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SOLVOLYSIS REACTIONS OF BIS(DIFLUORAMINO)ETHYLENES: A ROUTE TO NITRENIUM IONS

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SUMMARY

The reaction of tetrafluorohydrazine with acetylenes in inert solvent gives α,α-(fluorodifluoramino)fluorimines via unstable bis(difluoramino)-ethylenes. Under solvolytic conditions the rearrangement involves Sn1 cleavage of the N-F bond and the formation of a mesomeric nitrogen-carbon cation. The resulting ion pair can collapse to the α,α-(fluorodifluoramino)-fluorimine, which is stable under the reaction conditions, or react with solvent to give solvolysis products. Unsymmetrical acetylenes yield rearranged and solvolysis products from reaction of either of the dissimilar difluoramine groups.

INTRODUCTION

Perhaps the most thoroughly investigated organic reaction is the solvolysis reaction of the carbon-halogen (or other negative leaving group) bond. The mechanism of the reaction has been scrutinized in detail; results have been interpreted in terms of Sn1 and Sn2 mechanisms, carbenium and carbonium ions, internal and external ion pairs, and even subclasses of each of the above[1].

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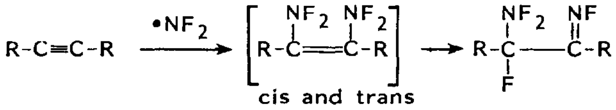
On the other hand, investigations of the reactions of the nitrogen-halogen bond under solvolytic conditions are much more limited. The positively charged, electron deficient nitrogen analog of the carbonium (carbenium) ion is termed a nitrenium ion It has commonly been postulated as an intermediate in solvolysis reactions of N-chloro and N-bromo derivatives; however, these reactions may be complicated by the tendency of these compounds to heterolyze to positive halogen or homolyze to free radicals[2]. In their elegant work Gassman and coworkers have made use of the silver ion, Ag^+, to greatly accelerate the formation of nitrenium ions from bicyclic aliphatic N-chloramines[3] To circumvent some of the problems associated with N-chloro derivatives N-arylsulfonyloxy leaving groups have been attached to nitrogen and undergo apparent nitrenium ion reactions; however these derivatives are relatively unstable and difficult to isolate and characterize at ambient temperature[4].

The electronegativity of fluorine precludes formation of positive fluorine and renders N-fluorine derivatives ideal as candidates to study the formation and reaction of nitrenium ions under solvolytic conditions. The pioneering work of C. B. Colburn[5] and coworkers at Rohm and Haas on the synthesis and characterization of tetrafluorohydrazine opened a new area of organic chemistry, usually based on the reactions of tetrafluorohydrazine[6,7] or difluoramine.[8]

The reaction of the difluoramino radical from tetrafluorohydrazine gives α,α-(fluorodifluoramino)fluorimines via unstable bis(difluoramino)ethylenes [7,9], which in the case of perfluoroalkyl acetylenes have been isolated[10].



The rearrangement of fluorine on the vinyl difluoramine function to carbon is formally analogous to the common rearrangement of allyl halides[11]. This rearrangement has been investigated under solvolytic conditions as a means to probe for the intermediacy of the nitrenium ion and to study its reactivity as a function of acetylene structure and solvent.

RESULTS AND DISCUSSION

Addition of tetrafluorohydrazine to methylphenyl-, diphenyl-, and diethylacetylene was carried out at 68-93°C under the several solvolytic conditions summarized in Table 1. The products were obtained in the relative yields indicated; the percentages represent the mole fraction of the total of those products listed for any one reaction. The product distribution was determined by measurement of the areas under the fluorimine ^{19}F peaks; an example of the ^{19}F spectrum in the fluorimine region for the reaction products of methylphenylacetylene and tetrafluorohydrazine in ethanol is shown in Fig. 1.

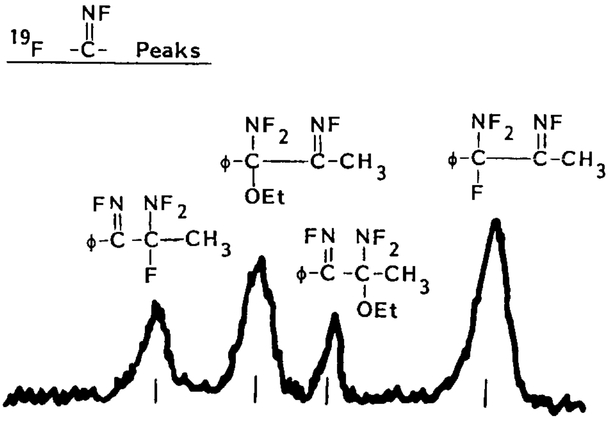


Fig. 1. ^{19}F NMR spectrum in fluorimine region of $\phi C\equiv CCH_3/N_2F_4$ reaction products in ethanol.

Material balances were generally 50-90%. Identification of products was based on their infrared, ^{19}F and ^{1}H spectra; elemental analyses of the products isolated by chromatography were satisfactory. The products isolated are shown in Fig. 2. The α,α(fluorodifluoramino)fluorimines were stable under the reaction conditions. Therefore, solvolysis products were not formed by subsequent reactions of the α,α(fluorodifluoramino)fluorimines

TABLE 1

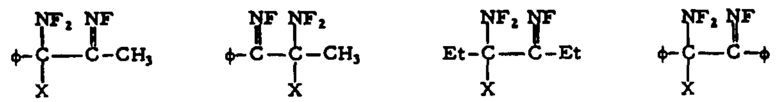
Reaction of Acetylenes and N_2F_4 Uner Solvolytic Conditions

		Product (% of Total)							
		Path 1[a]		Path 2[a]					
Acetylene	Medium	ki	ks	ki	ks	$\frac{ki_1}{ks_1}$[a]	$\frac{ki_2}{ks_2}$[a]	$\frac{k_1}{k_2}$[b]	$\frac{ki_1}{ks_1} \Big/ \frac{ki_2}{ks_2}$
$\phi C \equiv CCH_3$	MeOH, urea	5(39)	6(28)	9(25)	10(8)	1.39	3.13	2.03	0.444
$\phi C \equiv CCH_3$	EtOH, NaF	5(41)	7(29)	9(19)	11(11)	1.41	1.73	2.33	0.815
$\phi C \equiv CCH_3$	EtOH, urea	5(48)	7(25)	9(19)	11(8)	1.92	2.38	2.70	0.807
$\phi C \equiv CCH_3$	HOAc, urea	5(51)	8(31)	9(14)	12(4)	1.64	3.50	4.56	0.468
$\phi C \equiv CCH_3$	HOAc, NaOAc	5(50)	8(30)	9(15)	12(5)	1.67	3.00	4.00	0.556
$EtC \equiv CEt$	HOAc, urea			13(58)	14(42)		1.38[c]		
$EtC \equiv CEt$	HOAc, NaOAc			13(56)	14(44)		1.27[c]		
$\phi C \equiv C\phi$	HOAc, urea	15(71)	16(29)			2.45[c]			

[a] Path 1 for the methylphenylacetylene is that which places the mesomeric cation adjacent to the phenyl group.
Path 2 - adjacent to methyl or ethyl group.

[b] Ratio of total reaction by path 1 over that by path 2.

[c] In symmetrical acetylene either path leads to same products.



5, X = F
6, X = OMe
7, X = OEt
8, X = OAc

9, X = F
10, X = OMe
11, X = OEt
12, X = OAc

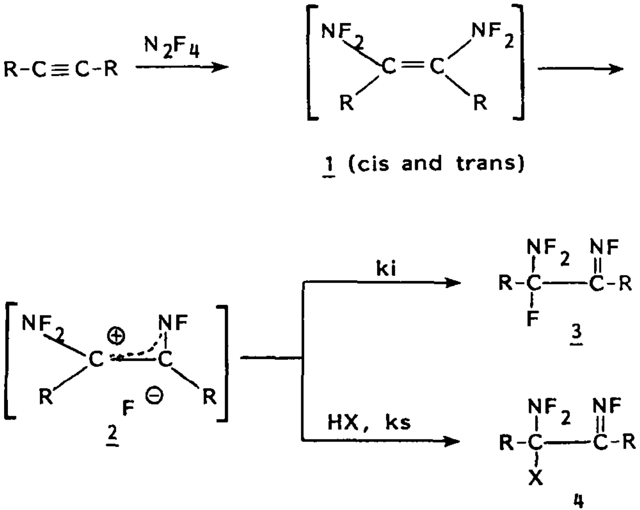
13, X = F
14, X = OAc

15, X = F
16, X = OAc

Fig. 2. Products of acetylene/tetrafluorohydrazine under solvolytic conditions.

The results suggest that the intermediate bis(difluoraminoethylene) reacts by Sn1 dissociation to a mesomeric nitrogen-carbon cation and fluoride internal ion pair; return of fluoride ion produces the thermodynamically stable C-F bond of compounds 5, 9, 13, or 15[12]. The stability of the perfluoroalkyl derivatives of bis(difluoramino)ethylenes[10] probably derives from the high energy of any carbonium ion intermediates in the perfluoro derivatives. The ion pair can produce the solvolysis products by reaction with solvent or exhange with added anionic species.

The generalized reaction scheme may be represented as in Scheme I.



1 (cis and trans)

2

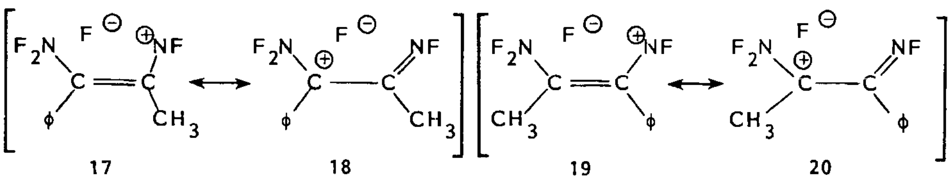
3

4

Scheme 1.

Rationalization of the reaction by other mechanisms is unappealing. Free radical reactions with the solvent would lead to entirely different products. In fact a small amount of such a byproduct, formed by hydrogen abstraction from solvent, was observed in the reaction of dimethyacetylenedicarboxylate with tetrafluorohydrazine[13] Three experimental facts support the Sn1 as opposed to an Sn2 mechanism: (1) the higher ratios of substitution adjacent to the phenyl group, (2) the constancy of the ratio of fluoride to acetate when either sodium acetate or urea[14] was added to the runs in acetic acid, and (3) the greater relative yield of fluoride to ethyl ether when urea was added to ethanol compared to addition of sodium fluoride

In the case of an unsymmetrical acetylene such as methylphenylacetylene reaction can take place by two paths, depending on which difluoramino group ionizes. The ion pair itermediates can be represented by the two pairs of mesomeric structures 17/18 and 19/20:



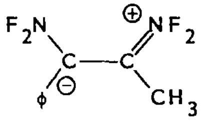
17 18 19 20

The reaction path by 17/18 (path 1) over 19/20 (path 2) was preferred in all reactions by a factor of 2 to 5. However, the ratio of rearranged fluoro product to solvolysis product for path 1 (k_{i_1}/k_{s_1}) is about 0.4 to 0.8 of that for path 2 (k_{i_2}/k_{s_2}) in all cases. This suggests that ion stabilization by the phenyl group allows more intervention by solvent, presumably because the fluoride ion is not bound as tightly in the transition state as in the higher energy mesomeric carbonium ion adjacent to the methyl group.

As solvent effects go in carbon solvolysis reactions the differences observed here are relatively small. The ratio of k_i to k_s is relatively constant (within a factor of 2) for all of the systems investigated Solvent nucleophilicity, hydrogen bonding capability, or added salts have little influence on the internal return/solvolysis ratios. In fact, Gassman and Cryberg[15], obtained a similar ratio, 2.95, of return _versus_ solvolysis in the methanolysis of 2-chloro-4,7,7-trimethyl-2-azobicyclo[2.2.1] heptane, another nitrenium ion reaction.

A comparison of the relative rate of ionization in the vinyl _versus_ saturated nitrogen-fluorine systems and the allyl _versus_ saturated carbon-halogen systems is instructive. Saturated N-F compounds ionize only under strongly acidic conditions[16], whereas the vinyldifluoramines rearrange even in non-polar organic solvents[9, 10]. Such a marked difference in chemical stability suggests a difference of at least 10^5-10^6 in ionization rate between the saturated and unsaturated system. Although allylic substitution reactions are complex because of competing Sn2 mechanisms and multiple substitution, data compiled by Streitwieser[17] suggest that the unsaturated allylic chlorides react about 10-100 times more readily than saturated chlorides. These considerations suggest that participation of the π electrons in the ionic transition state is much more pronounced in the vinyl N-F compounds than in the allyl halides. In resonance theory terminology valence structures 18 and 20 are much more heavily weighted in the solvolysis transition state hybrid than 17 and 19. The bond energies of the hetero system support the relative weighting of structures 18 and 20 The difference between carbon-carbon double and single bond is 67 kcal while the carbon-nitrogen double and single bond difference is 79 kcal [18]. This provides a 12 kcal advantage for structure 18 and 20 over 17 and 19.

Based on this analysis alone, the small difference in reaction rate by path 1 and path 2 is puzzling. The stabilization of the intermediate carbonium ion by the γ-phenyl of cinnamyl chloride over the γ-methyl of crotyl chloride enhances the rate of solvolysis in 50% aqueous ethanol by a factor of 85[17]. However, a possible explanation may lie in the relative importance of ground state resonance stabilization of structure 21 compared to 22.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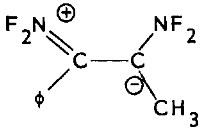
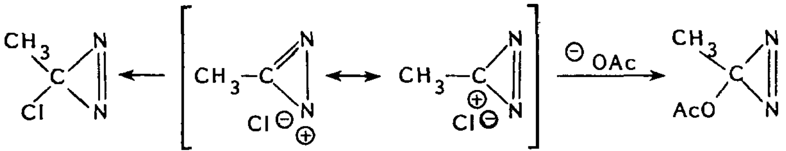
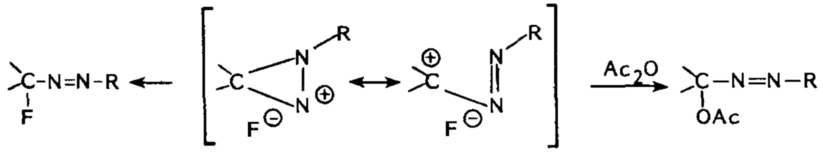

22

This resonance is similar to that of vinylamines (enamines)[19]. The electron pair adjacent to the phenyl ring can be further stabilized by resonance into the ring. This ground state stabilization would have the effect of placing a partial positive charge on the opposite difluoramino group and making bond breaking to the nitrenium ion relatively more energetic. This would mitigate the 85 fold difference in rate between the phenyl and methyl group stabilized carbonium ions in the all carbon system where no such ground state resonance is possible. This type resonance would provide even a greater difference in ground and transition state energies for the perfluoro bis(difluoramino) ethylenes[10] and help explain their stability.

Other structurally related nitrenium ion intermediates appear to react by similar mesomeric nitrogen-carbon cations. Thus, the reaction of acetamidine with sodium hypochlorite in the presence of sodium acetate proceeds through the mesomeric cation 23 to form both the methylchlorodiazirine 24 and methylacetoxydiazirine 25[20].


24 23 25

Moss confirmed the formation of the acetoxy product, but was unable to extend the reaction to the methoxy or phenyl derivatives[21]. Moss has interpreted the reactions of the diazirinum ions 23 in terms of an ion-pair mechanism. A second reaction, believed to proceed via the mesomeric nitrogen-carbon cation 26, is the reaction of certain imines with difluoramine to give α-fluoro- and α-acetoxyazo compounds 27 and 28[22]:


27 26 28

This reaction pathway competes with one where the R group (t-octyl) is lost as a carbonium ion with the formation of diazirines. The latter pathway is favored when the substituents on the carbon atom of the three-membered ring possess limited ability to stabilize the mesomeric cation 26.

EXPERIMENTAL

General

Caution: Mixtures of tetrafluorohydrazine with organic compounds can be highly explosive. All reactions with these compounds should only be conducted with adequate shielding and precautions.

NMR (^{19}F and ^{1}H decoupling) spectra were obtained with a Varian Associates, Model V-3000-B, high resolution spectrometer using a 40 Hz probe; ^{1}H spectra were obtained on a Varian Model 60, 60 Hz probe. Infrared spectra were measured on a Perkin Elmer Infracord double-beam instrument using sodium chloride plates. The chemical shift ϕ and δ values of the ^{19}F and ^{1}H NMR spectra are reported as ppm upfield relative to internal $CFCl_3$ and downfield relative to tetramethylsilane, respectively.

Reactions of Acetylenes with Tetrafluorohydrazine

The reactions of the acetylenes and tetrafluorohydrazine were carried out in glass pressure vessels at temperatures in the range of 68 to 93°C for approximately 2 to 5 hours at N_2F_4 pressures up to 260 psi The starting acetylene, 0.05 mole, was dissolved in approximately 1.0 to 1.3 moles of solvent which also contained approximately 0.07 mole of added urea, NaF or NaOAc. At the end of the reaction, ^{1}H and ^{19}F NMR spectra were taken on the crude product mixture. The contents were then shaken with H_2O and CH_2Cl_2, washed with 10% $NaHCO_3$, H_2O, dried over $CaCl_2$ or $MgSO_4$, filtered, and the product concentrated under vacuum. The ^{1}H, ^{19}F, and infrared spectra of the residue were obtained. The ^{19}F spectrum of the fluorimino region was used to measure the relative ratio of the internal return and solvolysis products. See Fig. 1 for an example.

Separation of the Product Mixtures

The reaction mixture residues were usually separated into approximately 9 fractions by column chromatography through silica gel using n-pentane/ CH_2Cl_2 mixtures (3:1, 2:1, 1:1, 0:1). The α-difluoramino-α-fluoro products eluted in the earlier fractions, usually affording the maximum residue in fractions 3 and 4. The more polar solvolysis products eluted later, usually leaving the maximum residues in fractions 6, 7, and 8. All fractions with substantial residues were submitted to ^{1}H, ^{19}F, and infrared analysis. Selected fractions were also examined by gas chromatography (GC), usually through SF-96 columns at temperatures ranging from 70 to 150°C. The total weights of the products obtained in the various fractions were roughly equal to the weight of product residue obtained. The reaction product of diethylacetylene and N_2F_4 in acetic acid/NaOAc was distilled on a Holtzman column instead of being chromatographed. The α-difluoramino-α-fluoro product, 13, was isolated as a liquid product, 2.27 g, bp 58-62°C/85 mm; the α-difluoramino-α-acetoxy product, 14, was a liquid, 1.16 g, bp

56-80°C/3 mm. A sample of the α-difluoramino-α-fluoro product, 13, was trapped out from GC analysis on SF-96 at 80°C. The product was submitted for a C, H, N, and F elemental analysis; Anal Calcd for $C_6H_{10}N_2F_4$ C, 38.70; H, 5 37; N, 15.05; F, 40.08; Found: C, 38 66; H, 5.40; N, 14.98; F, 40.83. A sample of the acetoxy derivative, 8, was obtained as a white, crystalline solid after column chromatography, m.p 111-112 5°C Anal. Calcd. for $C_{11}H_{11}N_2F_3O_2$; C, 50.8; H, 4 23, N, 10 75; F, 21.5; Found: C, 51 3, H, 4.45; N, 10 94; F, 21.6

Stability of the α -Fluoro Products Under the Reaction Conditions

A product mixture, 0.55 g (0.0025 mole) of compounds 5 and 10, was heated for 3 hours at 80°C in 3 ml of acetic anhydride containing 0.3 g (0.0043 mole) NaOAc. The ^1H and ^{19}F NMR spectra showed no change in the starting materials No evidence of acetoxy products was obtained.

Assignment of Product Structures

The α-difluoramino-α-fluoro fluorimines, 5, 9 and 15 were reported previously [9, 10]. The ^{19}F NMR spectrum of each was documented in some detail. Our observations match the reported spectra closely except for the position of the C-F peak of compound 5 which we believe should have been 5199 cps rather than 4199 as reported [10] The ^{19}F spectra were used principally to assign the various structures of the products The product mixtures contained the ^{19}F fluorimine peaks in the range ϕ-30 to -40, difluoramino peaks in the range ϕ-22.4 to -31.2, and the CF peaks in the range ϕ^{+}141.4 to $^{+}$160.8. The ratio of the areas of the C-F peaks were matched with the areas of the corresponding =NF peaks The assignment of the absolute location of the $-NF_2$ ^{19}F peaks was more difficult because of the overlap of the peaks from as many as four products in the reaction mixture. The areas under the ^{19}F peaks of the fluorimino, =NF, fluorines were measured to obtain the relative yields of each internal return and solvolysis product. The ^{19}F peak assignments for each of the reported products, arranged by structural function, follows (ϕ, compound) Φ-C=NF: -38.7, 9; -37.2, 10; -37.4, 11; -40.3, 12; -38.8, 15; -35.1, 16

Et,CH_3-C=NF: -34.7, 5; -38.2, 6; -38.3, 7; -30.1, 8; -32.4, 13; -30.7, 14. All the fluorimino peaks were singlets with some evidence of slight coupling. The $-NF_2$ ^{19}F peak assignments, their shape and coupling where evident follows (Φ, compound, shape, J values). Φ-C-NF_2 : -38.5, -24.2, -22 4, -8.1, 5, AB, J_{FAFB} = 572 Hz; -23 5, 6, singlet; -23.1, 7, singlet; -45.3, -31.0, -28.1, -13.7, 8, AB, J_{FAFB} = 574 Hz; -24.7, -22.7, 15, AB, J_{FNF_2} = 8 Hz; -31.7, -30.7, 16, probable central peaks of AB. Et,CH_3C-NF_2: -22.9, -22.7, 9, doublet, J_{FNF_2} = 12 Hz; -23, 10, probable singlet; -23 4, 11, probable singlet; -24.5, 12, singlet; -23 6, 13, singlet; -24.7, 14, doublet, J = 28 Hz. Φ-C-F: +160.8, 5, triplet, J_{FNF_2} = 12 Hz; +157.8, 15, triplet, J_{FNF_2} = 8 Hz Et,CH_3C-F. +141 4, 9, quartet, J_{HF} = 20 Hz, 157.7, 13, triplet, J_{HF} = 20 Hz.

Decoupling experiments were used to help define the structures of the two solvolysis products 7 and 11, from the reaction of methylphenylactylene in ethanol. The methyl protons adjacent to the fluorimino fluorine were a doublet centered at δ 1.86, J_{HNF} = 8 Hz This doublet collapsed upon irradiation of the fluorimine fluorine, indicating that the fluorimine function was adjacent to the CH_3 function in compound 7. The unresolved coupling of the CH_3 protons in the ^{19}F fluorimine peak can be detected in Fig. 1. Decoupling experiments were also carried out with compound 13. Irradiation of the methylene protons showed no coupling to the $-NF_2$ peak and only a slight sharpening of the fluorimine peak. However, the CF triplet centered at 157.7 collapsed to a structured singlet indicative of slight coupling to other fluorines. Irradiation of the -NF and NF_2 fluorines showed the coupling was somewhat more pronounced to the fluorimine fluorine.

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