, °C (mm)	ref
$XC_6H_4CH=C(CN)C_6H_4Y$						
X = OCH_3	Y = H	235/4.20; 318/4.27	1603	2205	128	*d*
X = CH_3	Y = H	229/4.24; 299/4.22	1605	2210	94	*d*
X = H	Y = H	224/4.36; 295/4.22	1604	2222	137 (0.25)	*e*
X = Cl	Y = H	228/4.22; 298/4.19	1590	2190	70	*d*
X = NO_2	Y = H	265/4.14; 316/4.22	1597	2223	121	*d*
X = H	Y = OCH_3	233/4.15; 326/4.09	1607	2214	55	*d*
X = H	Y = CH_3	225/4.22; 299/4.04	1606	2212	140 (0.35)	*d*
X = H	Y = Cl	234/4.39; 295/4.20	1595	2215	57	*e*
X = H	Y = NO_2	264/4.19; 308/4.05	1594	2220	133	*d*
						
Z = O		235/3.95; 320/4.25	1610	2210	142 (0.3)	*d*
Z = S		245/3.73; 320/4.28	1597	2212	157 (0.3)	*d*
Z = Se		244/3.75; 299/4.24	1595	2215	168 (0.35)	*d*

[a] Satisfactory combustion analytical data for C, H, N (±0.2%) were found. [b] Measured in 95% C_2H_5OH. [c] Measured in $CHCl_3$. [d] This work. [e] Reference 37.

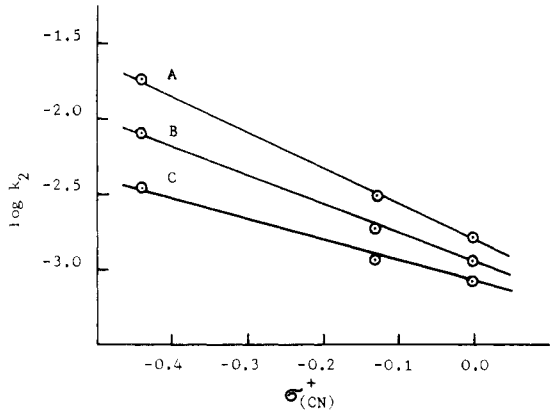


Figure 4. Correlation between log k_2 of the base-catalyzed isomerization at 150 (A), 170 (B), and 190 °C (C) with the following σ_{CN}^+ values of the heterocycles: thiophene, −0.44; furan, −0.13; benzene, 0.00.[36] The data for selenophene derivative are not included in the correlations because of the lack of the appropriate σ_{CN}^+ value.

In this case no correlation with σ or with a combination of σ and ϑ values can be expected, because the rate-limiting step also involves elimination of *tert*-butoxide anion from the less sterically hindered trans rotamer. Hence, some correlation with mesomeric constants can be expected.

The reactivity order suggests a dependence on σ_{CN}^+ values,[35] which are a measure of the electron release from heterocycles to a side chain having a moderate electron request. The correlation (Figure 4) indicates that the reaction center is moderately conjugated with the heterocycle and is stabilized by electron-donating groups,[36] just required for the departure of an anion in the rate-determining step.

Experimental Section

Materials. *cis*- and *trans*-1,2-diarylacrylonitriles were synthesized following literature methods.[2,37-39] Melting or boiling points and spectroscopic characteristics (UV and IR) of the new cis isomers are reported in Table VI. Decahydronaphthalene, methanesulfonic acid, and potassium *tert*-butoxide (commercial products, AnalaR grade) were used without further purification.

Kinetic Procedure. To an appropriate amount of cis isomer in 5 mL of decahydronaphthalene (about 0.15 M), placed in a glass stoppered bottle and maintained at constant temperature, was added 5 mL of a catalyst solution (for catalyst concentration, see Table I). At suitable intervals, aliquots were removed by a microsyringe and analyzed by GLC by the procedure already described.[1,2]

Statistical Calculations. The statistical parameters of eq 2 (Table V) have been calculated by a program on the CDC 7600 computer. To find the best equation we used the stepwise regression procedure.[40]

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Registry No. 1 (X = OCH_3, Y = H), 10077-32-4; 1 (X = CH_3, Y = H), 10077-34-6; 1 (X = H, Y = H), 16610-80-3; 1 (X = Cl, Y = H), 70528-19-7; 1 (X = NO_2, Y = H), 10077-28-8; 1 (X = H, Y = OCH_3), 16610-79-0; 1 (X = H, Y = CH_3), 70528-20-0; 1 (X = H, Y = Cl), 16610-81-4; 1 (X = H, Y = NO_2), 16610-82-5; 2 (Z = O), 70528-21-1; 2 (Z = S), 70528-22-2; 2 (Z = Se), 70528-23-3.

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