Mononuclear Heterocyclic Rearrangements. Part 13.[1] Substituent Effects on the Rearrangement of Some *Z*-Arylhydrazones of 3-Benzoyl-5-phenyl-1,2,4-oxadiazole to 2-Aryl-4-benzoylamino-5-phenyl-1,2,3-triazoles in Benzene, Dioxane, Ethyl Acetate, Acetonitrile, and Methanol

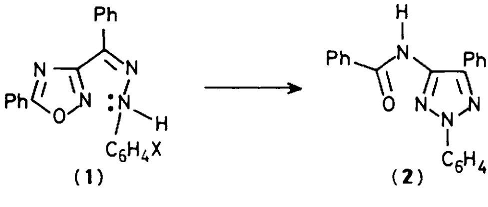
Vincenzo Frenna, Nicolò Vivona, and Luciano Cannella
Istituto di Chimica Organica, Università di Palermo, Via Archirafi 20, Palermo 90123, Italy
Giovanni Consiglio and Domenico Spinelli *
Istituto di Scienze Chimiche, Facoltà di Farmacia, Via S. Donato 15, Bologna 40127, Italy

The effects of substituents in the aryl fragment of the *Z*-arylhydrazones of 3-benzoyl-5-phenyl-1,2,4-oxadiazole (**1**) on the rate of the title reaction have been studied at 313.15 K. The results indicate a changeover of mechanism with changing substituent: in fact in benzene, dioxane, and methanol non-linear concave-upward Hammett plots were observed. In ethyl acetate and acetonitrile also, a tendency to an inversion in the substituent effects is present, but it is less pronounced. A comparison of reactivity in the various solvents of the *p*-nitrophenylhydrazone with that of the unsubstituted compound shows reactivity ratios which strongly increase on going from benzene to ethyl acetate, through dioxane, according to the polar nature of the transition state for the mononuclear heterocyclic rearrangement.

We have recently studied the mononuclear heterocyclic rearrangements[2] of a series of *Z*-arylhydrazones of 3-benzoyl-5-phenyl-1,2,4-oxadiazole in dioxane–water (DIOX–W), at various pS^+ values.[3] The substituent effects, as represented by Hammett correlations, were shown to be affected by pS^+. Moreover, we showed that a changeover of the structure of the transition state occurs as a function of pS^+ and of the substituent present. For example, at pS^+ 3.80 (in the pS^+-independent range)[3a] the reactivity of *Z*-arylhydrazones depends on a balance of various factors, the nucleophilicity of N(α) being the prevailing one. As a result, the reaction rate increases or decreases with increasing electron-donating or -withdrawing power of the substituents, respectively (negative Hammett ρ value). The course of reaction is affected by the susceptibility to cleavage of the N(α)–H bond, as a function of the substituent, in the opposite way; thus, the absolute value of the calculated susceptibility constant was small [the Ingold–Yukawa–Tsuno equation obtained was $\log k_X/k_H = -1.31[(\sigma^n + 0.10\Delta\sigma^+ + 0.25\Delta\sigma^-)]$.[3a] On the other hand, in the pS^+-dependent range, where the rearrangement is base-catalysed, both electron-donating and -withdrawing substituents increase the reactivity and the two relevant linear free energy relationships give rise to a non-linear concave-upward Hammett plot [for example, at pS^+ 11.5, $\log k_X/k_H = -0.33\sigma^+$ and $\log k_X/k_H = +2.21\ (\sigma^n + 0.60\Delta\sigma^-)$ for electron-donating and -withdrawing substituents, respectively].[3b] At intermediate pS^+ values scattering was observed in the Hammett plots.

In order to gain information on the effects of substituents in the arylhydrazone moiety on the reaction rate, as a function of solvent, we have studied the rearrangement, catalysed by piperidine (PIP), of compounds (**1a**—**o**) in benzene (PhH), of (**1a**, **b**, and **e**—**o**) in dioxane, and of (**1a**, **f**, and **o**) in ethyl acetate (EA), methanol (MeOH), and acetonitrile (ACN), at 313.15 K.†

As we have recently pointed out, in the rearrangement of (**1f**) in various solvents the nature of the solvent (protic or aprotic, polar or apolar, basic or not) strongly affects the structures of the transition states and thus the reactivity.[4] Moreover, depending on the solvent, different kinetic laws have been obtained.



(**1**) (**2**)

a; X = *p*-OMe
b; X = *p*-Me
c; X = *p*-Et
d; X = *m*-Et
e; X = *m*-Me
f; X = H
g; X = *p*-Cl
h; X = *p*-Br
i; X = *m*-Cl
l; X = *m*-Br
m; X = *p*-CN
n; X = *m*-NO_2
o; X = *p*-NO_2

For example in PhH, (**1f**) rearranges to (**2f**) through two different catalysed pathways, involving one or two molecules of piperidine according to equation (1).‡ The same kinetic law

$$k_A/[\mathrm{PIP}] = k_{II} + k_{III}[\mathrm{PIP}] \qquad (1)$$

applies to the rearrangements of (**1f**) in DIOX and in EA.

In PhH, DIOX, or EA (low-polarity solvents) the uncatalysed pathway makes only a little contribution to the global reactivity (For a discussion of this point see ref. 4.) In contrast, the uncatalysed pathway provides a significant contribution to the reaction rate in both MeOH and ACN, according to the polar nature of these solvents. Moreover, the catalysis of catalysis, as measured by the k_{III} term, is absent in MeOH and is detectable in ACN only at high piperidine concentrations. (For a discussion of this point see ref. 5.) Therefore (**1f**) rearranges to (**2f**) in ACN according to equation (2) or (3) (where k_u refers to the

$$k_A = k_u + k_{II}[\mathrm{PIP}] \qquad (2)$$

$$k_A = k_u + k_{II}[\mathrm{PIP}] + k_{III}[\mathrm{PIP}]^2 \qquad (3)$$

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† The piperidine-catalysed reaction pathway in these solvents[4] corresponds to the base-catalysed pathway in DIOX–W.

‡ Here k_{II} and k_{III} refer to reaction pathways involving one molecule of (**1f**) and one or two molecules of PIP, respectively.

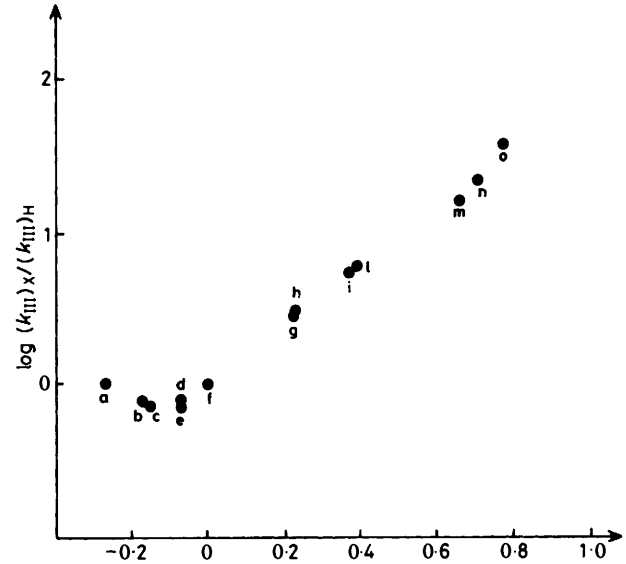

Figure. Plot of $\log(k_{III})_X/(k_{III})_H$ *vs.* σ for the rearrangement (**1**) $\longrightarrow$ (**2**) at 313.15 K in PhH

uncatalysed pathway), depending on the range of piperidine concentrations used, as a function of the reaction temperature. For example at 313.15 K the observed catalysis law is equation (2), whereas at 283.15 K it is equation (3).[5]

The protonation of piperidine in MeOH (PIP + MeOH $\rightleftharpoons$ PIP·H$^+$ + MeO$^-$) causes the presence of a significant concentration of methoxide ion in the reaction mixtures. Because of the ability of methoxide ion to behave as a basic catalyst, the rearrangement rate depends on both PIP and MeO$^-$ concentrations according to equation (4).*

$$k_A = k_u + k_{PIP}[\mathrm{PIP}] + k_{MeO}[\mathrm{MeO}^-] \qquad (4)$$

Results and Discussion

Rearrangement of Hydrazones (**1a**—**o**) *in* PhH.—The apparent first-order kinetic constants, k_A, for the rearrangement (**1**) $\longrightarrow$ (**2**) have been measured at various piperidine concentrations. For all the substituents we observed a strong dependence of the reactivity on piperidine concentration, with excellent plots of k_A/[PIP] *versus* [PIP]. The results of linear regression analysis of k_A values according to equation (1) are reported in Table 1. The dependence of the reactivity on the substituent parallels that observed in DIOX–W for the pS^+-dependent range:[3b,6] *i.e.* both electron-donating and -withdrawing substituents increase the reactivity.

The k_{II} values are statistically different from zero only for the rearrangements of compounds (**1a**—**f**), *i.e.* those containing electron-donating substituents. Indeed, since the reaction rate is related, *inter alia*, to the ability of N(α) to act as a nucleophile, the electron-withdrawing substituents disfavour the bimolecular reaction pathway and make k_{II} undetectable. Accordingly, the k_{II} values give a good Hammett plot with a negative susceptibility constant (ρ − 1.02; see Table 4). In contrast, the k_{III} values, which can be calculated for the whole range of substituents, give a non-linear concave-upward Hammett plot[7] (Figure) with a minimum between (**1c**; X = *p*-Et) and the pair of points for (**1d**, **e**; X = *m*-Et and *m*-Me). The high susceptibility constant (ρ 1.93; see Table 4) relative to compounds (**1d**—**o**) indicates that the electron-withdrawing substituents greatly increase the reactivity.†

The reactivity also increases on going from (**1c**; X = *p*-Et) to (**1a**; X = *p*-OMe), *i.e.* with increasing electron-donating power of the substituent, indicating a negative susceptibility constant: therefore we observe again the prevalence of the nucleophilic character of the nitrogen atom. In this case, a choice of a particular type of substituent constant (σ$^+$ or σ) for calculating the ρ value has no meaning, because two out of the three electron-donating substituents have very close σ and σ$^+$ values and the two different linear free energy relationships would be based on only two points.

The relative importance of the termolecular catalysed pathway (probably the second molecule of piperidine exerts catalysis of catalysis[4,8]) increases with decreasing electron-donating power of the substituent: in fact k_{III}/k_{II} (see Table 1) ranges from 12 for strongly electron-donating substituents (*p*-OMe, *p*-Me, and *p*-Et), to 14 for weakly electron-donating substituents (*m*-Et and *m*-Me), to 23 for hydrogen, and to infinity for electron-withdrawing substituents.

Rearrangement of Hydrazones (**1a**, **b**, *and* **e**—**o**) *in DIOX and* (**1a**, **f**, *and* **o**) *in EA*.—The apparent first-order kinetic constants, k_A, for the rearrangement (**1**) $\longrightarrow$ (**2**) in the two solvents have been measured at various piperidine concentrations. In both solvents we observed a strong dependence of the reactivity on piperidine concentration for all the substituted compounds and obtained linear plots of k_A/[PIP] *versus* [PIP]. The k_{II} and k_{III} values calculated as before are set out in Tables 2 and 3. In agreement with the sharp decrease observed in the k_{III}/k_{II} ratios for (**1f**) on going from PhH to DIOX and EA (k_{III}/k_{II} 24, 3, and 3.2 l mol^{-1}, respectively) both catalysed reaction pathways are operating in the two latter solvents whatever the substituent present.

In DIOX both k_{II} and k_{III} give non-linear concave-upward Hammett plots (not shown) with a minimum between (**1b**; X = *p*-Me) and (**1e**; X = *m*-Me). In both cases, excellent linear free energy correlations with positive susceptibility constants can be observed for the arylhydrazones (**1e**—**o**). The correlations are improved if the Yukawa–Tsuno treatment is used instead of the Hammett equation (see Table 4). Both k_{II} and k_{III} increase with increasing electron-donating power of the substituents [$(k_{II})_{(1a)} > (k_{II})_{(1b)}$ and $(k_{III})_{(1a)} > (k_{III})_{(1b)}$] but no linear free energy correlation makes sense with only two substituents (see before).

In EA, data have been collected only for two arylhydrazones, containing an electron-donating (**1a**; X = *p*-OMe) and an electron-withdrawing substituent (**1o**; X = *p*-NO$_2$), respectively, and have been compared with previous data for the unsubstituted phenylhydrazone (**1f**). The introduction of an electron-withdrawing and of an electron-donating substituent causes, respectively, a large increase and a small decrease in reactivity, showing that in EA the tendency to an inversion in the substituent effects is less pronounced than in PhH and in DIOX.

In both DIOX and EA the relative weight of the two catalysed pathways changes with the substituent: k_{III}/k_{II} increases on

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* Since in MeOH the rearrangement is *general* base-catalysed, in equation (4) we have specified the contributions of the various catalytic pathways and used the symbol k_{PIP} instead of k_{II}.

† The behaviour of compounds (**1d**—**o**) agrees with the expectation that for this range of substituents the reaction pathway depends on the acidic character of the hydrazonic hydrogen atom [N(α)–H) which increases with increasing electron-withdrawing power of the substituents. The higher the degree of fission of the nitrogen–hydrogen bond brought about by the first molecule of piperidine, the greater the need for a second molecule of piperidine which favours the dispersion of the positive charge in the non-polar solvent.

Table 1. Linear regression analysis[a] of apparent first-order kinetic constants for the rearrangements (**1a**—**o**) ⟶ (**2a**—**o**) in benzene at 313.15 K, in the presence of piperidine, according to the equation $k_A/[PIP] = k_{II} + k_{III}[PIP]$

Compound	$10^5(k_{II} \pm s_{II})$ / $l\ mol^{-1}\ s^{-1}$	$10^5(k_{III} \pm s_{III})$ / $l^2\ mol^{-2}\ s^{-1}$	r	n	k_{III}/k_{II} / $l\ mol^{-1}$
(**1a**)	0.614 ± 0.047	7.60 ± 0.08	0.9996	10	12.4
(**1b**)	0.481 ± 0.004	5.62 ± 0.01	1.0000	10	11.7
(**1c**)	0.457 ± 0.005	5.42 ± 0.01	1.0000	9	11.9
(**1d**)	0.398 ± 0.023	5.81 ± 0.03	0.9999	10	14.6
(**1e**)	0.383 ± 0.019	5.39 ± 0.03	0.9999	9	14.1
(**1f**)[b]	0.321 ± 0.004	7.65 ± 0.06	0.9999	9	23.8
(**1g**)	0.01 ± 0.06	20.7 ± 0.1	0.9999	10	∞
(**1h**)	0.14 ± 0.17	22.8 ± 0.2	0.9995	11	∞
(**1i**)	0.07 ± 0.12	40.6 ± 0.2	0.9999	12	∞
(**1l**)	0.02 ± 0.21	45.2 ± 0.3	0.9998	10	∞
(**1m**)	−0.07 ± 0.51	125 ± 1	0.9998	11	∞
(**1n**)	−0.39 ± 0.52	163 ± 1	0.9998	12	∞
(**1o**)[c]	−0.3 ± 1.2	285 ± 2	0.9997	12	∞

[a] s_{II} and s_{III} are the standard deviations of the regression parameters k_{II} and k_{III}, respectively; r is the correlation coefficient; n is the number of experimental points. The confidence levels for significance of regression parameters are all better than 99.9%. [b] Data from V. Frenna, N. Vivona, D. Spinelli, and G. Consiglio, *J. Heterocycl. Chem.*, 1980, **17**, 861. [c] Data from V. Frenna, N. Vivona, D. Spinelli, and G. Consiglio, *J. Heterocycl. Chem.*, 1981, **18**, 723.

Table 2. Linear regression analysis[a] of apparent first-order kinetic constants for the rearrangements (**1a**, **b**, and **e**—**o**) ⟶ (**2a**, **b**, and **e**—**o**) in dioxane at 313.15 K, in the presence of piperidine, according to the equation $k_A/[PIP] = k_{II} + k_{III}[PIP]$

Compound	$10^5(k_{II} + s_{II})$ / $l\ mol^{-1}\ s^{-1}$	$10^5(k_{III} \pm s_{III})$ / $l^2\ mol^{-2}\ s^{-1}$	r	n	k_{III}/k_{II} / $l\ mol^{-1}$
(**1a**)	3.03 ± 0.03	8.92 ± 0.05	0.9999	9	2.94
(**1b**)	2.01 ± 0.03	7.37 ± 0.05	0.9998	9	3.67
(**1e**)	2.19 ± 0.03	7.26 ± 0.05	0.9999	9	3.32
(**1f**)[b]	3.18 ± 0.05	9.60 ± 0.08	0.9997	10	3.02
(**1g**)	6.87 ± 0.24	36.4 ± 0.4	0.9996	9	5.30
(**1h**)	7.09 ± 0.14	37.5 ± 0.2	0.9999	8	5.29
(**1i**)	9.11 ± 0.28	55.4 ± 0.5	0.9997	10	6.08
(**1l**)	9.31 ± 0.31	60.2 ± 0.5	0.9997	10	6.47
(**1m**)	34.4 ± 0.6	246 ± 1	0.9999	10	7.15
(**1n**)	28.1 ± 1.5	234 ± 2	0.9996	9	8.32
(**1o**)	60.6 ± 2.0	546 ± 4	0.9998	8	9.01

[a] The confidence levels for significance of regression parameters are all better than 99.9%; s_{II} and s_{III} are the standard deviations of the regression parameters k_{II} and k_{III}, respectively; r is the correlation coefficient; n is the number of experimental points. [b] Data from ref. 4.

Table 3. Linear regression analysis[a] of apparent first-order kinetic constants for the rearrangements (**1a**, **f**, and **o**) ⟶ (**2a**, **f**, and **o**) in ethyl acetate at 313.15 K, in the presence of piperidine, according to the equation $k_A/[PIP] = k_{II} + k_{III}[PIP]$

Compound	$10^4(k_{II} + s_{II})$ / $l\ mol^{-1}\ s^{-1}$	$10^4(k_{III} \pm s_{III})$ / $l^2\ mol^{-2}\ s^{-1}$	r	n	k_{III}/k_{II} / $l\ mol^{-1}$
(**1a**)	0.529 ± 0.006	1.75 ± 0.01	0.9999	9	3.31
(**1f**)[b]	0.574 ± 0.011	1.83 ± 0.02	0.9995	10	3.19
(**1o**)	127 ± 1	510 ± 3	0.9999	8	4.02

[a] The confidence levels for significance of regression parameters are all better than 99.9%; s_{II} and s_{III} are the standard deviations of regression parameters k_{II} and k_{III}, respectively; r is the correlation coefficient; n is the number of experimental points. [b] Data from ref. 4.

Table 4. Linear free energy relationships[a] for the mononuclear heterocyclic rearrangements (**1e**—**o**) ⟶ (**2e**—**o**) in PhH and in DIOX, at 313.15 K

Relationship	Solvent	$\rho \pm s_\rho$	$i + s_i$	r	C.L.	Hydrazones
$\log(k_{II})_X/(k_{II})_H = \rho\sigma$	PhH	−1.02 ± 0.04	0.01 ± 0.01	0.9962	>99.9	(**1a**—**f**)
$\log(k_{III})_X/(k_{III})_H = \rho\sigma$	PhH	1.93 ± 0.04	0.00 ± 0.02	0.9982	>99.9	(**1d**—**o**)
$\log(k_{II})_X/(k_{II})_H = \rho\sigma$	DIOX	1.56 ± 0.10	−0.05 ± 0.04	0.9868	>99.9	(**1e**—**o**)
$\log(k_{II})_X/(k_{II})_H = \rho\sigma$	DIOX	1.37 ± 0.05	−0.04 ± 0.02	0.9977	>99.9	(**1e**, **f**, **i**, **l**, and **n**)
$\log(k_{II})_X/(k_{II})_H = \rho[\sigma + 0.37(\sigma^- - \sigma)]$[b]	DIOX	1.38 ± 0.03	−0.04 ± 0.02	0.9984	>99.9	(**1e**—**o**)
$\log(k_{III})_X/(k_{III})_H = \rho\sigma$	DIOX	2.07 ± 0.09	0.03 ± 0.04	0.9933	>99.9	(**1e**—**o**)
$\log(k_{III})_X/(k_{III})_H = \rho\sigma$	DIOX	1.96 ± 0.03	0.01 ± 0.01	0.9997	>99.9	(**1e**, **f**, **i**, **l**, and **n**)
$\log(k_{III})_X/(k_{III})_H = \rho[\sigma + 0.15(\sigma^- - \sigma)]$[b]	DIOX	1.97 ± 0.06	0.04 ± 0.03	0.9971	>99.9	(**1e**—**o**)

[a] ρ, reaction constant; s_ρ, standard deviation of ρ; r, correlation coefficient; i, intercept of the regression line with ordinate $\sigma = 0$; s_i, standard deviation of i; C.L., confidence level (%); the substituents in the listed hydrazones (**1**) are those involved in the calculation of ρ. [b] *Cf.* ref. 3*b*.

Table 5. Linear regression analysis[a] of apparent first-order kinetic constants for the rearrangements (**1a**, **f**, and **o**) $\longrightarrow$ (**2a**, **f**, and **o**) at 313.15 K in methanol, according to the equation $k_A = k_u + k_{PIP}[PIP] + k_{MeO}[MeO^-]$

Compound	$10^4(k_u \pm s_u)$ s^{-1}	$10^4(k_{PIP} \pm s_{PIP})$ $l\ mol^{-1}\ s^{-1}$	$k_{MeO} \pm s_{MeO}$ $l\ mol^{-1}\ s^{-1}$	*r*	*n*
(**1a**)	0.406 ± 0.021	9.19 ± 0.03	1.87 ± 0.02	0.9998	48
(**1f**)[b]	0.167 ± 0.018	7.40 ± 0.03	1.39 ± 0.02	0.9998	52
(**1o**)	−0.106 ± 0.092	256 ± 1	162 ± 1	0.9998	54

[a] s_u, s_{PIP}, and s_{MeO} are the standard deviations of regression parameters k_u, k_{PIP}, and k_{MeO}, respectively; *r* is the multiple correlation coefficient. The confidence levels for significance of regression parameters are all better than 99.9%. [b] Data from ref. 4.

Table 6. Linear regression analysis[a] of apparent first-order kinetic constants for the rearrangements (**1a**, **f**, and **o**) $\longrightarrow$ (**2a**, **f**, and **o**) in acetonitrile, in the presence of piperidine, according to the equation $k_A = k_u + k_{II}[PIP]$ or $k_A = k_u + k_{II}[PIP] + k_{III}[PIP]^2$

Compound	$10^4(k_u \pm s_u)$ s^{-1}	$10^2(k_{II} \pm s_{II})$ $l\ mol^{-1}\ s^{-1}$	$10^2(k_{III} \pm s_{III})$ $l^2\ mol^{-2}\ s^{-1}$	*r*	*n*	k_{III}/k_{II} $l\ mol^{-1}$
		At 313.15 K				
(**1a**)	2.46 ± 0.10	41.5 ± 0.1		1.0000	10	
(**1f**)[b]	2.78 ± 0.88	45.4 ± 0.4		0.9997	9	
		At 283.15 K				
(**1a**)[c]	0.003 ± 0.002	3.10 ± 0.10	6.85 ± 0.02	0.9999	9	2.21
(**1f**)[c,d]	0.206 ± 0.097	3.19 ± 0.02	7.08 ± 0.11	1.0000	11	2.22
(**1o**)		415[e]			7	

[a] s_u, s_{II}, and s_{III} are the standard deviations of the regression parameters k_u, k_{II}, and k_{III}, respectively; *r* is the correlation coefficient. The confidence levels for significance of regression parameters are all better than 99.9%. [b] Data from ref. 4. [c] Kinetic data have been analysed according to the equation $k_A = k_u + k_{II}[PIP] + k_{III}[PIP]^2$. [d] Data from ref. 6. [e] Average second-order catalytic constant [see equation (5)].

Table 7. Kinetic constants and reactivity ratios for the mononuclear heterocyclic rearrangement (**1**) $\longrightarrow$ (**2**) in PhH, DIOX, EA, and ACN at 313.15 K

Solvent	$(k_u)_H$[a] s^{-1}	$(k_{II})_H$[a] $l\ mol^{-1}\ s^{-1}$	$(k_{III})_H$[a] $l^2\ mol^{-2}\ s^{-1}$	$(k_{III}/k_{II})_H$[a] $l\ mol^{-1}$	$(k_{III})_{p\text{-}NO_2}/(k_{III})_H$[b]	$(k_{II})_{p\text{-}NO_2}/(k_{II})_H$[b]
PhH		0.383×10^{-5}	7.65×10^{-5}	23.8	37.3	
DIOX		3.18×10^{-5}	9.60×10^{-5}	3.0	56.9	19.1
EA		0.574×10^{-4}	1.83×10^{-5}	3.2	280	221
ACN	2.78×10^{-4}	45.4×10^{-2}				
ACN[c]		3.19×10^{-2}	7.08×10^{-2}	2.2		134

[a] $(k_u)_H$, $(k_{II})_H$, $(k_{III})_H$, and $(k_{III}/k_{II})_H$ refer to kinetic constants and reactivity ratios for (**1f**). [b] $(k_{III})_{p\text{-}NO_2}/(k_{III})_H$ and $(k_{II})_{p\text{-}NO_2}/(k_{II})_H$ refer to the reactivity ratios of (**1o**) and (**1f**). [c] At 283.15 K.

going from arylhydrazones containing electron-donating substituents to arylhydrazones containing electron-withdrawing groups (see ratios in Tables 2 and 3).

Rearrangement of Hydrazones (**1a**, **f**, *and* **o**) *in* MeOH *and in* ACN.—The apparent first-order kinetic constants, k_A, for the rearrangements (**1a** and **o**) $\longrightarrow$ (**2a** and **o**) in these two solvents have been measured at various piperidine concentrations and compared with previous data for the unsubstituted phenylhydrazone (**1f**).

The data obtained for methanol, at various concentrations of piperidine, piperidine hydrochloride, and methoxide ion, indicate that the rearrangements studied are general base-catalysed, as previously shown for (**1f**).[4] In order to calculate the contribution of the single catalytic pathways we have fitted the kinetic data to equation (4). The k_u, k_{PIP}, and k_{MeO} values, calculated as before,[4] are set out in Table 5. Whereas both (**1a**) and (**1f**) give a slow uncatalysed rearrangement (k_u) in addition to the two catalysed pathways (k_{PIP} and k_{MeO}), in the case of (**1o**), on account of the expected substituent effect on this reaction route, the uncatalysed pathway is probably very slow and thus not detectable [$(k_{PIP} + k_{MeO})/k_u$ can be estimated to be as large as 10^3 l mol^{-1}]. As expected, k_u [depending essentially on the nucleophilicity of N(α)] is higher for (**1a**) than for (**1f**). With respect to k_{PIP} and k_{MeO}, both substituents increase the reactivity, although the increase is higher with an electron-withdrawing than with an electron-donating substituent; this suggests that in MeOH too a non-linear concave-upward Hammett plot would be obtained with more substituents. Indeed, we did not think it worthwhile to extend the study to other substituents since exact knowledge of the susceptibility constants could not give further information.

The kinetic data for (**1a**) in ACN at 313.15 K fit equation (2) well, as previously shown for (**1f**);[4] the calculated kinetic constants are set forth in Table 6. In order to investigate whether the absence of the pathway involving two molecules of piperidine depended on the relatively small range of piperidine concentrations examined, we studied the kinetics of the reaction at a lower temperature (283.15 K) and extended the range of concentrations. The k_u, k_{II}, and k_{III} values calculated according to equation (3) are set out in Table 6. The kinetic data at 283.15 K show the occurrence for (**1a**) of the termolecular catalysed pathway (k_{III}), so duplicating the case for (**1f**).[4,5] As expected k_{III}/k_{II} calculated for (**1a**) and (**1f**) in ACN (*ca.* 2.2 l mol^{-1}; see Table 6) are lower than those calculated for PhH, DIOX, and EA.

At 283.15 K we also measured the reactivity of (**1o**), a substrate too reactive to be studied at 313.15 K. Because the highest piperidine concentration used with (**1o**) is relatively low (7.7×10^{-3}M) no termolecular catalytic constant can be obtained. Also the k_u pathway does not give any contribution to the total reactivity, owing to the low nucleophilic character of N(α) caused by the strong electron-withdrawing effect of the substituent; therefore the kinetic data fit equation (5).

$$k_A = k_{II}[\mathrm{PIP}] \qquad (5)$$

In ACN a large increase in reactivity on going from (**1f**) to (**1o**) and (*vice versa*) a small decrease in going from (**1f**) to (**1a**) are observed. The Hammett plots (not shown) indicate that in this case the tendency to an inversion in the substituent effects is less pronounced than in PhH, DIOX, and MeOH. The situation appears similar to that observed in EA.

Conclusions.—The data collected in the various solvents[*] allow the following conclusions to be drawn, in agreement with the mechanism previously proposed.[4,8] (*a*) In the base-catalysed reaction pathways both electron-withdrawing and -donating substituents can increase the reactivity, but with significantly different efficiency and electronic transmission (see, in Table 4, susceptibility constants calculated and substituent constants used in PhH and in DIOX). (*b*) Complete data are available for electron-withdrawing substituents in PhH and DIOX, and give similar ρ values for the k_{III} coefficient, with k_{III}/k_{II} substituent-dependent. The values of k_{III}/k_{II}, in fact, increase with increasing electron-withdrawing effect of the substituent. Also in EA, where only three arylhydrazones have been studied, the same trend of k_{III}/k_{II} has been observed. Moreover k_{III}/k_{II} values for the same arylhydrazone are solvent-dependent and decrease with increasing polarity of the solvent [*e.g.* for (**1f**) the following values have been calculated: 23.8 (PhH), 3.0 (DIOX), 3.2 (EA), and 2.2 l mol^{-1} (ACN)], showing that as the polarity of the solvent increases, the need for catalysis of catalysis strongly decreases. (*c*) In the absence of complete data for all the solvents studied, an estimate of the susceptibility of the reaction to substituent effects can be made by comparison of $(k_{III})_{p\text{-}NO_2}/(k_{III})_H$ and $(k_{II})_{p\text{-}NO_2}/(k_{II})_H$ at 313.15 K (see Table 7). These values increase on going from PhH (37) to DIOX (57 and 19) and EA (280 and 221), *i.e.* the substituent effects on reactivity increase with increasing polarity of the solvent, *as expected* for reactions with a polar transition state. These results agree with the variations of k_{II}, k_{III}, and k_{III}/k_{II} with changing solvent, observed for (**1f**) and already discussed.[4]

The data relative to ACN are not homogeneous with those pertaining to the other solvents, on account of the different temperature used: moreover ACN is different from the other solvents, particularly because its high basicity strongly affects the stability of the polar transition states in the rearrangement reaction and exerts a levelling effect on the reactivity.

Experimental

Synthesis and Purification of Materials.—Compounds (**1a—o**)[3] and (**2a—o**),[3] piperidine,[9] methanol,[9] dioxane,[9] ethyl acetate,[10] and acetonitrile[10] were prepared and/or purified according to reported methods.

Kinetic Measurements.—The kinetics were followed spectrophotometrically as previously described[11] by measuring the disappearance of (**1a—o**) at the wavelengths of their absorption maxima, where the absorption of (**2a—o**) is minimal. The kinetic constants, the wavelengths, and the log ε values at the maxima used for spectrophotometric determinations, are available in Supplementary Publication No. SUP 56557 (9 pages).[†]

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[*] The data relative to MeOH have not been considered in the following discussion for two reasons: (i) the transition state–solvent interactions in methanol are very different from those occurring in the *aprotic* solvents studied; (ii) the catalysis in methanol involves kinetic contributions not homogeneous with those in the other solvents.

[†] For details of Supplementary Publications see Instructions for Authors, *J. Chem. Soc., Perkin Trans. 2*, 1986, Issue 1.