(m), 1380 (m), 1320 (w), 1270 (m), 1240 (w), 1220 (w), 1185 (m), 1160 (m), 1080 (w), 1065 (w), 1030 (w), 1010 (w), 970 (w), 940 (w), 920 (w), 845 (w), 805 (w), 770 (m), 760 (w), 740 (w), 715 (w), 705 (w), 690 (w), 645 (m) cm^{-1}; NMR (Me_2SO-d_6) δ 7.5 (s, 5), 3.0 (s, 4), 1.1 (s, 6).

Anal. Calcd for $C_{24}H_{22}N_6O_6$: C, 58.78; H, 4.49; N, 17.14. Found: C, 59.02; H, 4.55; N, 17.49.

Registry No. 1, 72708-70-4; 2, 72708-71-5; 3, 72708-72-6; 4, 72708-73-7; 5, 72708-74-8; 6, 72708-75-9; 7, 72708-76-0; 8, 72708-77-1; 9, 72708-78-2; 10, 72708-79-3; 11, 72708-80-6; 12, 72708-81-7; 13, 72708-82-8; PhTD, 4233-33-4; PD, 123-54-6; CHD, 504-02-9; EtAA, 141-97-9; ToPD, 72708-83-9; DBzM, 120-46-7; MeTD, 13274-43-6; DMCHD, 126-81-8.

Supplementary Material Available: NMR spectra of compounds 2 (in Me_2SO-d_6, Figure 1), 5 (in $CDCl_3$, Figure 2), 9 (aromatic region, Figure 3), and 11 (aromatic region, in Me_2SO-d_6, Figure 4) before and after addition of D_2O and tabulation of NMR (Table I), IR, and UV (Table II) data for compounds 1–13 (6 pages). Ordering information is given on any current masthead page.

Photostimulated Reactions of *N,N*-Disubstituted Amide Enolate Anions with Haloarenes by the $S_{RN}1$ Mechanism in Liquid Ammonia [1]

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The photostimulated reactions of chloro-, bromo-, and iodobenzenes, 1-chloronaphthalene, and 9-bromophenanthrene with the enolate anion of *N*-methyl-*N*-phenylacetamide in liquid ammonia gave good yields of substituted products. In the dark, iodobenzene gave 34% of substitution product, but chlorobenzene did not react. The enolate anion of *N,N*-dimethylacetamide was only partially soluble in liquid ammonia, but good yields of substitution products were obtained. The enolate anion of *N*-acetylpiperidine was insoluble in liquid ammonia, but the enolate anion of *N*-acetylmorpholine was soluble and good yields of substitution products were obtained under photostimulation. It is suggested that these reactions occur by the $S_{RN}1$ mechanism of aromatic substitution.

Subsequent to the discovery that ketone enolate anions can be arylated by the photostimulated $S_{RN}1$ mechanism in liquid ammonia,[2] this type of reaction has been demonstrated to have wide applicability as to both the aromatic substrates and the ketone enolate anions that can be successfully employed.[3,4]

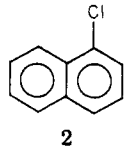
The photostimulated arylation of ester enolate anions, such as *tert*-butyl acetate enolate anion, has been carried out by several research groups.[5-7] The photostimulated arylation of enolate anions derived from aldehydes was attempted, but their very low reactivity and the high yields of dehalogenation products obtained make this reaction useless for synthetic purposes.[7]

We now report the reactions of haloarenes with several *N,N*-disubstituted amide enolate anions in liquid ammonia under photostimulation by the $S_{RN}1$ mechanism.

Results and Discussion

The anion of acetamide formed in liquid ammonia by acid–base reaction with amide ions failed to undergo photostimulated reaction with 1-chloronaphthalene (2). The reason is probably that the hydrogens attached to nitrogen are much more acidic than the hydrogens attached to the carbon atom; thus the enolate anion is not formed at all, and the nitranion nucleophile (eq 1) is apparently not a good nucleophile for the photostimulated $S_{RN}1$ reaction (eq 2). The p*K* for dissociation of the N–H

$$CH_3CONH_2 + NH_2^- \rightarrow \underset{1}{CH_3CONH^-} + NH_3 \quad (1)$$



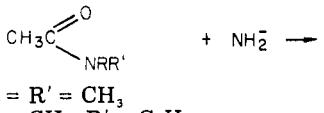
$$+ \ 1 \xrightarrow{h\nu} \text{no reaction} \quad (2)$$

2

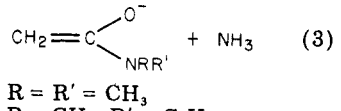
bond in acetamide is 25.5 in Me_2SO whereas the p*K* for dissociation of the C–H bond in *N,N*-dimethylacetamide is above 32.[8] Although these values are not known in liquid ammonia, it is reasonable to expect the same order, namely, $pK_{C-H} > pK_{N-H}$.

The nucleophile 1 and the anion derived from *N*-methylacetamide have been shown to be unreactive toward aryl radicals in reactions stimulated by electrons from an electrode.[9]

On the other hand, *N,N*-disubstituted amide enolate anions are known to be formed in liquid ammonia by acid–base reaction with amide ion (eq 3).[10]



3a, R = R′ = CH_3
b, R = CH_3, R′ = C_6H_5



(3)

4a, R = R′ = CH_3
b, R = CH_3, R′ = C_6H_5

(1) This research was supported in part by the Consejo Nacional de Investigaciones Científicas y Técnicas and the Secretaría de Ciencia y Tecnología, Argentina.
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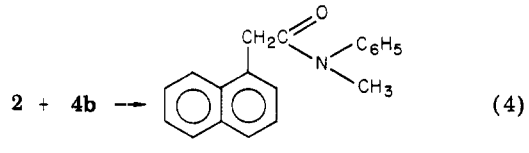
Table I. Photostimulated Reactions of Haloarenes with *N,N*-Disubstituted Amide Enolate Anions in Liquid Ammonia

expt	ArX	amt of ArX, mmol	$RR'NCOCH_2K$[a] R	R'	amt, mmol	irradn time, min	% yield X^-	% yield products obtained[b]
1	1-chloronaphthalene	14.7	H[c]	H	42.3	60	1	
2	chlorobenzene	4.4	CH_3	Ph	17.5	120	100	$PhCH_2CON(CH_3)Ph$, 72
3	chlorobenzene	5.4	CH_3	Ph	16.2	120[d]	2	
4	bromobenzene	5.7	CH_3	Ph	22.9	120	98	$PhCH_2CON(CH_3)Ph$, 60
5	iodobenzene	4.0	CH_3	Ph	16.5	30	*e*	$PhCH_2CON(CH_3)Ph$, 80[f] $Ph_2CHCON(CH_3)Ph$, 10[f]
6	iodobenzene	4.1	CH_3	Ph	16.7	30[d]	*e*	$PhCH_2CON(CH_3)Ph$, 34[f]
7	1-chloronaphthalene	5.0	CH_3	Ph	20.0	120	97	1-naphthyl-$CH_2CON(CH_3)Ph$, 50
8	1-chloronaphthalene	4.3	CH_3	Ph	17.3[g]	120	1	
9	9-bromophenanthrene	6.1	CH_3	Ph	24.5	90	*e*	9-phenanthryl-$CH_2CON(CH_3)Ph$, 80 phenanthrene, 5
10	bromobenzene	4.9	$(CH_2)_5$		15.0[h]	120	9	*e*
11	bromobenzene	4.2	CH_3	CH_3	12.8[i]	120	81	$PhCH_2CON(CH_3)_2$, 72[f] $Ph_2CHCON(CH_3)_2$, 9[f]
12	bromobenzene	2.8	CH_3	CH_3	14.1[i]	120	100	$PhCH_2CON(CH_3)_2$, 80[f] $Ph_2CHCON(CH_3)_2$, 18[f]
13	bromobenzene	2.7	CH_3	CH_3	16.2[i]	120	*e*	PhH, 1[f] $PhCH_2CON(CH_3)_2$, 62
14	bromobenzene	5.3	$(CH_2)_2O(CH_2)_2$		15.8	180	92	$PhCH_2CONC_4H_8O$, 56 $Ph_2CHCONC_4H_8O$, 12
15	chlorobenzene	5.1	$(CH_2)_2O(CH_2)_2$		15.3	180[d]	3	
16	chlorobenzene	5.2	$(CH_2)_2O(CH_2)_2$		15.5	180	95	$PhCH_2CONC_4H_8O$, 75[f] $Ph_2CHCONC_4H_8O$, 18[f]

[a] Prepared in situ by acid-base reaction of the *N,N*-substituted amides with KNH_2. [b] Yield of product isolated, unless otherwise indicated. [c] Acetamide is ionizated on the nitrogen. [d] Dark reaction. [e] Not determined. [f] Determined by GLC. [g] The base used was *t*-BuOK. [h] Insoluble. [i] Partially soluble in liquid ammonia.

In the photostimulated reaction of 1-chloronaphthalene (**2**) with *N*-methyl-*N*-phenylacetamide enolate anion (**4b**) so prepared, a high yield of substitution product was formed (eq 4). With chloro-, bromo-, and iodobenzenes, the yields of arylation products were also high (Table I).

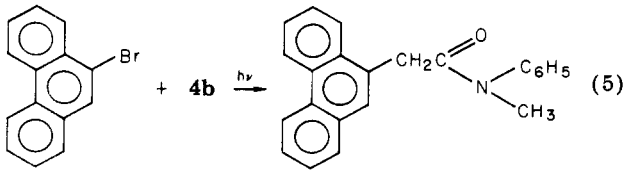


(4)

In the dark, during 30 min of reaction with iodobenzene, a 34% yield of substitution product was formed. Under irradiation in the same period of time, the yield of substitution product was 80%, and there was also 10% of diphenylation product. With chlorobenzene and during 120 min of irradiation, 100% of chloride ion was liberated, but in the dark in the same period of time there was only 2% of chloride ion formation.

Inasmuch as the acid–base reaction with potassium *tert*-butoxide is an effective method to form enolate anions from ketones, we tried to prepare the enolate anion of *N*-methyl-*N*-phenylacetamide (**3b**) by the same procedure. To the resulting solution we added **2** but after 120 min of irradiation there was no reaction at all. This result suggest that the enolate anion **4b** is not formed and that in liquid ammonia the hydrogens attached to the α carbon of *N,N*-disubstituted amides are less acidic than those of ketones, which is in agreement with the more than 4.5 p*K* unit difference between acetone and **3a** found in Me_2SO.[8]

From 9-bromophenanthrene and **4b**, after 90 min of irradiation, the substitution product was isolated in 80% yield (eq 5).



(5)

Scheme I

$$ArX + CH_2{=}C(O^-)NRR' \xrightarrow{h\nu} (ArX)^{-\cdot} + \text{residue} \quad (6)$$

$$(ArX)^{-\cdot} \longrightarrow Ar^{\cdot} + X^- \quad (7)$$

$$Ar^{\cdot} + CH_2{=}C(O^-)NRR' \longrightarrow (ArCH_2C(=O)NRR')^{-\cdot} \quad (8)$$

$$(ArCH_2C(=O)NRR')^{-\cdot} + ArX \longrightarrow ArCH_2C(=O)NRR' + (ArX)^{-\cdot} \quad (9)$$

In order to know about the scope and limitations of this reaction we prepared several other *N,N*-disubstituted amide enolate anions.

The potassium enolate of *N,N*-dimethylacetamide (**4a**) is partially soluble in liquid ammonia. It reacted with bromobenzene under irradiation to form good yields of substitution products. The main product was that of monophenylation but some diphenylation also occurred. In a preliminary experiment with less solvent, the yield of disubstitution product was significantly greater.

The potassium enolate of *N*-acetylpiperidine was found to be insoluble in liquid ammonia. After 120 min of irradiation with bromobenzene, only 9% of bromide ion was liberated. Isolation of the substitution product was not attempted.

Since a major problem seems to be the solubility of the potassium enolates in liquid ammonia, we prepared *N*-acetylmorpholine, with the hope that the ether linkage would increase the solubility of the potassium enolate, In fact, the enolate anion of *N*-acetylmorpholine was completely soluble and very good yields of substitution products were obtained in reactions with chloro- and bromobenzenes (Table I). No reaction occurred in the dark.

We suggest that this reaction occurrs by the photostimulated $S_{RN}1$ mechanism as despicted in Scheme I,[2,3] adapted to the present case.

Photons probably stimulate electron transfer from the enolate anion to the substrate, forming a radical anion (eq

6), which then decomposes into an aryl radical and the leaving group (eq 7). The aromatic radical then reacts with the nucleophile to give the substitution product through eq 8 and 9. Equation 6 is the initiation step, and eq 7–9 are the propagation steps of a chain mechanism.

The dark reaction of iodobenzene with **4b** may be due to a benzyne mechanism or to initiation by thermal electron transfer. The basicity of *N,N*-disubstituted amide enolate anions may be enough to form the *o*-halophenyl anion, which decomposes to benzyne and halide ion, and it is known that iodobenzene is more reactive than chlorobenzene by this mechanism.[11] On the other hand, iodobenzene reacts with several nucleophiles in the dark by the $S_{RN}1$ mechanism.[3,12] From our results it is not clear which mechanism applies for this dark reaction, but the facts that chlorobenzene does not react in the dark and that all the reactions are accelerated by light, as required by eq 6, indicate the prevailing mechanism for the photostimulated reaction.

Experimental Section

General Procedures. NMR spectra were recorded on a Varian T60 nuclear magnetic resonance spectrometer, and all spectra are reported in parts per million relative to Me_4Si (δ), using CCl_4 as solvent. Mass spectral measurements were obtained with a Hitachi Perkin-Elmer Model TMU-6E mass spectrometer. Potentiometric titrations were carried out with a Seybold Model GTE digital pH meter, using a combined silver–calomel electrode. Gas chromatographic analyses were performed on a Varian Aerograph Series 2400 chromatograph with a flame ionization detector, using a column packed with 4% silicon rubber SE30 on Chromosorb G (80-100 mesh). Column chromatography was performed on neutral aluminum oxide (Merck). Melting points are uncorrected. Irradiation was conducted into a reactor equipped with two Philips Model HPT water-refrigerated, 250-W UV lamps emiting maximally at 350 nm.

Reagents were all commercially available materials and were purified by standard procedures. *N*-Acetylpiperidine and *N*-acetylmorpholine were obtained by standard procedures. Liquid ammonia was dried over Na metal and distilled under nitrogen into the reaction flask. K metal was cut and washed free of oil with dried diethyl ether immediately before addition to the reaction flask.

Photostimulated Reactions. The photostimulated reaction of the potassium enolate of *N*-acetylmorpholine with bromobenzene is representative: 250 mL of ammonia was condensed into a three-necked, 500-mL, round-bottomed flask, equipped with a cold finger condenser charged with solid CO_2 and alcohol, a nitrogen inlet, and a magnetic stirrer. K metal (0.616 g, 0.0158 mol) and a small amount of $FeCl_3$ were added to the ammonia to form KNH_2. *N*-Acetylmorpholine (2.038 g, 0.0158 mol) was added, and after 5–10 min, bromobenzene (0.832 g, 0.0053 mol) was added and the solution irradiated for 180 min. The reaction was quenched by adding distilled water (~15 mL) and the ammonia was allowed to evaporate. Water (100 mL) was added to the residue, and the mixture was extracted three times with diethyl ether (100 mL). In the water, bromide ion was determined potentiometrically. The ether extract was dried over anhydrous Na_2SO_4 and distilled. The residue was then sublimed at 90 °C (5 torr) to obtain 4-(phenylacetyl)morpholine. This product was recrystallized from petroleum ether: mp 62.5–64 °C (56% yield) (lit. mp 62–64,[13a] 71–72[13b]); NMR (δ) 3.40 (8 H, m), 3.60 (2 H, s), 7.13 (5 H, s). 4-(2,2-Diphenylacetyl)morpholine was obtained by sublimation at 120 °C (5 torr): mp 115–118 °C (12% yield) (lit.[14] 124–125 °C); NMR (δ) 3.44 (8 H, m), 5.00 (1 H, s), 7.13 (10 H, s). By the same procedure the following amides were isolated by column chromatography: *N*-methyl-*N*-phenylbenzeneacetamide eluted with petroleum ether (72% yield): NMR (δ) 3.20 (3 H, s), 3.36 (2 H, s), 6.8–7.6 (10 H, m); mass spectrum, *m/e* 225, 134, 106, 91, 77; *N*-methyl-*N*-phenyl-1-naphthaleneacetamide eluted with benzene–chloroform (9:1) and was recrystallized from petroleum ether (50% yield): mp 88–89 °C; NMR (δ) 3.08 (3 H, s), 3.70 (2 H, s), 6.65–7.90 (12 H, m); *N*-methyl-*N*-phenyl-9-phenanthreneacetamide eluted with petroleum ether (80% yield): NMR (δ) 3.10 (3 H, s), 3.70 (2 H, s), 6.7–7.0 (5 H, m), 7.1–8.5 (9 H, m); *N,N*-dimethylbenzeneacetamide was isolated by sublimation at 60 °C (30 torr) (62% yield); mp 36.5–37°C (lit.[15] mp 37 °C).

Acknowledgment. R.A.A. gratefully acknowledges receipt of a fellowship from the Consejo Nacional de Investigaciones Cientificas y Técnicas, Argentina. The mass spectrum was run at the University of California at Santa Cruz through the courtesy of Professor J. F. Bunnett. We thank Professor J. M. Saveant for seding us a preprint of this work.

Registry No. **2**, 90-13-1; **4a**, 72377-89-0; **4b**, 72377-90-3; chlorobenzene, 108-90-7; bromobenzene, 108-86-1; iodobenzene, 591-50-4; 9-bromophenanthrene, 573-17-1; acetamide potassium enolate, 72377-91-4; *N*-acetylpiperidine potassium enolate, 72377-92-5; *N*-methyl-*N*-phenylbenzeneacetamide, 40669-47-4; *N*-methyl-*N*-phenyl-1-naphthaleneacetamide, 72377-93-6; *N*-methyl-*N*-phenyl-9-phenanthraceneacetamide, 72377-94-7; phenanthrene, 85-01-8; *N,N*-dimethylbenzeneacetamide, 18925-69-4; *N*-acetylmorpholine potassium enolate, 72377-95-8; 4-(phenylacetyl)morpholine, 17123-83-0; *N,N*-dimethyldiphenylacetamide, 957-51-7; 4-(2,2-diphenylacetyl)-morpholine, 14135-68-3; *N*-methyl-*N*-phenyldiphenylacetamide, 22050-96-0.

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