85–86° (ethanol); ir (Nujol), 1727 (C=O), 1220 cm^{-1} (CO); uv (isooctane) sh 245 (ε 5320) and sh 225 nm (ε 6880); nmr ($CDCl_3$) δ 2.38 (s, CH_3, 6 H), 7.2–7.4 (m, phenyl, 8 H).

Anal. Calcd for $C_{18}H_{14}O_4$: C, 73.46; H, 480. Found: C, 73.22; H, 5.07.

Ethanethiol with 3. A solution of 2.0 g (17 mmol) of **3** in 10 ml of dry benzene was added dropwise to a stirred mixture of 3.1 g (50 mmol) of ethanethiol and 4 g of NaF in 40 ml of benzene at 10°. After 18 hr at 10°, the mixture was filtered followed by removal of benzene and excess thiol under vacuum. Distillation of the orange residue yielded a light yellow liquid: bp 49–56° (0.9 Torr). The infrared spectrum of the distillate indicated a mixture of α-ethylthiofumaroyl and -maleoyl fluorides: ir (neat) 1842 and 1802 (COF), 1572 cm^{-1} (C=C); nmr ($CDCl_3$), α-ethylthiofumaroyl fluoride, δ 1.37 (t, CH_3, 3 H), 3.08 (q, $-CH_2S-$, 2 H), 6.52 (doublet, J_{H-F} = 4.5 Hz, HC=C, 1 H), and α-ethylthiomaleoyl fluoride, δ 1.45 (t, CH_3, 3 H), 3.17 (q, $-CH_2-$, 2 H) (doublet of doublets, J_{H-F} = 4.5 Hz; J_{H-H} (trans) = 1.3 Hz, HC=C, 1 H).

General Method for the Preparation of Acetylenic Diamides 10. A mixture of 26 mmol of **3** and 6 g of NaF in 75 ml of dry methylene chloride was treated dropwise at 0° with 102 mmol of the primary or secondary alkyl amine in 30 ml of dry methylene chloride. After 0.5 hr, the mixture was warmed to 25° and filtered. The volatiles were removed on a rotary evaporator to yield dark semisolid residues. These residues were chromatographed on SiliCAR CC-7 employing a chloroform–carbon tetrachloride mixture as the eluent. The products, which eluted first, were then recrystallized from either chloroform, acetone, or a chloroform–hexane mixture and vacuum dried over P_2O_5 at 25° to yield analytically pure samples. In the case of **10f,g** the products precipitated from solution during the addition. In these cases the filter cake was washed with water (400 ml) and air dried prior to recystallization.

***N,N'*-Dicyclohexylacetylenedicarboxamide. Aqueous Method.** An Osterizer blender was charged with 3.64 g (33.4 mmol) of cyclohexylamine, 250 ml of distilled water, and 13.3 ml of 10% NaOH (33.4 mmol). The blender was started, and a solution of 3.0 g (16.7 mmol) of **3** in 125 ml of dry carbon tetrachloride was added in one portion. The mixture was stirred vigorously for 10 min and filtered. The yield of **10f** by this method was 2.3 g (50%) after recrystallization.

Registry No.—**3**, 675-75-2; **5a**, 139-02-6; **5b**, 4549-72-8; **6a**, 53683-88-8; **7a**, 53683-89-9; **7b**, 53683-90-2; **8**, 53683-91-3; **9**, 53683-92-4; **10a**, 25883-23-2; **10b**, 29453-12-1; **10c**, 53683-93-5; **10d**, 53683-94-6; **10e**, 29606-11-9; **10f**, 53683-95-7; **10g**, 53683-96-8; **10h**, 53683-97-9; **10i**, 29453-10-9; **10j**, 53683-98-0; **10k**, 25883-25-4; diallyl acetylenedicarboxylate, 14447-07-5; allyl alcohol, 107-18-6; dipropargyl acetylenedicarboxylate 3154-91-4; propargyl alcohol, 107-19-7; ethanethiol, 75-08-1; diethylamine, 109-89-7; propylamine, 107-10-8; isopropylamine, 75-31-0; allylamine, 107-11-9; dibutylamine, 111-92-2; cyclohexylamine, 108-91-8; benzylamine, 100-46-9; 1-adamantylamine, 768-94-5; piperidine, 110-89-4; morpholine, 110-91-8; pyrrolidine, 123-75-1.

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Acetylenedicarbonyl Fluoride. II. Its Reaction with Arylamines to Yield Isomaleimides, Maleimides, and α-Phenylimino- and α-Phenylaminofuramides

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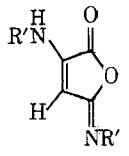
Contrary to expectation, acetylenedicarbonyl fluoride, **2**, had been found to react with aniline and substituted anilines under strict nonacid conditions to yield 1-arylamino-4-arylimino-α-crotonolactones (*i.e.*, isomaleimides), **3**. Under acidic conditions, the isomeric 1-arylaminomaleimides, **4**, are formed. The configuration of **3** was deduced chemically by mild reduction of **3a** (R = H) with sodium borohydride to give 2-anilino-1-hydroxy-4-phenylimino-2,5-dihydrofuran, **9**, which in turn could be reoxidized back to **3a** with MnO_2. Similarly, the reduction of **4a** (R = H) yielded 4-anilino-5-hydroxy-2-pyrrolin-2-one, **10**. With excess aniline and **2**, the only product isolated was the 3:1 adduct, *N,N*-diphenyl-*N*-phenyliminofuramide, **13**. The imino isomer, **13**, was found to tautomerize slowly in DMSO at 50° producing the isolatable enamino derivative, **16**. The isomerization was observed to be irreversible and catalyzed by acid. The physical and spectral properties of **3** and **4** are summarized as well as the pnmr data for all the compounds described.

Several reports on the synthesis of *N,N'*-diphenylacetylenedicarboxamide (**1**) have recently appeared. Schulte,[2a] *et al.*, obtained **1** by addition of phenyl isocyanate to acetylenedimagnesium iodide. A later report by Dehmlow[2b] described the formation of **1**, based on infrared data, by photolysis of diethoxycyclobutenedione in an aniline–ether mixture. With the reported[3,4] synthesis of acetylenedicarbonyl fluoride (**2**) there appeared to be an additional and more general route to **1** and other acetylenic dianilids.

The condensation of primary and secondary aliphatic and alicyclic amines with **2** was observed[3] to yield the corresponding acetylenic diamides with minimal addition of

Table I
Physical Properties of 1-Arylamino-4-arylimino-α-crotonolactones[a]

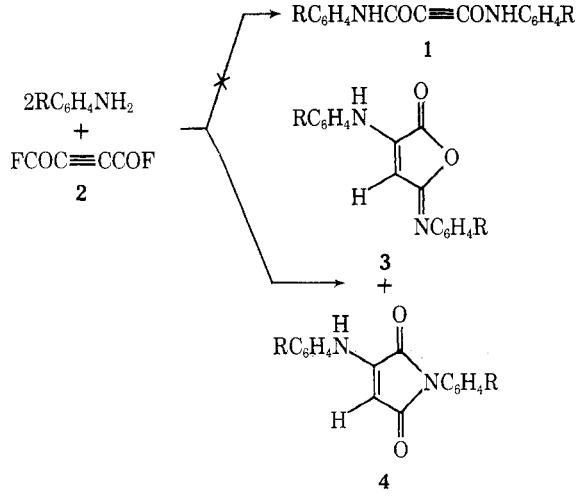


3

Compd	R′	% yield[b]	Mp, °C	νC=O, cm⁻¹	νC=N, cm⁻¹	νC=C, cm⁻¹
a	C_6H_5	65	329	1786	1706	1629
b	$4\text{-}FC_6H_4$	37	198	1779	1730	1629
c	$2\text{-}FC_6H_4$	34	155	1805	1715	1647
d	$4\text{-}CH_3C_6H_4$	31	160–162	1786	1701	1634
e	$4\text{-}ClC_6H_4$	50	190	1783	1704	1637
f	$4\text{-}NO_2C_6H_4$	45	284–285	1812	1706	1650
g	$2\text{-}NO_2C_6H_4$	16	179–181	1786	1712	1647

[a] Satisfactory analytical data were reported for all new compounds. [b] Isolated yield.

the amine to the triple bond. Extension of this reaction with aniline or ring-substituted anilines, however, failed to produce the expected acetylenic dianilids. Instead, isomeric products were isolated which involved the addition of 2 equiv of aniline with **2.** Under a variety of reaction conditions, these products were the new isomaleimides (**3**) and maleimides (**4**). With excess aniline, only a 3:1 adduct was isolated.



In this paper are reported the results of a study of the synthesis, structure proof, configurational assignment, and reactions of 1-arylamino-4-arylimino-α-crotonolactones (**3**). The preparation and chemistry of 1-arylamino-*N*-arylmaleimides (**4**) are also described.

Results and Discussion

Addition of aniline to a methylene chloride solution of freshly distilled **2** containing NaF at 5° produced a 65% yield of 1-anilino-4-phenylimino-α-crotonolactone (**3a**). Under strict nonacid conditions none of the isomeric maleimide, **4a,** was observed. Similar results were obtained using other substituted anilines. With crude (*i.e.*, once distilled) **2** a mixture of both the isomaleimide (**3**) and maleimide (**4**) was produced and could be separated and purified by column chromatography. For example, with aniline and **2,** the major product is α-anilino-*N*-phenylmaleimide (**4a**)[5] formed by acid-catalyzed rearrangement of **3a** during the course of the reaction. Pure **3a** could also be isomerized to

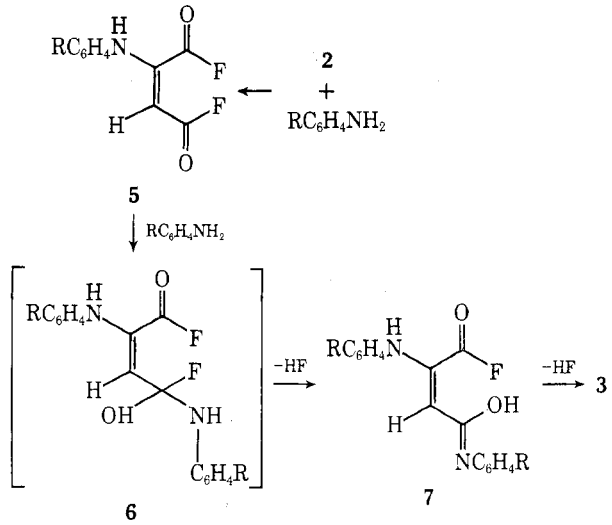
Table II
^{1}H Nmr[a] and Uv[b] Data for 1-Arylamino-4-arylamino-α-crotonolactones (3)

Compd	δNH	δvinyl	λ, nm (ε)	λ, nm (ε)
3a	9.95	5.82	233 (20,300)	335 (15,800)
3b	9.93	5.83	232 (17,300)	328 (15,400)
3c	9.86	5.41[c]	231 (19,900)	332 (10,500)
3d	9.76	5.72	240 (25,500)	365 (10,200)
3e	10.0	5.93	240 (24,800)	337 (20,100)
3f	*d*	6.59	250 sh (12,000)	365 (25,500)
3g	*d*	6.33	231 (27,900)	323sh (11,500)

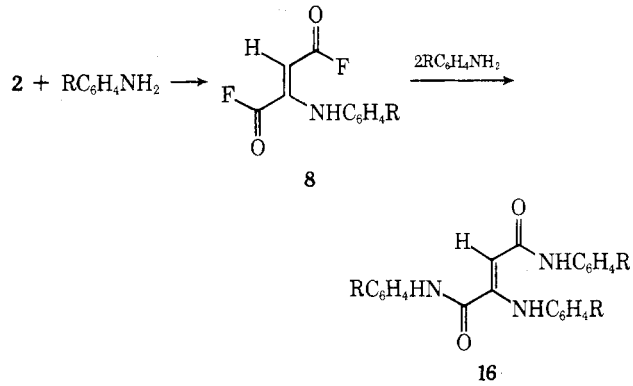
[a] Recorded in DMSO-d_6 and expressed in ppm downfield from internal TMS. [b] Measured in acetonitrile. [c] Doublet. [d] Not observed.

4a with anhydrous HCl, BF_3–etherate, and methanolic sodium methoxide. Use of an acidic solvent such as hexafluoro-2-propanol and pure **2** with 4-fluoroaniline gave the maleimide **4b.** The physical properties of **3** are summarized in Table I.

Isomaleimides 3. The formation of **3** involves an initial cis addition of the arylamine to **2** yielding the anilinomaleoyl fluoride, **5,** followed by addition of a second equivalent of arylamine to yield the intermediate **6.** Loss of HF



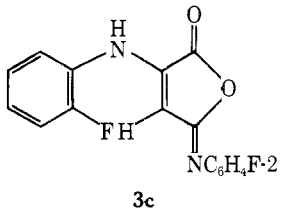
can then occur to form the hydroxy imino intermediate **7** which in turn cyclizes with loss of a second mole of HF to yield **3.** In all cases **3** was the only product isolated when freshly distilled **2** was used. It is possible that some trans addition occurred or isomerization of **5** took place to yield the anilinofumarolyl fluoride, **8.** Herbig[6] has reported an 80:20 distribution of cis–trans addition of aniline to dimethyl acetylenedicarboxylate in benzene at 0°. On standing the cis isomer dimethyl α-anilinomaleate was observed



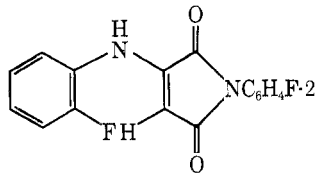
to isomerize to the thermodynamically more stable[7] dimethyl α-anilinofumarate. In the case of **2** with aniline, the initial kinetic product **5** reacts quickly with aniline to produce **3.** The trans addition isomer **8,** if produced, could react further with additional arylamine to yield the 3:1 adduct **16.** Alternatively, **16** could also be produced by addition of the arylamine to **3.** Inspection of the ir and pnmr spectra of the crude products before chromatography did not reveal the presence of **16.**

The structure and identification of **3** and **4** were based on elemental, infrared, pnmr, and mass spectral analyses. The infrared spectra of **3** exhibited intense characteristic[8] carbonyl absorption peaks in the 1783–1805-cm^{-1} region, absorption in the C=N region at 1704–1730 cm^{-1}, and N–H absorption of 3268–3378 cm^{-1} for the anilino hydrogen. The pnmr in DMSO-d_6 (Table II) displayed singlet absorptions at δ 9.8–10.0 and 5.4–6.6 for the respective anilino and vinyl protons in both **3** and **4.** In **3c** and **4c** the vinyl proton was split into a AX doublet with J_{H-F} = 2.5 Hz. The AX doublet of **3c** and **4c** is attributed to a through space coupling of the vinyl hydrogen with the ortho fluorine atom of the anilino group.

With both rings lying in the same plane, their internuclear distance would predict a large coupling. The observed H–F coupling of 2.5 Hz suggests, based on Myrhre's work,[9] that the H–F distance is in fact *ca.* 2.7 Å indicating a perpendicular or skewed conformation of the two rings. Direct H–F coupling through six bonds including a nitrogen atom would appear remote in **3c** and **4c.**



3c



4c

The mass spectrum of **3a** is essentially indistinguishable from **4a.** A comparison of their spectra under similar conditions is shown in Table III. The major fragment loss of phenyl isocyanate is observed in both compounds, and only a small loss of CO_2, characteristic of isoimides, from **3a** is observed.

Maleimides 4. The infrared spectra of the known and new maleimides displayed an unsymmetric doublet in the carbonyl region at 1757–1779 and 1704–1721 cm^{-1} characteristic of imides[6] and absorptions of 1626–1645 and 3257–3333 cm^{-1} for the vinyl and anilino N–H absorptions, respectively. The maleimides were yellow to yellow-orange in color and exhibited fluorescence in the solid form with ultraviolet light. In direct contrast, the isoimides **3** were not colored. The structure of **4a** was further confirmed by hydrogenation over PtO_2 to α-anilino-*N*-phenylaspartimide[4b] and comparison of the properties of **4a** with an authentic sample prepared from aniline and dimethyl acetylenedicarboxylate.[5] The pathway for the formation of **4** from crude **2** is envisioned as an acid-catalyzed ring opening of the initially formed **3,** rearrangement, and subsequent ring closure through nitrogen (Scheme I). Similarly, **3** could be isomerized quantitatively to **4** in methylene chloride at 25° using anhydrous HCl or BF_3–etherate. With longer reaction times using crude **2,** there was also observed some of the arylamine addition product. For example, with aniline **16** was detected. In these cases attack by the arylamine on the isoimidium salt can yield the ring-opened furamide product.[10]

Scheme I

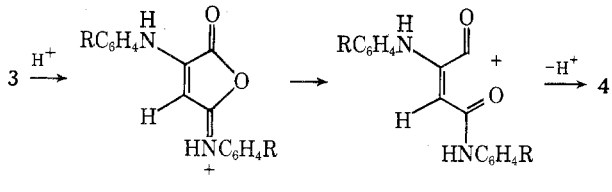
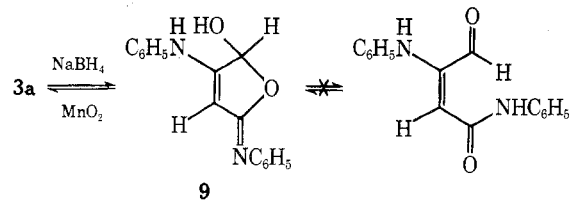


Table III
Mass Spectrum of 3a and 4a (70 eV)[a]

m/e	Ion+	Rel intensity 3a	Rel intensity 4a
265	M + 1	41.6	18.4
264	M	100	100
263	M − 1	29.0	10.0
220	M − CO_2	1.3	0
171	M − $C_6H_5NH_2$	3.6	1.3
145	M − C_6H_5NCO	61.5	12.7
144	M − C_6H_5NHCO	100	62.7
117	$C_6H_5NHC{\equiv}CH$	26.5	9.0
116	$C_6H_5NHC{\equiv}C$	17.8	5.1
93	$C_6H_5NH_2$	51.0	3.1
77	C_6H_5	9.0	9.3

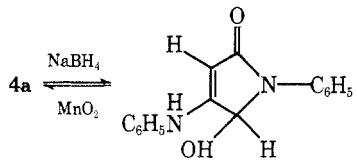
[a] Direct injection at 150°.

Configuration of Isomaleimides. In the case of **4** there is only one configurational isomer due to its inherent symmetry. However, in **3** there are two possible isomeric structures differing only by the substitution of the arylamino group relative to the carbonyl or arylimino carbon. Infrared, pnmr, ultraviolet (Table II), and mass spectroscopy were of little help in assigning the position of the arylamino substituent. Conventional attempts to hydrogenate **3a** failed. By chance, a mild chemical reduction of **3a** was found employing sodium borohydride in ethanol to yield 2-anilino-1-hydroxy-4-phenylimino-2,5-dihydrofuran (**9**).



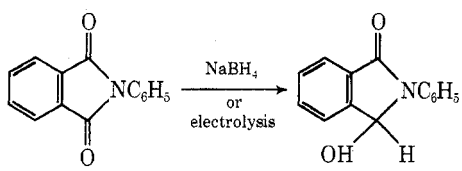
9

The infrared spectrum of **9** showed only the imino and olefinic absorptions at 1678 and 1684 cm^{-1} and the absence of the original carbonyl peak at 1786 cm^{-1}. Analysis of the 220-MHz pnmr spectrum of **9** in DMSO-d_6 exhibited a doublet of doublets for the 1-hydroxy and 1-methine protons at δ 6.25 and 5.93, respectively, with J = 10 Hz. A singlet peak at δ 6.04 was observed for the vinyl proton. Addition of D_2O collapsed the doublet at δ 5.93 to a singlet and completely exchanged the doublet at δ 6.25 and the singlet for the anilino hydrogen at δ 8.10. The chemical shifts for the vinyl, hydroxyl, and methine protons and their coupling constants are similar to those reported for hydroxyfurans formed either by photooxidation of pyrroles[11–13] or by ammonolysis of 2,5-dihydrofuran-2-ones.[14] The absence of coupling between the vinyl and methine protons supports the configuration shown for **9.** The mass spectrum of **9** displayed the parent ion at *m/e* 266 and peaks at *m/e* 248, 220, and 218 for the loss of H_2O, HCO_2H, and HCO_2H^+, respectively. Mild oxidation of **9** with activated MnO_2 in methylene chloride re-formed **3a.** The use of *excess* sodium borohydride for the reduction of **3a** repeatedly caused isomerization to **4a** followed by a similar reduction of the carbonyl in **4a** to yield 4-anilino-5-hydroxy-3-pyrrolin-2-



10

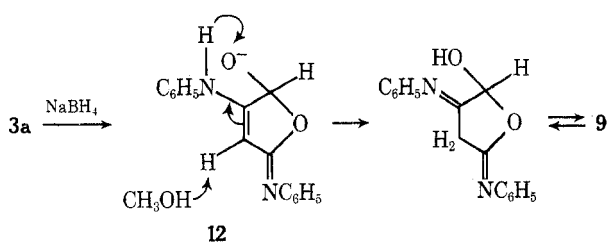
one (**10**) in almost quantitative yield. Its infrared spectrum displayed absorptions for the anilino group and a peak at 1664 cm^{-1} for the carbonyl function. The 220-MHz pnmr in DMSO-d_6 displayed singlet absorptions at δ 9.33 and 5.35 for the anilino and vinyl protons, and a doublet of doublets at δ 5.94 and 6.77 for the respective methine and hydroxyl protons with J = 10 Hz. Addition of D_2O exchanged the anilino and hydroxyl proton leaving only a singlet absorption for the methine and vinyl protons, supporting the configuration shown in **10**. Mild reoxidation of **10** to **4a** could also be effected using activated MnO_2 in methylene chloride. The reaction of sodium borohydride with **3a** and **4a** represents the first case of maleimide and isomaleimide reduction to yield stable cyclic products. No tautomerism to the open ring structure was observed by solution pnmr for **9** and **10**. Similar reductions of phthalimide either electrolytically[15] or with sodium borohydride[16] have been reported to yield the corresponding hydroxyphthalimidines



(**11**). *N*-Phenylmaleimide failed to react with methanolic sodium borohydride under the reaction conditions used for **3a** and **4a**.

The presence and proximity of the anilino group adjacent to the carbonyl appear to provide activation and/or stabilization for the carbonyl as well as a potential source for an intramolecular proton abstraction in the case of the primary adduct, **12** (Scheme II). Proton abstraction of **12**

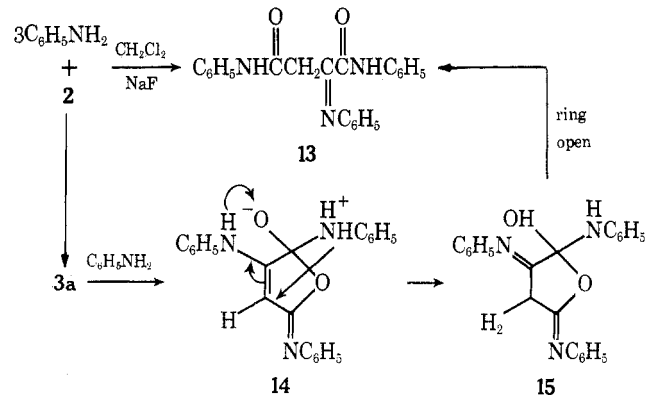
Scheme II



12

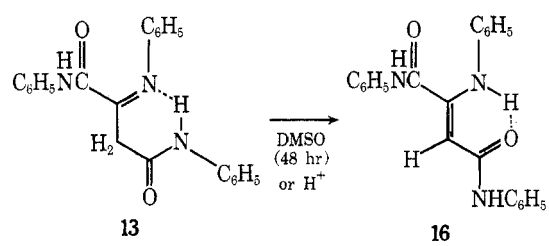
can also occur from the decomposition of the initial borohydride complex similar to that described by Horii, *et al.*[16]

3:1 Adduct of Aniline and 2. When excess aniline was employed with purified **2** under similar conditions described for **3a**, the 3:1 adduct, *N,N*-diphenyl-*N*-phenyliminofuramide (**13**) was the only product isolated. The furamide **13** appears to be formed by addition of a third mole of aniline to **3a** since the reaction could be carried out in a stepwise fashion employing **3a** and aniline. The pnmr of **13** in DMSO-d_6 indicated that the imino form was the only tautomer present. The spectrum displayed a singlet at δ 3.67 for the methylene hydrogens and singlets at δ 10.05 and 10.30 for the amide protons. The lower field amide absorption at δ 10.05 is less deshielded than the higher field amide proton because of intramolecular hydrogen bonding between the amide hydrogen and the amino nitrogen. The



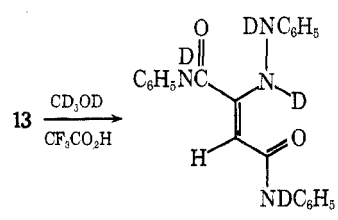
infrared spectrum exhibited a peak with shoulder at 1661 cm^{-1} for the carbonyl group and an intense absorption at 1704 cm^{-1} for the C=N stretch.

The isolation of **13** suggests that aniline can attack **3a** in either the imino or enamino tautomeric form. The absence of the imino isomer in the pnmr of **3a** suggests that it is not the reacting species with aniline. Rather, it appears that aniline adds to the enamino form to yield the intermediate **14** which could by a series of proton transfers produce **15** followed by ring opening yielding **13**. When a DMSO-d_6 solution of **13** was allowed to stand 48 hr at 25°, a quantitative conversion to the enamino tautomer, *N,N*-diphenyl-α-anilinofuramide (**16**), was observed. The pnmr in



13 16

DMSO-d_6 displayed only a vinyl singlet at δ 5.65 and the appearance of a third amino proton at δ 10.00. Singlet absorptions for the amide protons were also observed at δ 10.60 and 10.65. Addition of trifluoroacetic acid failed to alter the pnmr spectrum of **16**. Addition of trifluoroacetic acid–perdeuteriomethanol to a freshly prepared solution of **13** in DMSO-d_6 converted it to the deuterated enamine **17**.



17

No methylene, vinyl, or N–H absorptions were observed after 1 min at 35° indicating a fast acid-catalyzed equilibration of the enamine and imino forms. Similar observations on the independent isolation of primary enamine and its tautomeric imine have been reported for the anilino and phenyliminoethyl butenonates[17] and crotonates[18] as well as other amine[19] derivatives. The formation of **13** in methylene chloride, a nonpolar solvent, thus allows for the isolation of an imino derivative which when dissolved in a polar–aprotic solvent such as DMSO produces the isolable thermodynamically more stable enamine derivative.

Experimental Section

Melting points were measured with a Thomas-Hoover capillary melting point apparatus without correction. Proton nmr spectra were recorded on a Varian Associates A-60 nmr spectrophotometer

using DMSO-d_6 as the solvent. Chemical shifts are expressed in δ (parts per million) downfield from an internal standard of TMS. The 220-MHz nmr spectra of **9** and **10** were recorded on a Varian Associates High Resolution 220-MHz nmr spectrometer. Infrared spectra were recorded on a Perkin-Elmer 21 and mass spectra on a Du Pont CEC 21-103C mass spectrometer. Ultraviolet spectral analyses were obtained usinga Cary 17 ultraviolet spectrometer. Elemental analyses were performed by the Analytical Laboratories of the Central Research Department.

Materials. All solvents including methylene chloride, chloroform, carbon tetrachloride, and hexane were dried over molecular sieves (Type 4A). Silica gel (SilicAR CC7) having 100–200 mesh was obtained from Mallinckrodt Co. The anilines used in the preparation of **3** and **4** were all commercially available and were used without further purification. Acetylenedicarbonyl fluoride (**2**) was prepared from acetylenedicarboxylic acid monopotassium salt and SF_4 in dimethylcyclohexane.[4] The diacid fluoride was distilled directly from the filtrate after removal of KF, KHF_2, and unreacted starting acid. This distillate represented once distilled **2**.

General Preparation of α-Arylamino-4-arylimino-α-crotonolactones (3). A solution of 53 mmol of the appropriate arylamine in 200 ml of methylene chloride was added dropwise to a slurry of 12 g of NaF and 26 mmol of **2** (freshly distilled from NaF directly into the reaction vessel) in 600 ml of methylene chloride at 5°. After stirring 1 hr, the mixture was warmed to 25° and filtered. Removal of the solvent under vacuum left a residue which was chromatographed on 90 g of neutral silica gel with 2:1 v/v carbon tetrachloride–chloroform to yield the isomaleimides, **3.** Mixed solvent recrystallization using chloroform and hexane yielded analytically pure samples. Their yields and physical and spectral properties are summarized in Tables I, II, and III.

α-Anilino-*N*-phenylmaleimide (4a).[5] A solution of 6.4 g (0.070 mol) of aniline in 50 ml methylene chloride was added dropwise to a slurry of 4.0 g (0.034 mol) of crude **2** (once distilled) and 4 g of NaF in 100 ml of methylene chloride at −5°. The mixture was stirred 1.5 hr, warmed to 25°, and filtered. The solvent was removed under vacuum, and the residue was chromatographed on 90 g of neutral silica gel with 4:1 v/v chloroform–carbon tetrachloride to yield 3.0 g (43%) of **4a:** mp 238–239° (chloroform); dipole moment (dioxane) 5.393 D; ir (KBr) 3257 (NH), 1767, 1704 (C=O), 1626 cm^{-1} (C=C); uv (CH_3CN) 239 (ϵ 23,300), 280 (ϵ 7330), and 376 nm (ϵ 8030).

Anal. Calcd for $C_{16}H_{12}N_2O_2$: C, 72.71; H, 4.58; N, 10.60. Found: C, 72.69; H, 4.79; N, 10.84.

α-(4-Fluoroanilino)-*N*-(4-fluorophenyl)maleimide (4b). A mixture of 2.0 g (0.017 mol) of purified **2** and 20 g of NaF in 125 ml of hexafluoro-2-propanol was treated dropwise with a solution of 3.8 g (0.034 mol) of 4-fluoroaniline in 20 ml of hexafluoro-2-propanol at 5°. After stirring 15 min, the mixture was warmed to 25° and filtered and the solvent was removed from the filtrate. Chromatography of the residue on 90 g of neutral silica gel with 1:1 v/v chloroform–carbon tetrachloride yielded 2.1 g (41%) of **4b.** Recrystallization from chloroform gave mp 256° dec; ir (KBr) 3311 (NH), 1757, 1709 (C=O), and 1642 cm^{-1} (C=C); uv (CH_3CN) 237 (ϵ 16,700), 288 (ϵ 11,500), and 375 nm (ϵ 4740); mass spectrum, *m/e* 300 (M^+).

α-(2-Fluoroanilino)-*N*-(2-fluorophenyl)maleimide (4c). A mixture of 2 g (0.017 mol) of crude **2** and 8 g of NaF in 50 ml of methylene chloride was treated dropwise with a solution of 3.8 g (0.034 mol) of 2-fluoroaniline in 20 ml of methylene chloride at 25°. After stirring 1 hr, the mixture was filtered and filtrate was concentrated under vacuum. The residue was chromatographed on 90 g of neutral silica gel with 1:1 v/v carbon tetrachloride–chloroform to yield 2.8 g (55%) of product. The first eluted compound was the isomaleimide, **3c** (1.0 g, 20%). The second eluted product was **4c** (1.8 g, 35%): mp 119–121° (chloroform–hexane); ir (KBr) 3322 (NH), 1779, 1727 (C=O), and 1642 cm^{-1} (C=C); uv (CH_3CN) 231 (ϵ 20,800), 262 (ϵ 8940), and 367 nm (ϵ 8850).

Anal. Calcd for $C_{16}H_{10}N_2O_2F_2$: C, 64.00; H, 3.33; N, 9.33. Found: C, 63.33; H, 3.31; N, 9.15.

α-(4-Methylanilino)-*N*-(4-methylphenyl)maleimide (4d). A mixture of 3.0 g (0.026 mol) of crude **2** and 12 g of NaF in 200 ml of methylene chloride at 10° was treated dropwise with a solution of 5.4 g (0.051 mol) of 4-toludine in 30 ml of methylene chloride at 10° and allowed to react at 25° for 18 hr. The solids were filtered and the solvent was removed from the filtrate. Recrystallization of the residue from chloroform gave 3.4 g (46%) of **4d:** mp 228–229°; ir (KBr) 3300 (NH), 1757, 1706 (C=O), and 1637 cm^{-1} (C=C); uv (CH_3CH) 240 (ϵ 18,150), 288 (ϵ 13,000), and 382 nm (ϵ 5140); mass spectrum *m/e* 292 (M^+).

Anal. Calcd for $C_{18}H_{16}N_2O_2$: C, 73.95; H, 5.52; N, 9.58. Found: C, 74.59; H, 5.83; N, 9.85.

α-(4-Chloroanilino)-*N*-(4-Chlorophenyl)maleimide (4e). A slurry of 8 g of NaF and 2.0 g (0.017 mol) of crude **2** in 50 ml of methylene chloride was treated dropwise with a solution of 4.3 g (0.034 mol) of 4-chloroaniline in 25 ml of dioxane at 5°. After stirring for 1.5 hr, the mixture was warmed to 25° and filtered, and the solvent was removed from the filtrate. Methylene chloride (25 ml) was added to the residue and the yellow maleimide was filtered to yield 2.2 g (39%) of **4e:** mp 244–245° (chloroform–hexane); ir (KBr) 3333 (NH), 1773, 1724 (C=O), and 1645 cm^{-1} (C=C); uv (CH_3CN) 246 (ϵ 24,700), 290 (ϵ 11,100), and 377 nm (ϵ 7490).

Anal. Calcd for $C_{16}H_{10}N_2O_2Cl_2$: C, 57.41; H, 3.01; N, 8.41. Found: C, 56.65; H, 2.98; N, 8.10.

The second filtrate was chromatographed on 90 g of neutral silica gel with 1:1 carbon tetrachloride–chloroform to yield 2 g (35%) of the isomaleimide, **3e.**

***N,N'*-Diphenyl-α-*N*-phenyliminofuramide (13).** A solution of 0.8 g (0.102 mol) of aniline in 300 ml of methylene chloride was treated dropwise with 3 g (0.025 mol) of purified **2** in 50 ml of methylene chloride at 5°. After 15 min, the mixture was filtered and the solvent was removed. Recrystallization of the tan residue from chloroform gave 4 g (60%); mp 207–208°; ir (KBr) 3333 (NH), 1661 (C=O), 1704 cm^{-1} (C=N); uv (C_2H_5OH) 224 (ϵ 22,800), 240 (ϵ 19,700), and 325 nm (ϵ 8560); mass spectrum, *m/e* 357 $(M)^+$, 264 $(M - C_6H_5NH_2)^+$, 237 $(M - CONHC_6H_5)^+$, 144 $(237 - C_6H_5NH_2)^+$, 118 $(C_6H_5NCO)^+$, 93 $(C_6H_5NH_2)^+$, 77 $(C_6H_5)^+$; ^1H nmr (DMSO-d_6) δ 3.31 (s, HOD or H_2O), 3.67 (s, CH_2), 10.05 (s, NH), and 10.30 (s, NH). Ratio of NH:NH:CH_2 was 1:1:2. A complex multiplet for the aromatic protons was observed.

Anal. Calcd for $C_{22}H_{19}N_3O_2 \cdot \frac{1}{2}H_2O$: C, 72.19; H, 5.51; N, 11.48. Found: C, 72.36; N, 5.07; N, 11.72.

The furamide **13** could also be prepared by allowing a solution of 200 mg of **3a** and 5 ml of aniline in 25 ml of methylene chloride to stir for 2 hr at 0° and then 1 hr at 25°. Removal of solvent and recrystallization from chloroform–hexane gave **13,** mp 206–207°.

***N,N'*-Diphenyl-α-anilinofuramide (16).** A solution of **13** in dimethyl sulfoxide was allowed to stand 48 hr. The solution was added to ice water and the mixture was filtered. The solid filtered was dried under vacuum over P_2O_5: mp 197–198°; ir (KBr) 3484 (NH) and 1639 cm^{-1} (C=O); uv (C_2H_5OH) sh 227 (ϵ 17,100) and 338 nm (ϵ 26,100); ^1H nmr (DMSO-d_6) δ 5.65 (s, vinyl H), 10.00 (s, enamine NH), 10.60 and 10.65 (s, amide NH), complex multiplet for aromatic protons.

3-Anilino-2-hydroxy-5-phenylimino-2,5-dihydrofuran (9). A mixture of 1.0 g (3.8 mmol) of **3a** in 15 ml of dry dimethoxyethane was treated in one portion at 5° with 0.20 g (3.9 mmol) of sodium borohydride. After stirring 1 hr at 5° and 4 hr at 25°, the mixture was filtered. The solvent was removed under vacuum and the residue was hydrolyzed with 5 ml of an aqueous saturated ammonium chloride solution. The product was filtered, dried, and recrystallized from acetonitrile: mp 209–210° dec; ir (KBr) 3289 (wide, NH and OH), 1684 (C=N), 1664 cm^{-1} (C=C); uv (C_2H_5OH) 253 (ϵ 20,900) and sh 315 nm (ϵ 5690); ^1H nmr (DMSO-d_6) (220 MHz) δ 8.10 (s, NH), 6.04 (s, vinyl H), 5.93 (d, >CH), 6.25 (d, >C—OH), with J = 10 Hz). Addition of D_2O collapsed the doublet at δ 5.93 to a singlet and completely exchanged the doublet at δ 6.25 and singlet at δ 8.10. Mass spectrum: *m/e* 266 $(M)^+$, 248 $(M - H_2O)^+$, 219 $(M - H_2CO_2H)^+$, 220 $(M - HCO_2H)^+$, 117 $(C_6H_5NHC{\equiv}CH)^+$.

Anal. Calcd for $C_{16}H_{14}N_2O_2 \cdot \frac{3}{2}H_2O$: C, 65.58; H, 4.82; N, 9.56. Found: C, 65.00; H, 5.02; N, 9.68.

A mixture of **6** and activated MnO_2 in 25 ml of methylene chloride was stirred 2 hr at 25°. The mixture was filtered and the solvent was removed from the filtrate to yield a product whose infrared spectrum was identical with the isomaleimide, **3a.**

4-Anilino-5-hydroxy-Δ³-pyrrolin-2-one (10). A solution of 0.40 g (1.6 mmol) of **4a** in a mixture of 35 ml of dioxane–25 ml of ethanol was treated in one portion with 0.11 g (3.0 mmol) of sodium borohydride and mixture was stirred for 3 hr at 25°. The excess hydride was decomposed with acetic acid (*ca.* 1 ml) and the solvents were removed under vacuum. Water (5 ml) was added to the residue and the product was filtered and dried to yield 0.39 g. Recrystallization from the methanol–chloroform mixture gave mp 218–220°; ir (KBr) 3289 (broad, NH and OH), 1664 (C=O), and 1629 cm^{-1} (C=C); uv (C_2H_5OH) 232 (ϵ 12,500) and 315 nm (ϵ 23,500); 220-MHz ^1H nmr (DMSO-d_6) δ 9.33 (s, NH), 5.35 (s, vinyl H), 5.94 (d, CH), 6.77 (d, C—OH) with J = 10 Hz. Addition of D_2O completely exchanged the doublet at δ 6.77 and the singlet at δ 9.33 and collapsed the doublet at δ 5.94 to a singlet. Mass spectrum:

m/e 266 (M^+), 338 (monosilylated product)$^+$, 410 (disilylated product)$^+$, 248 [monosilylated − $(CH_3)_3SiOH$]$^+$.

Anal. Calcd. for $C_{16}H_{14}N_2O_2$: C, 72.24; H, 5.31; N, 10.53. Found: C, 71.15; H, 5.26; N, 10.34.

A mixture of 100 mg of **10** and 500 mg of activated MnO_2 in 10 ml of methylene chloride was stirred at 25° for 1 hr. Removal of MnO_2 and solvent yielded the yellow fluorescent maleimide, whose infrared spectrum was identical with an authentic sample of **4a**.

Registry No.—**2**, 675-75-2; **3a**, 53683-74-2; **3b**, 53683-75-3; **3c**, 53683-76-4; **3d**, 53683-77-5; **3e**, 53683-78-6; **3f**, 53683-79-7; **3g**, 53683-80-0; **4a**, 13797-26-7; **4b**, 24978-25-4; **4c**, 53683-81-1; **4d**, 53683-82-2; **4e**, 53683-83-3; **9**, 53683-84-4; **10**, 53683-85-5; **13**, 53683-86-6; **16**, 53683-87-7; aniline, 62-53-3; 4-fluoroaniline, 371-40-4; 2-fluoroaniline, 348-54-9; 4-methylaniline, 106-49-0; 4-chloroaniline, 106-47-8; 4-nitroaniline, 100-01-6; 2-nitroaniline, 88-74-4.

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Bromination and Chlorination of 1,1,1-Trifluoro-*N*-phenylmethanesulfonamides

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Bromination of aryl-substituted 1,1,1-trifluoro-*N*-phenylmethanesulfonamides in ethanol–water usually gave only one product when an extra equivalent of bromine was used to react with the acidic sulfonamide. Chlorination was much less selective and mixtures were always obtained. The (1,1,1-trifluoromethanesulfonyl)amino moiety was ortho–para directing in both cases. A number of halogen aryl substituted 1,1,1-trifluoro-*N*-phenylmethanesulfonamides were prepared by bromination and chlorination in higher overall yields than with prior syntheses which consisted of sulfonylation of the previously prepared halogenated aniline with trifluoromethanesulfonyl fluoride or anhydride. The chlorination of unsubstituted 1,1,1-trifluoro-*N*-phenylmethanesulfonamide was surveyed in various solvent–catalyst systems to prepare *N*-(2,4-dichlorophenyl)-1,1,1-trifluoromethanesulfonamide. The CH_3COOH–$AlCl_3$ and nitrobenzene–$AlCl_3$ systems gave the best selectivity with up to 70% 2,4-dichloro product produced in the latter system. Incremental addition of $AlCl_3$ to nitrobenzene during chlorination increased the rate of reaction and resulted in a mixture containing 81% 2,4-dichloro-, 10.4% 4-chloro-, and 8.6% 2,4,6-trichlorosulfonamide. Pure *N*-(2,4-dichlorophenyl)-1,1,1-trifluoromethanesulfonamide was then obtained by fractional crystallization in a yield of ~60%.

We have recently reported that halogen substituted 1,1,1-trifluoro-*N*-phenylmethanesulfonamides possess interesting and unique biological activity as herbicides and plant growth regulators.[1,2] The preparation of these compounds was generally by reaction of the substituted aniline with trifluoromethanesulfonyl fluoride or the corresponding anhydride. However, sulfonylations of di- and trihalogenated anilines were usually low yield reactions and often required usage of the more reactive and more expensive trifluoromethanesulfonic acid anhydride. In extreme cases, such as the preparation of *N*-(2,4,6-trichlorophenyl)-1,1,1-trifluoromethanesulfonamide, the sodium salt of the substituted aniline had to be preformed before sulfonylation could be effected.[2]

It has now been found that sulfonylation of mono- or unsubstituted anilines with trifluoromethanesulfonyl fluoride is generally a facile reaction (yields greater than 75%) and suitable starting materials are therefore readily available for subsequent halogenation. For this reason, halogenation of the parent and monosubstituted 1,1,1-trifluoro-*N*-phenylmethanesulfonamides was investigated as a possible alternate, higher yield route to the di- and trihalogenated compounds reported in this paper. Additionally, to the best of our knowledge, a careful study of the mixture of products resulting from halogenation of any alkanesulfonanilide previously had not been undertaken with presently available gas–liquid partition chromatography techniques.

The (methanesulfonyl)amino group has been shown to be an ortho–para director in electrophilic aromatic substitution. Shriner[3] in 1932 nitrated methanesulfonanilide with nitric acid in sulfuric acid and obtained only 2,4-dinitromethanesulfonanilide while Kostova[4] in 1959 treated ethanesulfonanilide in dichloroethane with chlorine and zinc oxide and obtained only 2,4-dichloroethanesulfonanilide. Low yields (5–10%) of other products probably would not have been detected because of the analytical procedures used by these authors. In addition, no attempt was made to moderate experimental conditions such that only monosubstitution would have occurred. More recently, the (1,1,1-trifluoromethanesulfonyl)amino moiety was shown to be an ortho–para director in the nitration of 1,1,1-trifluoro-*N*-phenylmethanesulfonamide.[5,6] However, the