Synthesis and Hydrolysis of Substituted Imidazolinium Salts. Behaviour of the Degradation Products on Varying *p*H

Beatriz M. Fernández*, Ana M. Reverdito, Guillermo A. Paolucci and Isabel A. Perillo

Departamento de Química Orgánica, Facultad de Farmacia y Bioquímica, Universidad de Buenos Aires, Junín 956, Buenos Aires, Argentina

Received August 4, 1986

Reaction of 1-alkyl-2,3-diarylimidazolinium iodides **1a-i** with alkaline solutions afforded *N'*-alkyl-*N*-aroyl-*N*-arylethylenediamines **2a-i**. Compounds **2** are stable under acid conditions but in neutral or alkaline media rearrange giving *N*-alkyl-*N*-aroyl-*N'*-arylethylenediamines **3a-i**. Treating compounds **3** with concentrated acids reverse reaction **3** → **2** takes place.

Kinetic studies were performed on this intramolecular *N* → *N'* aroyl transfer over the H_o-*p*H range −0.9 to 2.30. Compounds **3** undergo acyl transfer to give **2** by a mechanism which involves a change in the rate determining step from formation to catalysed decomposition of a heterocyclic intermediate I^{2+} on going from H_o to *p*H values. The existence of maxima in the *p*H rate profile allowed to determine apparent pK_a values of the imidazolidine intermediates which gave good correlation with Hammett sigma values. Stability of these heterocycles was also predicted by determination of thermodynamic parameters.

J. Heterocyclic Chem., **24**, 1717 (1987).

This is an extension of our work on the synthesis and properties of 1,2,3-trisubstituted cyclic amidinium salts [1-3]. We report here the synthesis and alkaline hydrolysis of some 1-alkyl-2,3-diarylimidazolinium iodides **1a-i**, and enlarge the study on the behaviour of their degradation products.

Compounds **1** were obtained by treatment of the corresponding 1,2-diaryl-1*H*-4,5-dihydroimidazoles with alkyl iodides in methylene chloride solutions.

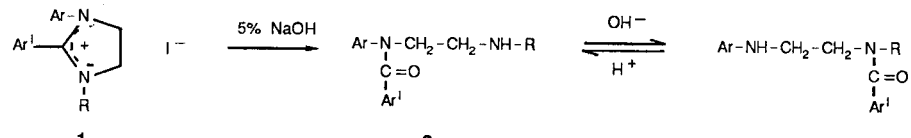
Treatment of an aqueous solution of **1** with 5% sodium hydroxide afforded *N'*-alkyl-*N*-aroyl-*N*-arylethylenediamines **2**. Compounds **2** are stable under acid conditions. In neutral or alkaline solutions they rearrange giving *N*-alkyl-*N*-aroyl-*N'*-arylethylenediamines **3** (Scheme I). The structure asignments of compounds **2** and **3** were based on microanalysis and spectroscopic properties (Tables II and III).

When compounds **3** are treated with concentrated acids it might be expected to obtain the corresponding imidazolinium salt **1** as it was observed for *N*-acyl-*N,N'*-diarylethylenediamines [4-7]. However, in our case reverse reaction to **2** takes place. Thus, we tried to gain further insight into the mechanism of these reactions which involves the formation and acid decomposition of an imidazolidine intermediate **I** which is present under steady state conditions as can be demonstrated by kinetic methods [3].

In fact, reaction **3** $\overset{H^+}{\rightleftharpoons}$ **2** exhibit a *p*H rate maximum (Figure) which can be explained by postulating a change in the rate determining step from formation to decomposition of a heterocyclic intermediate **I**. The appearance of **2** was followed by uv spectrophotometry and reactions were found to be irreversible.

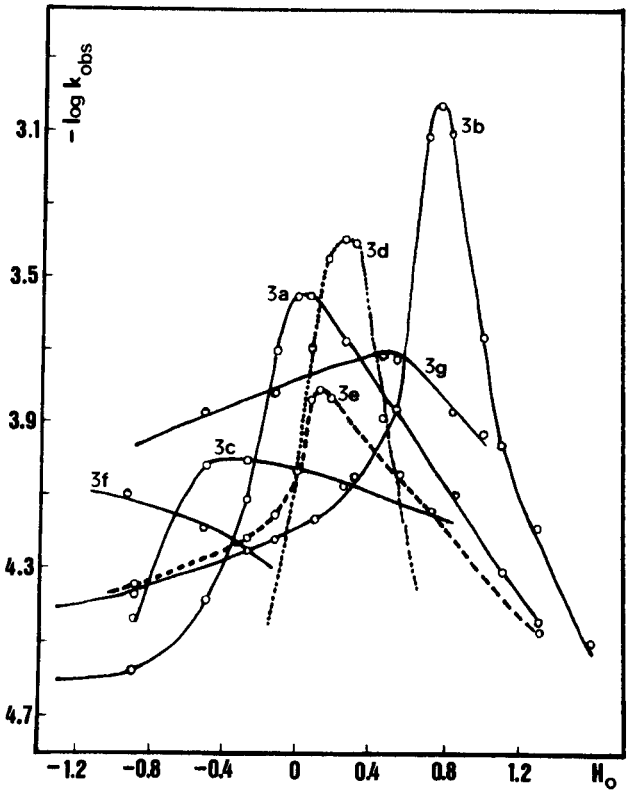
On the right hand side of the curves (Figure) rate constants increase upon increasing proton concentration cor-

Scheme I



1 **2** **3**

1,2,3	Ar	Ar¹	R
a	C_6H_5	C_6H_5	CH_3
b	*p*-$CH_3OC_6H_4$	C_6H_5	CH_3
c	*p*-ClC_6H_4	C_6H_5	CH_3
d	*m*-$CH_3C_6H_4$	C_6H_5	CH_3
e	β-$C_{10}H_7$	C_6H_5	CH_3
f	C_6H_5	*p*-$NO_2C_6H_4$	CH_3
g	C_6H_5	*p*-$CH_3OC_6H_4$	CH_3
h	C_6H_5	C_6H_5	C_2H_5
i	C_6H_5	C_6H_5	*n*-C_4H_9



Figure

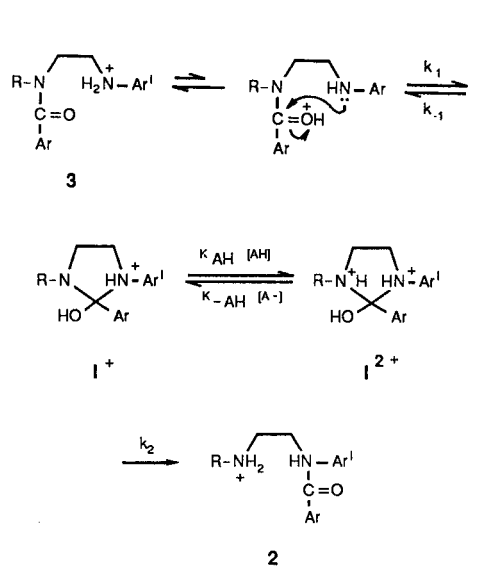
responding to acid catalysed reactions which follow the rate law $v = k\,[3]a_{H^+}$ in terms of protonate material.

The presence of the intermediate **I** could be detected by hptlc being observed that **3** was not completely converted to the imidazolidine **I** during the initial rapid phase of the reaction (*i.e.* $k_{-1} \neq 0$) and when the equilibrium **3** $\underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}}$ intermediate had been attained reactions recovered their normal profile.

Points of the curves in the Figure were achieved by time plots of the logarithm of differential absorbance measurements at any time and time zero (A_t-A_o) and followed first order kinetics or consisted of two linear segments according to the biexponential equation $(A_t\text{-}A_o) = M \exp(b_1 t) + N \exp(b_2 t)$ where M and N are preexponential constants and b_1 and b_2 are exponential factors related to the observed rate constants of the pseudo first-order reactions.

Results for the ascendent right side of the curves (Figure) are interpreted according to the mechanisms in Scheme II as follows. The intermediates $\mathbf{I}^+$ is formed by intramolecular attack of the anilino group at the protonated carbonyl group of the *O*-protonated form of **3** and accumulates during the initial rapid phase of the reaction. This intermediate then undergoes an acid catalysed decomposition to give **2** during the subsequent slower phase.

Scheme II



Aroyl migration was not observed in the uncatalysed reactions and only sufficiently low *p*H values providing protonation of both amine groups of the imidazolidine are capable to promote migration (*i.e.* breakdown of $\mathbf{I}^+$ requires proton donation by the acid catalyst to the weakly basic amine).

The fact that bell-shaped curves are obtained on going to higher H^+ concentrations indicates a change in the mechanism of the reactions (*i.e.* a new barrier appears between $\mathbf{I}^{2+}$ and **2**). The new step that becomes rate determining on going to the H_o side must be a simple proton transfer by the acid catalyst to the imidazolidine $\mathbf{I}^{2+}$ which is initially formed (Scheme III). As the *p*H is decreased the intermediate decomposes to **2** more rapidly than it is formed so formation of $\mathbf{I}^{2+}$ starts to be rate determining and, if H_o could be significantly lowered, the observed rates would come *p*H independent. This can be clearly observed for compounds **3a-b** and **3e** in the Figure [9].

Scheme III

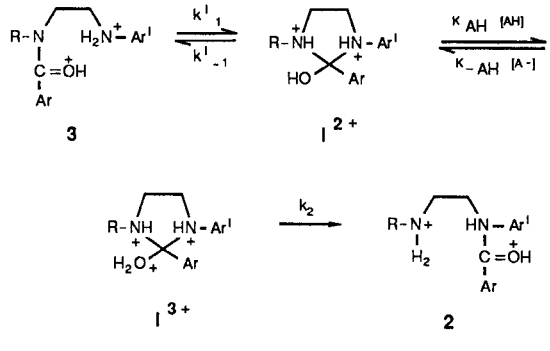
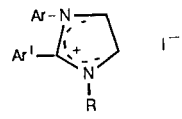


Table I

1-Alkyl-2,3-diarylimidazolinium Iodides **1b-i**



Compound No.	Yield %	MP (°C)	Recrystallization Solvent	Analyses Calcd./Found %C	%H	%N	IR ν (cm^{-1})		^{1}H NMR δ (ppm)	Multiplicity	Assignment
											$-C_6H_4N^+\equiv$
1b	95	187	isopropyl alcohol	51.78	4.82	7.11	2940 (w)	(C-H)	7.82	d	(2 *ortho* H)
				51.85	4.93	7.15	1620 (s)	amidinium	7.70-7.40	m	$-C_6H_5$
							1600 (s)	(C=C)			
							1378 (m)	(C-N)			$-O-C_6H_4-$
							1300 (s)	(C-N)	6.88	d	(2 *ortho* H)
							1258 (s)	(C-O)	4.74	s	$-CH_2-CH_2-$
							705 (s)	(C_6H_5)	3.87	s	CH_3-O-
							840 (s)	($-C_6H_4-$)	3.36	s	$CH_3N^+\equiv$
1c	99	195	isopropyl alcohol	48.18	4.01	7.03	2940 (w)	(C-H)			$C_6H_4N^+\equiv$
				48.05	4.16	7.08	2980 (w)	(C-H)	7.70-7.55	m	(2 *ortho* H)
							1600 (s)	amidinium			
							1355 (m)	(C-N)	7.40-6.85	m	aromatics
							1295 (m)	(C-N)			
							818 (s)	($-C_6H_4-$)	4.45	s	$-CH_2-CH_2-$
							760 (s)	(C-Cl)			
							680 (s)	(C_6H_5)	3.10	s	$CH_3-N^+\equiv$
1d	92	146	isopropyl alcohol	53.92	5.03	7.41	2950 (w)	(C-H)			$-C_6H_4-N^+\equiv$
				53.80	5.22	7.19	1640 (s)	amidinium	7.60-7.42	m	(2 *ortho* H)
							1604 (s)	(C=C)	7.37-6.75	m	aromatics
							1378 (m)	(C-N)			
							1300 (s)	(C-N)	4.40	s	$-CH_2-CH_2-$
							775 (s)	($-C_6H_4-$)	3.10	s	$CH_3-N^+\equiv$
							700 (s)	(C_6H_5)	2.10	s	$CH_3-C\equiv$
1e	88	198	isopropyl alcohol/*n*-hexane	57.97	4.59	6.76	2960 (w)	(C-H)	7.90-7.10	m	aromatics
				57.89	4.72	6.70	1640 (s)	amidinium	4.50	s	$-CH_2-CH_2-$
							1601 (s)	(C=C)	3.15	s	$CH_3-N^+\equiv$
							1380 (m)	(C-N)			
							1305 (s)	(C-N)			
							705 (s)	(C_6H_5)			
1f	80	125 [a]	isopropyl alcohol/cyclohexane	46.94	3.91	10.27	2960 (w)	(C-H)	8.10-7.30	m	aromatics
				46.85	4.12	10.10	1630 (s)	amidinium	4.90-4.70	m	$-CH_2-CH_2-$
							1600 (s)	(C=C)			
							1370 (m)	(C-N)	3.25	s	$CH_3N^+\equiv$
							1298 (s)	(C-N)			
							700 (s)	(C_6H_5)			
1g	80	197	isopropyl alcohol	51.78	4.82	7.11	2980 (w)	(C-H)	7.52-6.90	m	aromatics
				51.68	4.95	7.16	2920 (w)	(C-H)			
							1620 (s)	amidinium	6.73	d	$-O-C_6H_4-$
							1600 (s)	(C=C)			(2 *ortho* H)
							1362 (m)	(C-N)			
							1285 (m)	(C-N)	4.45	s	$-CH_2-CH_2-$
							1255 (s)	(C-O)			
									3.70	s	CH_3-O-
							838 (s)	($-C_6H_4-$)			
							700 (s)	(C_6H_5)	3.15	s	$CH_3-N^+\equiv$
											$C_6H_5N^+\equiv$
1h	73	187	isopropyl alcohol/ethylacetate	53.97	5.03	7.41	2970 (w)	(C-H)	7.95-7.68	m	(2 *ortho* H)
				53.82	5.28	7.37	1620 (m)	amidinium			
							1598 (s)	(C=C)	7.62-7.20	m	aromatics
							1360 (m)	(C-N)	4.93-4.70	m	$-CH_2-CH_2-$
							1300 (s)	(C-N)	3.75	q	$-CH_2-N^+\equiv$
							705 (s)	(C_6H_5)	1.56	t	$CH_3-C\equiv$

Table I (continued)

Compound No.	Yield %	MP (°C)	Recrystallization Solvent	Analyses Calcd./Found %C	%H	%N	IR ν (cm⁻¹)		^{1}H NMR δ (ppm)	Multiplicity	Assignment
1i	70	205	isopropyl alcohol/cyclohexane	56.16 56.03	5.66 5.80	6.90 6.94	2920 (w) 1625 (s)	(C-H) amidinium	7.96-7.76	m	C_6H_5-$N^+\equiv$ (2 *ortho* H)
							1600 (s)	(C=C)	7.70-7.21	m	aromatics
							1364 (m)	(C-N)	4.90-4.60	m	$\equiv\overset{+}{N}$-CH_2-CH_2-$\overset{+}{N}\equiv$
							1300 (s)	(C-N)	3.73	t	-CH_2-$N^+\equiv$
							702 (s)	(C_6H_5)	2.01-1.20	m	$\equiv$C-CH_2-CH_2-C$\equiv$
									0.96	t	CH_3-C$\equiv$

[a] Hygroscopic compound.

Dissociation Constants of the Imidazolidines.

According to our proposal in Scheme III the *p*H value at the inflection point of the curves in the figure can be assumed as the pK_a value of the intermediate (pK'_a = H_o + log $\frac{I^{3+}}{I^{2+}}$). This assumption is proved by the application of the Hammett equation [8]. Plotting H_o *vs.* sigma values (Table IV) the effect of the aryl group (Ar) upon the basicity of $\mathbf{I}^{2+}$ at the hydroxy group level is considered. In fact, a linear relationship is observed (φ = −2.33, r = 0.985, s = 0.08) which supports our mechanism in Scheme III.

Similarly, the plot of the pK_a values of arylamines (Table IV) *vs.* the reaction rate constants for compounds **3a-e** also results in a linear relationship with a slope ρ = −0.69 (r = 0.9964, s = 0.035), *i.e.* the more basic the attacking amine is the more rapid migrations are. This supports our mechanism in Scheme II according to which catalysis acts upon the weakly basic amine of the imidazolidine when decomposition is rate determining. Thus, the less basic the nucleophile (Ar-$\ddot{N}$<) the more concentrated the acid solution required to perform acyl transfer.

On the other hand, there is not a clear relationship between the electronic effect of substituents in the Ar′ group and reaction rates. In fact, flatter curves are observed for both compounds, **3f** and **3g** than that achieved for the unsubstituted compound **3a**.

Thermodinamics of the Reactions.

Determination of the activation parameters was performed at the *p*H value corresponding to the top of each curve in the figure at which concentrations of $\mathbf{I}^{2+}$ and $\mathbf{I}^{3+}$ are close according to the mechanism proposed in Scheme III.

From thermodinamic parameters in Table IV it can be inferred that: a) When decomposition of $\mathbf{I}^{+}$ is rate determining the higher basicity of the aromatic nitrogen favours catalysis which is traduced in lower E_a and ΔH# values for electron donor groups in the phenyl group (compounds **3a-b** and **3e**). b) The increase in the E_a values for compounds **3a** and **3h-i** on increasing the molecular volume of the alkyl group R_3 (Table IV) is obviously related to a major difficulty in the formation of the chiral carbon atom of the imidazolidine intermediate. c) The analysis of the ΔS# values indicates that the stability of the imidazolidines is favoured by the presence of bulky alkyl groups (R_3 = C_4H_9) at N-1 and diminished by electron donor substituents R_2 in the Ar′ but it cannot be inferred the influence of substituents R_1 in the Ar upon the stability of these heterocycles.

EXPERIMENTAL

Melting points were taken on a Büchi capillary apparatus and are uncorrected. The ir spectra were recorded on a Beckman 180A spectrophotometer using potassium bromide pellets. Intensity of the bands is quoted as w: weak, m: medium and s: strong. The nmr spectra were obtained on a Varian FT 80A spectrophotometer with tetramethylsilane as internal reference using deuteriochloroform as solvent. Chemical shifts are reported in parts per million (δ) and signals are quoted as: s (singlet), d (doublet), t (triplet), q (quartet), m (multiplet) and bs (broad signal). The presence of exchangeable protons was confirmed by use of deuterium oxide. The uv spectra were recorded on a Shimatzu 210A spectrophotometer.

N-(*p*-Methoxybenzoyl)-*N*′-phenylethylenediamine.

A mixture of 0.02 mole of *N*-(2-bromoethyl)-*p*-methoxybenzamide [10] and 0.04 mole of aniline, was heated in a water bath at 100° for one hour. The crude product was washed three times with boiling water. The oil was cooled and the resulting solid crystallized from ethanol affording *N*-(*p*-methoxybenzoyl)-*N*′-phenylethylenediamine (79% yield), mp 155° (ethanol); ir: 3400 (s) (NH), 3250 (s) (NH), 1630 (s) (C=O), 1600 (s) (C=C), 1290 (s) (C-N) and 700 cm⁻¹ (s) (C_6H_5); ^{1}H nmr: δ 8.15-6.50 (m, 10, aromatics and NH), 4.10-3.25 (m, 5, CH_2-CH_2 and NH) and 3.90 (s, 3, CH_3O).

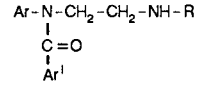
Anal. Calcd. for $C_{16}H_{18}N_2O_2$: C, 71.11; H, 6.67; N, 10.37. Found: C, 71.20; H, 6.81; N, 10.32.

2-(*p*-Methoxyphenyl)-1-phenyl-1*H*-4,5-dihydroimidazole.

N-(*p*-Methoxybenzoyl)-*N*′-phenylethylenediamine (1 g) was refluxed for two hours with 20 ml of chloroform solution of PPE [11]. The organic layer was extracted four times with water. Acid solutions were collected, cooled and made alkaline with 20% sodium hydroxide. The suspension was extracted three times with 30 ml of methylene chloride. The organic solution, after washing with water was dried and evaporated *in vacuo* af-

Table II

N'-Alkyl-*N*-aroyl-*N*-arylethylenediamines (**2b-i**)

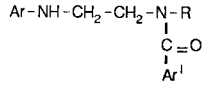


Compound No.	δ (ppm)	^{1}H NMR Multiplicity	Assignment	MP (°C)	Picrates Analyses Calcd./Found %C	%H	%N
2b	7.70-6.60	m	aromatics	172	53.80	4.48	13.64
	4.25	s	CH_3O-		53.90	4.59	13.68
	4.10	t	CO-N-CH_2				
	2.65	q [a]	-CH_2-NH-				
	2.05	s	CH_3-N				
	1.82	s [b]	NH				
2c	7.35-6.80	m	aromatics	167	51.01	3.86	13.53
	4.20	t	-CO-N-CH_2-		51.19	3.96	13.59
	2.70	t	-CH_2-NH				
	2.00	s	CH_3-N				
	1.65	s [b]	NH				
2d	7.30-6.63	m	aromatics	132	55.53	4.63	14.08
	3.90	t	-CO-N-CH_2-		55.39	4.78	14.01
	2.75	t	CH_2-NH				
	2.30	s	CH_3Ar				
	2.10	s	CH_3-N				
	1.50	s [b]	NH				
2e	7.61-7.18	m	aromatics	186	58.54	4.31	13.13
	4.05	t	-CO-N-CH_2-		58.47	4.49	13.02
	2.80	q [a]	-CH_2-NH				
	2.00	s	CH_3-N				
	1.82	s [b]	NH				
2f	8.10-7.30	m	aromatics	175	50.00	3.79	15.91
	4.20	t	-CO-N-CH_2		50.20	3.93	15.98
	2.85	t	-CH_2-NH				
	2.15	s	CH_3-N				
	1.65	s [b]	NH				
2g	7.65-6.65	m	aromatics	156	53.80	4.48	13.64
	4.30	s	CH_3-O		53.67	4.60	13.60
	3.92	t	-CO-N-CH_2				
	2.78	q [a]	-CH_2-NH				
	2.10	s	CH_3-N				
	2.00	s [b]	NH				
2h	7.56-7.15	m	aromatics	143	55.53	4.63	14.08
	4.22	t	-CO-N-CH_2		55.47	4.78	14.05
	3.30-2.70	m	-CH_2-NH-CH_2				
	1.85	s [b]	NH				
	1.20	t	CH_3-C				
2i	7.65-7.20	m	aromatics	183	57.14	5.14	13.33
	3.95	t	-CO-N-CH_2		57.28	5.23	13.20
	2.61-1.00	m [c]	-CH_2-NH-C_4H_9				

[a] Upon deuteration the quartet collapsed into a triplet. [b] Exchangeable. [c] One proton exchangeable.

Table III

N-Alkyl-*N*-aroyl-*N'*-arylethylenediamines **3b-i**



Compound No.	Mp (°C)	Recrystallization Solvent	Analyses Calcd./Found %C	%H	%N	IR ν (cm^{-1}) NH	C=O	C=C	C-N	C_6H_5	δ (ppm)	^{1}H NMR Multiplicity	Assignment
3b	61	cyclohexane	71.83	7.04	9.86	3350	1620	1600	1304	720	7.30	s	$-C_6H_5$
			71.89	7.20	9.98			[a]	1260		6.80-6.20	m	$-C_6H_4-$
											3.60	s	CH_3O-
											3.60-3.20	m [b]	$-NH-CH_2-CH_2-$
											2.90	s	CH_3-N
3c	77	cyclohexane	66.55	5.89	9.70	3250	1610	1600	1320	703	7.53	s	$-C_6H_5$
			66.48	5.98	9.59		[a]		1260		7.25-6.50	m	$-C_6H_4-$
											4.05-3.30	m [b]	$-NH-CH_2-CH_2-$
											3.16	s	CH_3-N
3d	64	cyclohexane	76.12	7.46	10.45	3360	1630	1605	1300	700	7.80-6.25	m	aromatics
			76.20	7.59	10.28				1265		4.20	bs [c]	NH
											3.80-3.15	m	$-CH_2-CH_2-$
											3.00	s	CH_3-N
											2.25	s	CH_3-Ar
3e	87	cyclohexane	78.95	6.58	9.21	3270	1605	1595	1288	702	800-6.60	m	aromatics
			79.04	6.60	9.10		[a]				4.00-3.30	m [b]	$-NH-CH_2-CH_2-$
											3.06	s	CH_3-N
3f	83	cyclohexane	64.21	5.69	14.05	3290	1620	1600	1320	695	8.50-8.20	m	$-C_6H_4-NO_2$ (2 *ortho* H)
			64.33	5.82	14.15				1270				
											7.80-7.10	m	aromatics
											7.05-6.60	m	$C_6H_5-N=$ (3, *ortho* & *para* H)
											4.20-3.40	m [b]	$-NH-CH_2-CH_2-$
											3.20	s	CH_3-N
3g	78	*n*-hexane	71.83	7.04	9.86	3360	1620	1603	1305	703	7.37-6.30	m	aromatics
			71.70	7.25	9.72		[a]		1265		4.10	bs [c]	NH
											3.75	s	CH_3-O-
											3.75-3.20	m	$-CH_2-CH_2-$
											3.03	s	CH_3-N
3h	75	cyclohexane	76.12	7.46	10.45	3300	1615	1600	1310	705	7.68-6.72	m	aromatics
			76.01	7.58	10.29				1270		3.88-3.35	m [b]	$-NH-CH_2-CH_2-NCH_3$
											1.10	t	CH_3
3i	oil [d]	—	—	—	—	3310	1620	1600	1300	700	7.60-6.50	m	aromatics
									1275		4.00-3.30	m [b]	$-NH-CH_2CH_2-N-CH_2-$
											2.00-0.95	m	$-CH_2-CH_2-CH_3$

[a] Shoulder. [b] One proton exchangeable. [c] Exchangeable. [d] Compound **3i** was analyzed as picrate, mp 158° (methanol). *Anal.* Calcd. for $C_{25}H_{27}N_5O_8$: C, 57.14; H, 5.14; N, 13.33. Found: C, 57.25; H, 5.29; N, 13.28.

fording 2-(*p*-methoxyphenyl)-1-phenyl-1*H*-4,5-dihydroimidazole, mp 75° (*n*-hexane); ir: 1620 (m) (C=N), 1598 (s) (C=C), 1310 (s) (C-N) and 704 cm^{-1} (s) (C_6H_5); ^{1}H nmr: δ 8.00-6.62 (m, 9, aromatics), 4.06 (s, 4, CH_2CH_2) and 3.80 (s, 3, CH_3O).

Anal. Calcd. for $C_{16}H_{16}N_2O$: C, 76.19; H, 6.35; N, 11.11. Found: C, 76.25; H, 6.40; N, 11.17.

1-Alkyl-2,3-diarylimidazolinium Iodides **1a-i**. General Procedure.

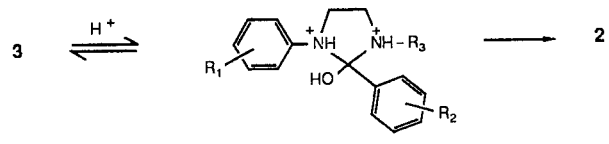
A mixture of 0.01 mole of 1,2-diaryl-1*H*-4,5-dihydroimidazole, 0.15 mole of the corresponding alkyl iodide and 50 ml of methylene chloride was refluxed for two hours. The solvent and the excess of alkyl iodide were removed *in vacuo*. The residue was crystallized from the appropriate solvent affording compounds **1a-i**. Yields, melting points, recrystallization solvents, elemental analyses and spectroscopic data of compounds **1b-i** are given in Table I. Compound **1a** was described by Fernández *et al.* [2].

Reaction of **1a-i** with Alkaline Solutions.

After dissolving compound **1a-i** in water with the aid of heating, the resulting solution was rapidly cooled and made alkaline with 5% sodium hydroxide. The solution slowly became turbid separating an oil. The oil

Table IV

Observed Rate Constants for the Acyl Transfer **3** → **2** in Acid Media at 25°.
Thermodynamic Parameters and Ionization Constants of the Imidazolidine Intermediates I^{2+}



Reaction	R_1	R_2	R_3	k_{obs}(min^{-1})	log k_{obs}	E_a(Kcal/mol)	ΔH#(Kcal/mol)	ΔS#(u.e.)	H_o = pK_a^1 [a]	σ [b]	pK_a [c] $R_1C_6H_4\dot{N}H_3$
3a → **2a**	H	H	CH_3	2.95×10^{-4}	−3.53	3.88	3.31	−75.43	0.08	0.000	4.61
3b → **2b**	*p*-CH_3-O	H	CH_3	9.22×10^{-4}	−3.03	6.21	5.64	−55.97	0.80	−0.269	5.33
3c → **2c**	*p*-Cl	H	CH_3	1.10×10^{-4}	−3.96	8.22	7.65	−50.56	−0.16	0.23	4.03
3d → **2d**	*m*-CH_3	H	CH_3	3.92×10^{-4}	−3.40				0.24	−0.07	4.73
3e → **2e**	3,4-C_4H_4	H	CH_3	1.58×10^{-4}	−3.80	4.31	3.75	−75.86	0.14	0.170	4.15
3f → **2f**	H	*p*-NO_2	CH_3	8.32×10^{-5}	−4.08				~ −1.40		
3g → **2g**	H	*p*-CH_3O	CH_3	2.01×10^{-4}	−3.70	3.46	2.90	−65.70	0.55		
3h → **2h**	H	H	C_2H_5	2.78×10^{-5}	−4.55	18.93	1.33	−74.35			
3i → **2i**	H	H	*n*-C_4H_9	2.33×10^{-5}	−4.63	24.43	1.88	−79.67			

[a] H_o values at the top of the curves (Figure) are assumed as the apparent pK_a values of the imidazolidine intermediates I^{2+} according to Scheme III. [b] Hammett sigma values [8]. [c] Average from reliable values at 25° [14].

was rapidly extracted with methylene chloride and the organic layer was washed, dried and concentrated *in vacuo* keeping the reaction flask in a water bath at 20° affording compounds **2a-i**. Bases were transformed into picrates after dissolving the bases in dilute hydrochloric acid and precipitating with aqueous solution of picric acid. The resulting picrates were crystallized from ethanol.

The ^{1}H-nmr of the bases and melting points of the picrates are given in Table II.

Compounds **2a-i** in neutral or alkaline media, spontaneously rearrange affording **3a-i**. Melting points, recrystallization solvents, elemental analyses and spectroscopic data of compounds **3b-i** are given in Table III.

Compounds **2a** and **3a** were described by Fernández *et al.* [2].

Acid solutions of compounds **2** are obtained by rearrangement of **3** in aqueous mineral acids solutions.

Kinetic Measurements.

Reactions **3** → **2** were performed at 25° over the *p*H-H_o range 1.30 to −0.9 using sulfuric acid-water mixtures. Values of H_o were taken from Hine [12].

Reactions performed with initial concentrations of 2×10^{-3} to 1×10^{-2} *M* showed first-order dependence on the substrate at every hydrogen ion concentration at which migration occurred. All rate constants were obtained from 2×10^{-3}*M* initial concentrations of the substrates. The appearance of **2** was followed spectrophotometrically at the appropriate wavelength and rate constants were calculated from plots of log (A_t-A_o) against time on semilogarithmic graph paper. The linear parts of the profiles account for pseudo first-order kinetics which follow the equation $v = k_{obs} . [3]a_H +$ and flat curves and the top parts of the steep profiles account for kinetics which consist of two linear segments according to the biexponential equation $(A_t\text{-}A_o) = M\, e^{b_1 t} + N\, e^{b_2 t}$ where b_1 depends on k_1 and $k_{-1}$and b_2 depends fundamentally on K_{AH} and k_2, while M and N are related to the maximum concentration of intermediate achieved in the reaction whichever the rate determining step that prevails. Feathering was employed to differentiate to two linear segments and apparent pseudo first-order rate constants (Table IV) were calculated from b_1 values by least squares fitting.

General Kinetic Procedure.

Solutions (2×10^{-3}*M*) of compounds **3a-i** in the acid buffers were prepared and thermostated at 25 ± 0.1°. At known intervals samples (2 ml) were taken and diluted with distilled water to give final solutions 8×10^{-5}*M*. The *p*H of the final solutions was above 2.5 in order to stop the reaction and the absorbance at time zero was estimated by extrapolation.

Chromatographic experiments were performed at *p*H 1.60 as it was reported in [3].

Determination of Activation Parameters.

Reactions **3** → **2** were performed in the acid buffers at three different temperatures (25°, 40° and 60°). The values of the enthalpy (ΔH#) and entropy (ΔS#) of activation were obtained according to the procedure described by Cagle and Eyring [13]. Values for E_a, ΔH# and ΔS# are listed in Table IV.

Acknowledgements.

Financial support of this investigation was given by the Consejo Nacional de Investigaciones Científicas y Técnicas and Universidad de Buenos Aires.

REFERENCES AND NOTES

[1] I. Perillo and S. Lamdan, *J. Chem. Soc., Perkin Trans. I*, 895 (1975).

[2] B. Fernández, I. Perillo and S. Lamdan, *J. Chem. Soc., Perkin*

Trans. II, 545 (1978).

[3] B. Fernández, I. Perillo and S. Lamdan, *J. Chem. Soc., Perkin Trans. II*, 550 (1978).

[4] M. May, T. J. Bardos, F. L. Barger, M. Lansford, J. M. Ravel, G. L. Sutherland and W. Shive, *J. Am. Chem. Soc.*, **73**, 3067 (1951).

[5] C. Barnett, P. H. Cleghorn, G. E. Cross, D. Lloyd and D. R. Marshall, *J. Chem. Soc. C*, 93 (1966).

[6] W. Hafferl, R. Lundin and L. L. Ingrahan, *Biochemistry*, **2**, 1298 (1963).

[7] L. Jaenicke and E. Brode, *Ann. Chem.*, **624**, 120 (1959).

[8] L. P. Hammett, "Physical Organic Chemistry; Reaction Rates, Equilibria and Mechanisms", McGraw-Hill, New York, 1970.

[9] Reactions with other compounds **3** could not be performed under very acidic conditions because degradations took place.

[10] P. Rehländer, *Ber.*, **27**, 2154 (1894).

[11] W. Pollmann and G. Schramm, *Biochim. Biophys. Acta*, **80**, 1 (1964).

[12] J. Hine, "Physical Organic Chemistry", McGraw-Hill, Tokyo, 2nd Ed, 1962.

[13] F. Wm. Cagle, Jr. and H. Eyring, *J. Am. Chem. Soc.*, **73**, 5628 (1951).

[14] D. D. Perrin, "Dissociation Constants of Organic Bases in Aqueous Solutions", Butterworths, London, 1965.