Nucleophilic Substitution at an Acetylenic Carbon. Kinetics of the Reaction between Bromoacetylene and Triethylamine in Dimethylformamide[1]

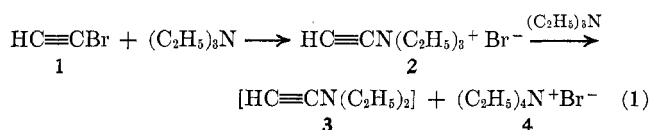RYUICHI TANAKA AND SIDNEY I. MILLER*

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Isolation of ethynyltriethylammonium bromide and chloride was achieved in the reaction between triethylamine and the respective monohaloacetylenes (1) in dry ether. The kinetics of the same reaction was studied in dimethylformamide (DMF). Because of the ready decomposition of 1 in air, a conductometric method of following the formation of 2 in a closed, oxygen-free system was devised. This conductance method could be used for kinetics in the range $[HC{\equiv}CBr]_0 = 0.002$–$0.004$ M and gave consistent rates for $[(C_2H_5)_3N]_0 < 0.4$ M. Higher concentrations of triethylamine, which lowered the dielectric constant of the medium, also reduced the rate of salt formation. The activation parameters for this second-order reaction are $\Delta H^{\pm} = 11.8$ kcal/mol and $\Delta S^{\pm} = -43$ eu. Several reaction paths to 2 can be discounted easily, but a choice between paths a *vs.* c and i in Scheme I cannot be made.

Although there is considerable interest in the properties of the haloalkynes, no kinetic study on any of the parent compounds $HC{\equiv}CX$ has been carried out.[2,3] Undoubtedly, the proclivity of these simple halides to burn, explode, or decompose on contact with oxygen may have been a factor. In our exploration of the scope of nucleophilic substitution at an acetylenic carbon,[2] we now examine process 1. When this

$$HC{\equiv}CBr + (C_2H_5)_3N \longrightarrow HC{\equiv}CN(C_2H_5)_3{}^+ Br^- \xrightarrow{(C_2H_5)_3N}$$
$$\underset{1}{\phantom{HC{\equiv}CBr}} \qquad \qquad \underset{2}{\phantom{HC{\equiv}CN(C_2H_5)_3}}$$

$$[HC{\equiv}CN(C_2H_5)_2] + (C_2H_5)_4N^+Br^- \quad (1)$$
$$\underset{3}{\phantom{[HC{\equiv}CN(C_2H_5)_2]}} \qquad \underset{4}{}$$

work was started, the chemistry of ynamines was just being developed. Now, these are familiar reagents,[4] although their salts are still rare.[5] The first results on process 1 were, in fact, incidental to a study of the dehydrobromination of 1,2-dibromoethylene by triethylamine in DMF.[6] In this study we isolated 2 and obtained the kinetics of and restricted the mechanistic alternatives in reaction 1.

(1) (a) Supported in part by the National Institutes of Health, Grant GM 7021; (b) Abstracted from the Ph.D. thesis of R. T., Illinois Institute of Technology, 1970.

(2) (a) G. R. Ziegler, C. A. Welch, C. E. Orzech, S. Kikkawa, and S. I. Miller, *J. Amer. Chem. Soc.*, **85**, 1648 (1963); (b) C. E. Orzech, C. A. Welch, G. R. Ziegler, J. I. Dickstein, and S. I. Miller, *ibid.*, **84**, 2020 (1962); (c) A. K. Kuriakose, and S. I. Miller, *Tetrahedron Lett.*, 905 (1962); (d) H. G. Viehe, S. I. Miller, and J. I. Dickstein, *Angew. Chem.*, **76**, 537 (1964); (e) A. Fujii, J. I. Dickstein, and S. I. Miller, *Tetrahedron Lett.*, 3435 (1970); (f) A. Fujii and S. I. Miller, *J. Amer. Chem. Soc.*, **93**, 3694 (1971); (g) R. Tanaka, M. Rodgers, R. Simonaitis, and S. I. Miller, *Tetrahedron*, **27**, 2651 (1971); (h) J. I. Dickstein and S. I. Miller, unpublished results; (i) R. Tanaka and S. I. Miller, *Tetrahedron Lett.*, 1753 (1971).

(3) S. Y. Delavarenne and H. G. Viehe in "The Chemistry of Acetylenes," H. G. Viehe, Ed., Marcel Dekker, New York, N. Y., 1969, Chapter 10.

(4) (a) H. G. Viehe, ref 3, Chapter 12; (b) J. Ficini and C. Barbara, *Bull. Soc. Chim. Fr.*, 2787 (1965); (c) S. R. Sandler and W. Karo, "Organic Functional Group Preparations," Academic Press, New York, N. Y., 1971, Chapter 4.

(5) J. L. Dumont, *C. R. Acad. Sci.*, **261**, 1710 (1960).

(6) W. K. Kwok, W. G. Lee, and S. I. Miller, *J. Amer. Chem. Soc.*, **91**, 468 (1969).

Experimental Section[1b]

Purified DMF,[6] bp 58° (30 mm), was redistilled over Linde 13X Molecular Sieves directly into a special solvent reservoir, in which it could be stored and from which it could be dispensed through Teflon tubing and syringe needles, always under dry nitrogen. An ir spectrum of the purified DMF (0.1 mm) showed no detectable water absorption (<0.05%). An nmr (neat) spectrum had no foreign peaks. The specific conductance at 25° was well below 10^{-6} ohm^{-1} cm^{-1} (lit.[7] 0.4–2.7 × 10^{-7} ohm cm^{-1}), which was the limit of measurement of our conductance bridge. Triethylamine, purified as described previously,[6] was checked and stored in the same way as DMF. Diethylamine was dried over potassium hydroxide, then fractionally distilled under nitrogen.

Bromoacetylene (1).[8]—This substance is dangerous and may burn or explode on contact with air; it was prepared, transferred, and stored under dry nitrogen.[6] The bromoacetylene generator was connected to a line which consisted of a bubbler containing aqueous potassium hydroxide, a column (2.5 × 30 cm) of calcium chloride, four U-traps, a receiver, and a bubbler (air seal). 1,2-Dibromoethylene was added dropwise to a solution of ethanolic sodium hydroxide and brought to reflux temperature. The monobromoacetylene was carried into the line by a stream of nitrogen and purified by trap-to-trap distillation, until it was finally condensed into the flask at −78° containing the solvents (15 g of DMF or 45 ml of ethyl ether).

For kinetic runs, the solution of 1 (*ca.* 1.2 M) in DMF was diluted *ca.* 10 times with DMF under nitrogen and stored in Dry Ice. For preparative runs, the ether solution was mixed directly with triethylamine under nitrogen.

Chloroacetylene (1′).[8]—Chloroacetylene is even more dangerous than bromoacetylene, because it is as reactive and much more volatile. It was generated from *cis*-1,2-dichloroethylene in essentially the same way as described above.

Reaction between Bromoacetylene and Diethylamine.—Bromoacetylene was introduced into a flask containing diethylamine (8 ml) 6 in anhydrous ether (45 ml) at −78°. This flask was brought to ~25°, venting occasionally to relieve excess pressure. After the solution was stirred magnetically for 24 hr, the white solid was filtered off under nitrogen, and the filtrate was concentrated under nitrogen to give a yellow oil (~1 ml). The ir spectrum of the solid precipitate was identical with that of authentic diethylamine hydrobromide. As for the liquid product, since it was unstable and decomposed during distillation,

(7) (a) D. P. Ames and P. G. Sears, *J. Phys. Chem.*, **59**, 16 (1955); (b) P. G. Sears, E. D. Wilholt, and L. R. Dawson, *ibid.*, **59**, 373 (1955).

(8) L. A. Bashford, H. J. Emeleus, and H. V. A. Briscoe, *J. Chem. Soc.*, 1358 (1938).

an elemental analysis was not obtained and spectral data were obtained on the crude oil. It contained halogen and is tentatively identified as cis-2-bromo-1-diethylaminoethylene. In the ir spectrum, the presence of bands at 1638, 1618 (sh), and 1260 cm^{-1} and the absence of bands at ~960 cm^{-1} indicated an analog of cis-dibromoethylene.[9] In the nmr spectrum, there was an apparent AX quartet of cis alkene protons consisting of two strong inner peaks and two weaker outer peaks: nmr (DMSO-d_6) δ 1.50 (t, J = 7.0 Hz), 3.18 (q, J = 7.0 Hz), 4.44 (d, J = 6.3 Hz), and 6.37 (d, J = 6.3 Hz).

Ethynyltriethylammonium Bromide (2).—To a stock solution of 1 in anhydrous ether (45 ml) at −78°, triethylamine (10 ml) was added with a hypodermic syringe. The system was brought to ~25° and stirred magnetically for 48 hr; inspection of the ir spectrum of the ether solution indicated that even after 24 hr a substantial amount of 1 remained. The volume of solution was reduced in a dry nitrogen stream and then pushed by nitrogen pressure directly from the flask through a sintered glass filter in which an off-white solid was collected. The filtrate was swept with nitrogen to remove ether, leaving only a minute amount of yellow oil, whose nmr (CCl$_4$) and ir (neat) spectra indicated N,N-diethylacetamide[6] and triethylamine. To remove traces of a dark impurity, the precipitate (ca. 500 mg) was repeatedly dissolved in Spectrograde acetonitrile (0.5–1 ml) in a stoppered flask equipped with a built-in glass filter, reprecipitated with anhydrous ether, and filtered off under nitrogen pressure. Finally, the solid was placed under high vacuum for 2 days and stored under nitrogen in the dark. It had ir (KBr) 3085 ($\nu_{HC\equiv}$), 2138 ($\nu_{C\equiv C}$), 1460, 1408, 1308, 1010 and 995 cm^{-1}; nmr (DMSO-d_6) δ 1.36 (t, 9 H, J = 7.3 Hz), 3.82 (q, 6 H, J = 7.3 Hz), and 4.86 (s, 1 H); mp 107–108° dec; mass spectrum m/e 110 and 108 (C$_2$H$_5$Br$^+$), 101 [(C$_2$H$_5$)$_3$N$^+$], 97 [(C$_2$H$_5$)$_2$NC≡CH$^+$], 86 (101 − 15), 82 (97 − 15), 54 (C$_4$H$_6$$^+$), 41 (C$_2H_3N^+$), 29 (C$_2H_5$$^+$).

Anal. Calcd for C$_8$H$_{16}$BrN: C, 46.61; H, 7.82. Found: C, 46.09; H, 7.87.

This solid could not be filtered in the open without rapid deliquescence and formation of a tar-like brown slurry. Nevertheless, the solid did not seem to react with water under neutral conditions. The ir spectrum of the tar resulting from the interaction of water and the solid was a superposition of the component spectra; the nmr spectrum in DMSO-d_6 of the dry solid was identical with that of its aqueous solution.

Compound 2 gave a positive Beilstein test and its aqueous solution with silver nitrate deposited silver bromide. When an alcoholic solution of 2 was added dropwise to an alkaline solution of potassium iodide and mercuric chloride mixture, precipitation of a bright yellow solid, possibly I$^-$(C$_2$H$_5$)$_3$N$^+$C≡CHgI, occurred: mp 157–158° from acetonitrile–water; ir (KBr) 1450, 1380, and 995 cm^{-1}; nmr (DMSO-d_6) δ 1.39 (t, J = 7.1 Hz) and 3.86 (q, J = 7.1 Hz); the mass spectrum had peaks for HgI$_2$$^+$, HgI, I$_2$$^+$, Hg$^+$, I$^+$, and m/e 156 (C$_2H_5I^+$), 128 (HI), 124 (C$_8H_4N^+$), 113 (C$_7H_{15}N^+$), 105 (C$_7H_7N^+$), etc.

When 2 (100 mg) was heated at 80° in an ampule with triethylamine (ca. 1 ml) for 2 hr and the mixture was worked up, a dark solid, chiefly 4, and an oil, chiefly, N,N-diethylacetamide, were identified by their spectra.[6] Several attempts to isolate or detect the ynamine 3 itself failed; for example, 2 and triethylamine were heated at 50° for 12 hr, they were refluxed in ether for 24 hr, or the reaction was carried out in hexamethylphosphoramide at 25°. At no stage of the above conditions could 3 be detected by spectral means.[4] Instead, an unidentified polymeric resin, which showed an ir absorption at 1670 cm^{-1}, was invariably obtained along with tetraethylammonium bromide and N,N-diethylacetamide.

Conductometric Kinetics.—A General Radio impedance bridge type 650-A, equipped with a General Radio unit oscillator which supplied 1000-cps alternating current between a pair of 4-kohm resistors at both terminals, was used. The null point on the Wheatstone bridge was detected by an oscilloscope.

Our conductance cells were constructed of glass in an H shape. The sides (legs) had ground glass caps fitted with stopcocks, and the platinum electrodes (10 × 10 mm) were set 10 mm apart in one leg. Since they were used only in nonaqueous solvents, the platinum black on the electrodes was removed by electropolishing.[10] The cells were washed thoroughly with water and metha-
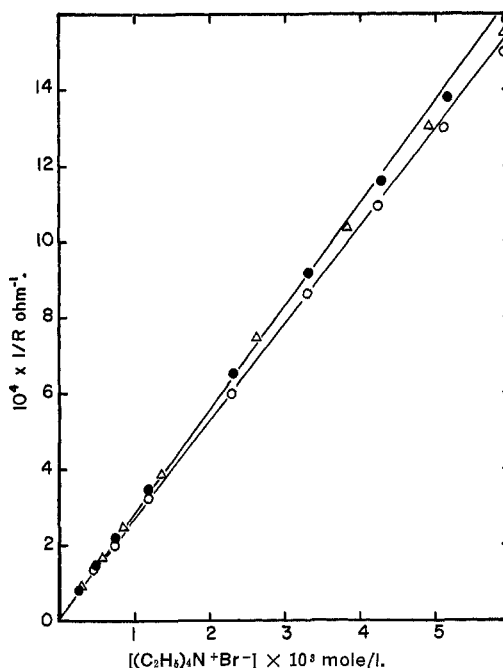
(9) J. M. Dowling, P. G. Puranik, A. G. Meister, and S. I. Miller, *J. Chem. Phys.*, **26**, 233 (1957).

(10) T. Shedlovsky in "Techniques of Organic Chemistry," A. Weissberger, Ed., 3rd ed, Vol. I, Wiley-Interscience, New York, N. Y., 1959, p 3036.

Figure 1.—The conductance of tetraethylammonium bromide in DMF–triethylamine solutions: [(C$_2$H$_5$)$_3$N] ●, 0.1; △, 0.2; ○, 0.3 mol/l.

nol, dried, and filled repeatedly with pure DMF, until R >10^6 ohms. To decide on the best concentration range for this study, we investigated the conductance (1/R) of triethylammonium bromide (0–0.12 M) in DMF–triethylamine. Conventional Kohlrausch plots (1/[Br$^-$]R vs. [Br$^-$]$^{1/2}$) had variable negative slopes, large at low and small at high concentrations.[10,11] Fortunately, 1/R was linear in [Br$^-$] in the limited range 0.002–0.004 M in DMF,[7] in which R ≅ 10^4–10^3 ohms (Figure 1).

For the kinetic runs, all glassware was dried and flushed with nitrogen. Solvents and solutions were transferred wholly under nitrogen when possible; pipet transfers were made quickly against a stream of nitrogen. Our stock solution of bromoacetylene (~0.12 M) in DMF was diluted to ~0.048 M and a stock solution of triethylamine (2.00 M) in DMF was prepared. The DMF, which had been soaking the electrodes, was drained from the conductance cell. The air in the conductance cell was swept out for ca. 2 hr with nitrogen, and the right and left legs were loaded in turn with known volumes of the reactant solutions to make up a final volume of 20.0 ml. The cell was immersed in a constant-temperature bath. After 5–10 min, it was removed from the bath, inverted and shaken vigorously, tilted so that all of the solution collected in the electrode compartment, and quickly replaced in the bath. Four such cells were usually set up together. At intervals up to 12 hr, R was taken from 10^5–1800 ohms; R_∞ was obtained in 3–5 days.

Under pseudo-first-order conditions of [(C$_2$H$_5$)$_3$N]$_0$ ≫ [HC≡CBr]$_0$, and subject to the linearity assumption 1/R ∝ [Br$^-$], second-order kinetics in process 1 leads to expression 2. Rate constants (k_ψ) could be obtained from "linear" plots of the type

$$k_\psi t = \ln[R/(R − R_\infty)] + \ln(1 − R_\infty/R_0) \qquad (2)$$

given in Figure 2; the early points were neglected because of the uncertainties in R at low [Br$^-$]. The rate law 2 was tested over a modest range in concentrations; reproducibility is evident from several pairs of initially identical runs (Table I). The results of a comparable number of runs are not given here: at the start of this work, 24 runs in the nonlinear range of 1/R were made; in addition, runs with inconsistent trends in R occasionally turned up, because of leaks in the system, problems with the electrodes, or for undetermined causes.

In order to correct the concentrations for volume changes of

(11) "Du Pont DMF Product Information," Industrial and Biochemicals Department, E. I. du Pont de Nemours & Co., Wilmington, Del., 1967, pp 3, 31.
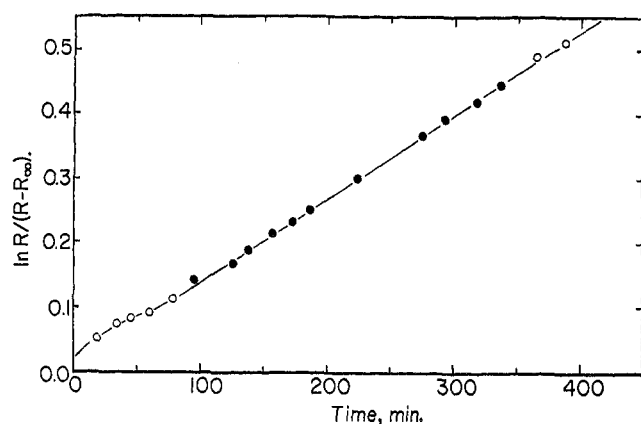
Figure 2.—The reaction of bromoacetylene ([HC≡CBr]$_0$ = 0.0024 M) with triethylamine ([(C$_2$H$_5$)$_3$N]$_0$ = 0.4 M) in DMF at 81.30 ± 0.1°; k_ψ was obtained from the shaded points.

TABLE I

CONDUCTOMETRICALLY DETERMINED PSEUDO-FIRST-ORDER
RATE CONSTANTS (k_ψ) OF THE BROMOACETYLENE–
TRIETHYLAMINE REACTION IN DIMETHYLFORMAMIDE

Temp, °C ± 0.1	[(C$_2$H$_5$)$_3$N]$_0$, mol/l.	[HC≡CBr]$_0$, mol/l.	$k_\psi \times 10^4$, min^{-1}
60.00	1.00	0.0024	9.124
60.00	1.00	0.0024	9.466
60.00	0.50	0.0024	5.720
60.00	0.50	0.0024	5.947
59.99	0.30	0.0024	3.708
60.02	0.20	0.0013	2.038
60.02	0.20	0.0013	2.667
71.46	0.50	0.0024	11.56
71.50	0.50	0.00052	16.49^a
71.45	0.30	0.0024	5.356
71.45	0.20	0.0024	4.816
71.45	0.10	0.0024	3.767^a
71.59	1.00	0.0024	16.956
71.59	0.70	0.0024	12.397
71.57	0.40	0.0024	8.497
71.57	0.30	0.0024	6.575
71.57	0.20	0.0024	4.677
71.53	0.50	0.0024	10.672
71.46	0.40	0.0024	7.874
81.30	0.50	0.0024	15.58
81.30	0.40	0.0024	12.91^b
81.30	0.20	0.0024	13.20^a
81.24	0.30	0.0024	10.07
81.24	0.30	0.0024	11.10
81.24	0.20	0.0024	8.38
81.24	0.20	0.0024	8.26
81.36	0.10	0.0017	4.333
81.36	0.20	0.0024	7.546
81.26	0.20	0.0024	7.211
81.26	0.10	0.0024	4.162

^{a} Not included in Figure 3. ^{b} This run is illustrated in Figure 2.

the medium, we used eq 3 for the density (d) variation with temperature (t, °C),[11,12] and assumed that the volumes of triethyl-

$$d(\text{DMF}) = 0.9445 - 0.000872 \ (t - 25)$$

$$d[(\text{C}_2\text{H}_5)_3\text{N}] = 0.73255 - 0.00091 \ (t - 15)$$

(3)

amine and DMF were additive. Plots of k_ψ vs. the temperature-corrected values of [(C$_2$H$_5$)$_3$N] are displayed in Figure 3. The linear portions (<0.5 M) of these curves represent the region of second-order kinetics of process 1, and the least-squares slopes

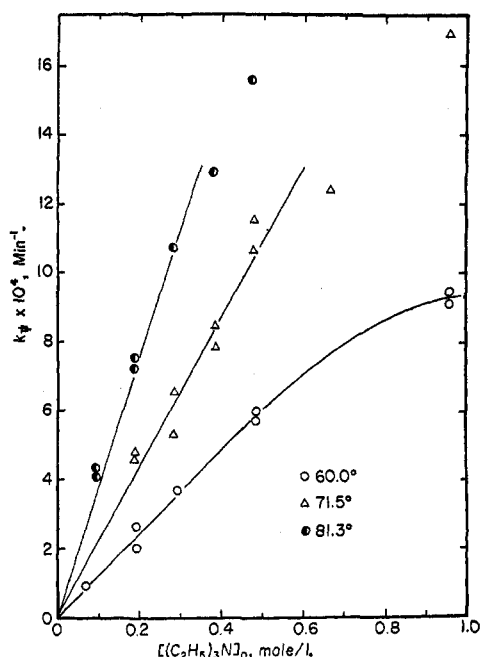(12) M. J. Timmermans and Hennault-Roland, *J. Chim. Phys.*, **29**, 529 (1932).

Figure 3.—Pseudo-first-order rate constants of bromoacetylene–triethylamine reaction vs. initial triethylamine concentrations.

($\Delta k_\psi / \Delta[(\text{C}_2\text{H}_5)_3\text{N}]$) yield the second-order rate constants (Table II). Activation parameters were obtained from standard expressions.[6]

According to the specifications of our conductance bridge, the uncertainty in R is 1%. A single reading in R could lead to an uncertainty in k_ψ of ~20%; for our typical run of about 10 points, this would be reduced to 6-7%; for a set of runs at one temperature, this would be cut to 3-4% in the final k value. In Table II, we simply give the probable errors calculated through the leasts square-fit of data given in Table I.

Titrimetric Kinetics.—Stock 1 in DMF and triethylamine (100.0 ml) were transferred in a nitrogen-filled glove bag to a volumetric flask (250 ml) and made up to volume with DMF. The flask was well shaken and removed from the glove bag, and aliquots (100 ml) were dispensed into nitrogen-flushed ampules, which were then capped. All of the ampules were cooled in Dry Ice-acetone until they were sealed. Apart from those ampules reserved for the "blank" estimate of bromide, the ampules were either left in constant-temperature baths for various times or otherwise stored at −78°. For analysis, the ampules were opened, rinsed into glacial acetic acid (7 ml), and titrated with standard silver nitrate.

By using an excess of triethylamine, we could show that process 1 followed pseudo-first-order kinetics. Under these conditions, it was not essential to know [HC≡CBr] at time zero. This was fortunate, since each run appeared to have a characteristic and large bromide blank (~15%) which presumably arose from the absorption of oxygen during the preparation of the solutions and filling of the ampules at ca. 25°. Nevertheless, pseudo-first-order plots were obtained (Figure 4). The second-order constants, k, were obtained from $k_\psi / [(\text{C}_2\text{H}_5)_3\text{N}]$ (Table III).

Chloroacetylene and Triethylamine.—A reaction in ether similar to that in the previous section was carried out for chloroacetylene, but for 64 hr at ~25°. The white solid had spectra virtually identical with those of 2. This compound was difficult to purify and no acceptable elemental analysis was obtained. Preliminary kinetic runs by the conductimetric method indicated that 1 and 1' reacted at comparable rates, with the chloro compound slightly slower than the bromo compound. Since k_ψ and [(C$_2$H$_5$)$_3$N]$_0$ were inconsistent in these first runs, we could only estimate k.

Results and Discussion

Stoichiometry and Kinetics.—At 25° in ether, the product of process 1 is the ynamine salt 2. (This incidentally is the parent of this class of compounds.)

TABLE II

SELECTED RATE DATA FOR THE REACTION OF ORGANIC BROMIDES AND AMINES

System	Solvent	Temp, °C	$k \times 10^5$, $M^{-1} sec^{-1}$	$\Delta H^{\ddagger}$, kcal mol^{-1}	$\Delta S^{\ddagger}$, eu	Ref
HC≡CBr + (C₂H₅)₃N	DMF	60.0	2.00 ± 0.06	11.8 ± 0.2	−43 ± 1	a
		71.5	3.72 ± 0.13			
		81.3	6.14 ± 0.18			
C₂H₅Br + (C₂H₅)₃N	(CH₃)₂CO	100	55			b
	C₆H₆	100	5			b
n-C₃H₇Br + (CH₃)₃N	C₆H₆	80.5	17.8	11.0	−44.9	c
H₂C=CHBr + C₅H₁₀NH	C₆H₅NO₂	100	0 (100 hr)			d
trans-p-C₇H₇SO₂CH=CHBr + C₆H₁₁NH₂	CH₃OH	25.0	198			e
C₆H₅Br + C₅H₁₀NH	C₆H₆	130	0 (200 hr)			f
p-C₆H₅SO₂C₆H₄Br + C₅H₁₀NH	C₆H₆	120	0.18	15.7	−45.6	f

ᵃ This work. ᵇ Reference 14. ᶜ C. A. Winkler and C. N. Hinshelwood, J. Chem. Soc., 1147 (1935). ᵈ G. Salomon and A. J. Ultée, Sr., Recl. Trav. Chim. Pays-Bas, 69, 95 (1950). ᵉ S. Ghersetti, G. Lugli, G. Melloni, G. Modena, P. E. Todesco, and P. Vivarelli, J. Chem. Soc., 2227 (1965). ᶠ F. Kalberer, Bull. Soc. Fribourg. Sci. Nat., 44, 225 (1954); Chem. Abstr., 50, 16718 (1956).

TABLE III

TITRIMETICALLY DETERMINED KINETIC DATA FOR THE
REACTION BETWEEN BROMOACETYLENE AND
TRIETHYLAMINE (2.8575 M) IN DIMETHYLFORMAMIDE

Temp, °C ± 0.1	[HC≡CBr]₀ᵃ mol/l.	$k\psi \times 10^2$, min⁻¹	$k \times 10^3$,ᵇ l. mol⁻¹ min⁻¹
59.55	0.123	0.650	2.36
59.50	0.0847	0.698	2.54
59.66	0.0522	0.510	1.85ᶜ
59.81	0.0636	0.627	2.28
78.85	0.123	1.17	4.35
78.95	0.0847	1.137	4.23
79.32	0.0522	0.99	3.68ᶜ
79.28	0.0636	1.013	3.77
79.58	0.0333	0.856	3.18
79.45	0.0115	0.705	2.62
101.00	0.123	1.95	7.44
102.00	0.0847	1.955	7.45
102.18	0.0522	1.73	6.60ᶜ
102.36	0.0333	1.619	6.17
102.20	0.135	3.10	10.83ᵈ

ᵃ Taken from [Br⁻]∞. ᵇ The correction for solvent expansion was made. At the three temperatures, the mean k's are 2.2 ± 0.02, 3.6 ± 0.5, and 6.6 ± 0.5 × 10⁻³ M⁻¹ min⁻¹; if plots of k vs. [HC≡CBr]₀ are extrapolated to [HC≡CBr]₀ = 0, the k's are 0.45, 2.4, and 4.5 × 10⁻³ M⁻¹ min⁻¹. ᶜ The actual run is shown in Figure 4. ᵈ Single value from ref 6.

At 80° in triethylamine, **2** is converted into **4**. Although we were unable to isolate **3**, its hydration product, N,N-diethylacetamide, was identified (eq 4). Previously, neither **2** nor **3** were detected[6] from this reaction, although **3** has been prepared in impure form by a different route from trichloroenamines.[4b] Strenuous efforts were made to exclude moisture, but some amide is always formed. The deliberate or inadvertent use of an ynamine as a desiccant has precedent.[2d,h,4] With less hazardous haloalkynes, scaling up may be a useful synthetic strategy so that relatively small quantities of product may be sacrificed to remove traces of water from the reagents and apparatus.[3]

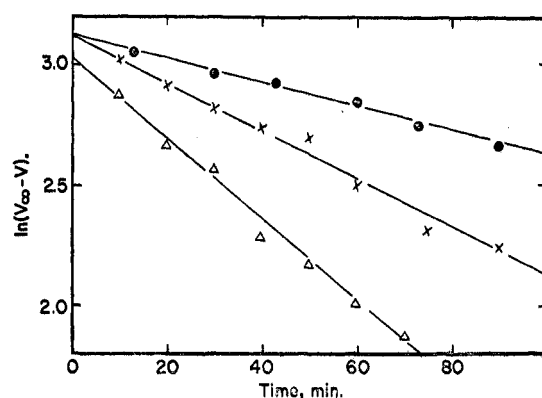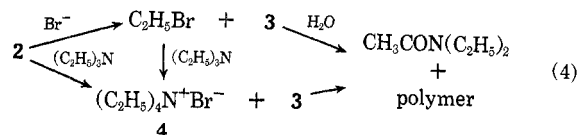Whether the final products are formed along the top or bottom branch of eq 4 is not established by this

$$
\mathbf{2}
\begin{array}{c}
\xrightarrow{\text{Br}^-} \text{C}_2\text{H}_5\text{Br} + \mathbf{3} \xrightarrow{\text{H}_2\text{O}} \\
{(\text{C}_2\text{H}_5)_3\text{N}} \quad \Big\downarrow {(\text{C}_2\text{H}_5)_3\text{N}} \qquad \searrow \\
\searrow (\text{C}_2\text{H}_5)_4\text{N}^+\text{Br}^- + \mathbf{3}
\end{array}
\begin{array}{c}
\text{CH}_3\text{CON}(\text{C}_2\text{H}_5)_2 \\
+ \\
\text{polymer}
\end{array}
$$

$$ \qquad (4) $$

4

Figure 4.—The reaction of bromoacetylene (ca. 0.68 M) with triethylamine (2.96 M) in DMF at 59.66° (●), 79.32° (×), and 102.18° (△). V is the volume of silver nitrate (0.0264 M).

work. Judging by its quaternization rate, a path via ethyl bromide is not precluded (Table II).[13] These "relative rates" for the two steps were determined under synthetic conditions, that is, in ether, in which **2** is essentially insoluble. In our kinetic solvent, DMF, the salts were soluble; in any case, DMF is more polar than ether and the rate of the second step (SN2) relative to the first (AdN2) should be enhanced.[14,15]

The kinetics of process 1 were followed conductometrically in the absence of air in the "low" triethylamine region (Table I). The reaction was first order in bromoacetylene and in triethylamine (Figures 2 and 3). The various derived quantities are collected in Table II. The large negative $\Delta S^{\ddagger}$ is characteristic of the reactions between neutral molecules to form charged species (Table II).[2f,16] Incidentally, bromoacetylene is both neutral and nonpolar ($\mu \cong 0$).[17]

Since two salts, **2** and **4**, could have been present in our product mixtures, it may appear that a rate law based on one salt could lead to problems. The fact that eq 2 was obeyed indicates that, if **2** and **4** were both present, their equivalent conductances were similar. This is also plausible, since the equivalent conductances of related salts can be close: Λ [(C₂H₅)₄-

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(14) A. J. Parker, Chem. Rev., 69, 1 (1969).

(15) (a) E. Tommila, Acta Chem. Scand., 13, 622 (1959); (b) M. H. Abraham, Chem. Commun., 293 (1970).

(16) A. A. Frost and R. G. Pearson, "Kinetics and Mechanism," 2nd ed, Wiley, New York, N. Y., 1965, p 138.

(17) H. Jones, N. L. Owen, and J. Sheridan, Nature, 213, 175 (1967).

NBr] = 81.71 and Λ [(CH$_3$)$_4$NBr] = 82.90 ohm cm^{-1} at 0.16 M in DMF at 25°.[7b,18] If this picture is correct, our rate data refer to the first step of eq 1 despite the fact that the second step, 2 → 3, may be relatively slow.

Process 1 was also followed titrimetrically at "high" triethylamine (2.86 M). Of necessity, there was some exposure of the solutions to air in the preparation of the kinetic runs. This led to substantial bromide ion blanks, before the samples were placed in the constant-temperature baths. Besides this, there were difficulties in treating the rate constants, which increased with [HC≡CBr]$_0$. For this reason, both a k value, obtained by extrapolation to [HC≡CBr]$_0$ = 0, and a mean k were estimated (Table III). Judging by the data of Figure 4, there does not appear to be any pronounced ionic strength effect during individual runs. We tentatively associate difficulties in the titrimetric k's with an "oxygen effect" which leads to both rapid and delayed conversions of bromoacetylene to bromide ion.

Although they cannot be weighted equally, it is interesting to compare the k's obtained in the two concentration ranges of triethylamine. Judging from the trends in Table I, the conductometric k's at 2.86 M triethylamine ($\epsilon \cong 6.5$) should be low. The plots in Figure 3 presumably reflect the fact that added triethylamine ($\epsilon = 2.14$), decreases both the polarity of the solvent DMF ($\epsilon = 28.1$) and the rate of quaternization.[15] These expectations are borne out by the extrapolated, but not the average, conductometric k's at 60 and 80° which tend to be "low" (Table III).

Mechanism.—Concerning process 1, the first mechanistic question concerns the point of attack, namely on bromine, α carbon, or β carbon. There is, in fact, evidence for the *triphilic* character of haloalkynes, that is, the conversion of phenylbromoacetylene by methoxide in methanol to phenylacetylene, phenyl methoxyacetylene (and E-β-bromo-β-methoxystyrene), and Z-β-bromo-α-methoxystyrene.[2g] Indeed, attack on bromine with amine nucleophiles is known both in the alkane[19] and alkyne series,[2d,h,3] and with some nucleophiles, *e.g.*, tributylphosphine or sodium diethylphosphite, bromine abstraction from an sp carbon may predominate.[2e] As for attacks on the carbon atoms in the simple alkylbromoalkynes, these do occur, but the choice between them is equivocal.[3,4]

In Scheme I, we give several mechanistic alternatives. However relevant these may be in other systems, most can be discarded here. As we shall see, two survive by default and because of simplicity.
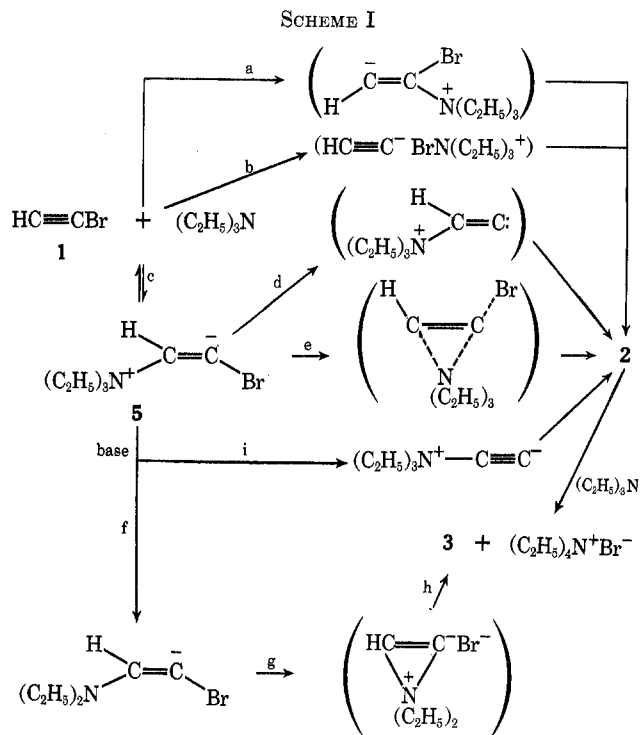
The addition of diethylamine to 1 (eq 5) under mild

$$1 \;+\; (C_2H_5)_2NH \;\xrightarrow{\sim25°}\; \underset{(C_2H_5)_2N}{\overset{H}{>}}C=C\underset{Br}{\overset{H}{<}} \quad (5)$$
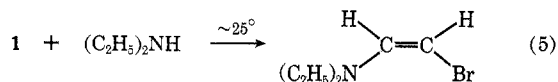
conditions was intended to provide a model for the formation of 2. If it was a model, this was not obvious, since diethylamine attacked the β carbon. A similar result has been reported for 1-bromohexyne, in which 1,2-bisdiethylaminohexene-1 is the isolable product.[20] It does appear that secondary amines attack the α car-

SCHEME I

bon of 1-bromo-3,3-dimethylbutyne-1 or 1-bromo-3-methylpentyn-3-ol to give low yields of 1,1-bisaminoalkene-1 or the related amide, but these are not really convincing models for process 1.[20,21]

Attack on bromine similar to that of step b of Scheme I is excluded, since the ion pair [HC≡C$^-$BrHN-(C$_2$H$_5$)$_2$$^+$] almost certainly should lead to acetylene.[2e-h,3,4,21]

The formation of the β adduct in eq 5 makes path c plausible in Scheme I. Although step e is known in the Fritsch–Buttenberg–Wiechell rearrangement,[22] here the necessary syn elimination would be unfavorable; in addition there is no precedent for the 1,2-anionic rearrangement of a quaternary nitrogen.[23] Step f seems to be unexceptional and the subsequent rearrangement (g, h) has precedent in examples provided by Viehe, *et al.*[24] There is, however, the problem of going from 3 to 2; because triethylamine is a stronger base (nucleophile) than 3, the direction shown in Scheme I, namely 2 → 3, is preferred.

The concerted 1,2 rearrangement in 5 of a hydrogen (or alkyl) group to anionic carbon (not shown) never occur—at least, reported examples turn out to be nonconcerted[25]—and moreover are unlikely for orbital symmetry reasons.[26] If, however, 5 sheds bromide ion along d to give a carbene, then the 1,2-hydride shift to 2 need not be forbidden. Again, the anti dehydrobromination along step i, followed by proton uptake, also leads to 2 and seems intuitively more attractive than d, under our reaction conditions. This group of

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(24) S. Y. Delavarenne and H. G. Viehe, *Chem. Ber.*, **103**, 1198, 1209, 1216 (1970).

(25) U. Schöllkopf, U. Ludwig, G. Ostermann, and M. Patsch, *Tetrahedron Lett.*, 3415 (1969); U. Schöllkopf, J. Schossig, and G. Ostermann, *Justus Liebigs Ann. Chem.*, **737**, 158 (1970).

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mechanisms cannot apply generally, of course, since a mobile group such as hydrogen is essential. Realistically, we believe we are left with steps a or c and i in Scheme I as alternate mechanisms in this system.

Rate Comparisons.—In Table II we have collected rate data for Menschutkin substitutions of differing types of organic bromides. Were it necessary, one could estimate the rate constant for triethylamine with ethyl bromide in DMF.[13,15] It should be appreciated

that any comparison of reactivity of saturated with unsaturated centers involves a comparison of an SN2 with an AdN2 process. Our preliminary and generally qualitative comparisons[6] stand up here: k (alkyl) $\cong$ k (ethynyl) $\gg k$ (vinyl) $\gg k$ (aryl).

Carbodiimide–Sulfoxide Reactions. XIII.[1] Reactions of Amines and Hydrazine Derivatives

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The acid-catalyzed reactions of a variety of amines and hydrazine derivatives with DMSO and DCC have been examined. Mildly basic aromatic amines such as nitroanilines readily react to form N-aryl-S,S-dimethyl-sulfilimines in high yield. The reaction of 2,4-dinitrophenylhydrazine leads to a variety of products arising via initial formation of the corresponding aryldiimide and aryldiazonium salt. Some reactions of methylthio(2,4-dinitrophenyl)diimide are reported. Acylhydrazides are largely converted into N,N'-diacylhydrazines, probably via the acyldiimides. A more complex array of products results from the reaction of an acylhydrazide with DMSO and phosphorus pentoxide. Sulfonylhydrazides lead ultimately to the formation of thiolsulfonates presumably via disproportionation of an intermediate sulfinic acid. The reaction of benzophenone hydrazone leads to the formation of diphenyldiazomethane which subsequently reacts further to give a number of products. Benzil dihydrazone gives as its major product diphenylacetylene. Indole slowly gives 3-(methylthiomethyl)indole which is partially converted into 3,3'-bisindolylmethane. Mechanisms are considered for all these types of reactions.

Previous papers in this series have described the mild, acid-catalyzed reactions of alcohols,[3] phenols,[4] enols,[5] oximes,[6] carboxylic and hydroxamic acids,[7] carboxylic acid amides,[7] and sulfonamides[1] with dimethyl sulfoxide (DMSO) and dicyclohexylcarbodiimide (DCC). These varied types of reactions can all be explained by initial formation of a DMSO–DCC adduct (**1**) which undergoes reaction with the appropriate nucleophile to form a sulfonium ylide (**2**) which can subsequently collapse or rearrange in a number of ways. Formation of the ylide **2** can occur either directly via a concerted cyclic process[8] or in two steps by facile loss of a proton from the corresponding sulfonium compound.

1

2
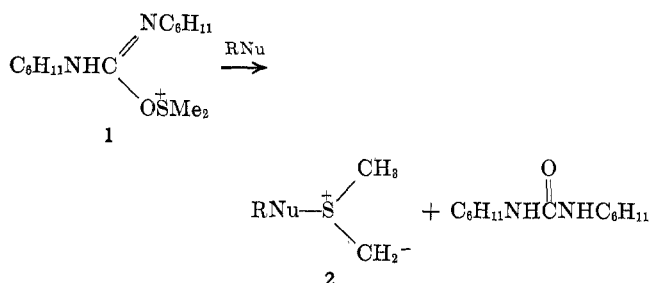
Since all the DMSO–DCC reactions we have examined have been found to require acidic catalysis, we felt that an extension of the above studies to amines as the reactive nucleophile might be difficult. This seemed particularly so since at an early stage we examined the reaction with 2,4-dinitroaniline, an amine that we felt might be sufficiently weakly basic to not block the acid-catalyzed formation of **1**. This compound showed no reaction whatsoever by tlc and an essentially quantitative yield of unreacted amine was recovered in crystalline form. A more strongly basic amine, *p*-anisidine, also failed to undergo any interesting reaction and was instead shown to undergo simple addition to DCC forming 1,3-dicyclohexyl-2-(4-methoxyphenyl)guanidine (**3**). The formation of **3** was

3   **4**   **5**
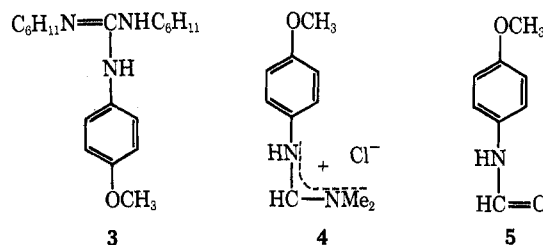
previously observed during preparation of nucleoside 5'-phosphoroanisidates, the latter compounds being isolated as their salts with this guanidine.[9] Since DMSO did not appear to be involved in the formation of **3**, a comparable reaction was carried out between *p*-anisidine, DCC, and anhydrous phosphoric acid in dimethylformamide (DMF). A totally different reaction then occurred giving N-(4-methoxyphenyl)-N',-N'-dimethylformamidine, which was isolated as its

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