for the H-1 signal of **5** (6.49 d instead of 6.94 d) escaped notice.
(14) N. R. Unde, S. V. Hiremath, G. H. Kulkarni, and G. R. Kelkar, *Tetrahedron*, **24**, 4661 (1968).
(15) The stereochemistry proposed for the C-11 methyl group is based on catalyst approach from the less encumbered α-side.
(16) A. Horeau, *Tetrahedron Lett.*, 506 (1961); *ibid.*, 965 (1962).
(17) W. Herz and H. B. Kagan, *J. Org. Chem.*, **32**, 216 (1967).
(18) The ^{13}C NMR spectra of tagitinin A and dehydrotagitinin A (Table I) are identical (except for the signals of the ester side chain on C-8) with ^{13}C NMR spectra of viguilenin and dehydroviguilenin which are 2-methylbutanoyl analogues of **7** and **14** (private communication from Professor N. S. Bhacca).
(19) A. Romo de Vivar, C. Guerrero, E. Diaz, and A. Ortega, *Tetrahedron*, **26**, 1657 (1970).
(20) A. Ortega, C. Guerrero, A. Romo de Vivar, J. Romo, and A. Palafox, *Rev. Latinoam. Quim.*, **2**, 38 (1971); A. Ortega, A. Romo de Vivar, F. Diaz, and J. Romo, *ibid.*, **1**, 81 (1970). These substances have been shown[21] to be heliangolides.
(21) W. Herz and I. Wahlberg, *J. Org. Chem.*, **38**, 2485 (1973).
(22) The H-8α configuration assigned to zexbrevin was based[19] in part on coupling constants involving H-7, H-8, and H-9, which, because they depend on delicately balanced conformational factors, are not very reliable guides to C-8 stereochemistry in this group of lactones (for example, $W_{1/2}$ of the H-8 signal narrows significantly in going from **7** to **16a** and **17a**). In fact, the Mexican authors have assigned the opposite C-8 stereochemistry (H-8α) to budlein A which differs from ciliarin and calaxin only in the nature of the C-8 ester side chain and in oxygenation at C-15 but exhibits essentially the same values for $J_{5,6}$, $J_{6,7}$, $J_{7,8}$, and $J_{8,9}$.[23] Similarly Bohlmann et al.[24] have assigned H-8α stereochemistry to two gummy lactones from *Isocarpha atriplicifolia* which they presume to be C-8 epimers of crystalline calaxin and ciliarin but which exhibit the same chemical shifts and J values and may well be identical with them since it is frequently difficult to obtain complex lactones in crystalline form without seed. A second argument for the H-8β configuration of zexbrevin was based[19] on application of the Horeau method to a hydrolysis product of hexahydrozexbrevin. The optical yield which is critical in this series[17] was not reported; moreover the rule has been shown to be misleading when applied[25] to eupatolide which also has a β-oriented hydroxyl group on C-8.
(23) A. Romo de Vivar, C. Guerrero, F. Diaz, E. A. Bratoeff, and L. Jimenez, *Phytochemistry*, **15**, 525 (1976).
(24) F. Bohlmann, P. K. Mohanta, A. A. Natu, R. M. King, and H. Robinson, *Phytochemistry*, **17**, 471 (1978).
(25) R. W. Doskotch and F. S. El-Feraly, *J. Org. Chem.*, **35**, 1928 (1970).
(26) Cf. provincialin epoxide,[21] the erioflorins,[27] and 1(10)-epoxynobilin.[28]
(27) S. Gnecco, J. P. Poyser, M. Silva, and P. G. Sammes, *Phytochemistry*, **12**, 2469 (1973).
(28) M. Holub and Z. Samek, *Collect. Czech. Chem. Commun.*, **42**, 1053 (1977).
(29) Supplied by Dr. Rastogi in 1976 for the purpose of obtaining the CD data reported in ref 3.
(30) W. Herz, R. de Groote, R. Murari, and J. F. Blount, *J. Org. Chem.*, **43**, 3559 (1978), and ref 19–24 cited therein.
(31) C. Guerrero, A. Ortega, E. Diaz, and A. Romo de Vivar, *Rev. Latinoam. Quim.*, **4**, 118 (1973).
(32) Melting points are uncorrected. NMR spectra were recorded in $CDCl_3$ on a Varian T-60 instrument, except those in Tables I and II, IR spectra on a Perkin-Elmer 237B grating spectrophotometer, and UV spectra on a Beckman DV instrument. Low-resolution mass spectra were obtained on a MS-30 and high-resolution mass spectra on a MS-902 instrument. Silica gel G was used for preparative TLC.
(33) W. Herz and G. Högenauer, *J. Org. Chem.*, **27**, 905 (1962).
(34) W. Herz and Y. Sumi, *J. Org. Chem.*, **29**, 3438 (1964).
(35) D. K. Bhardwaj, S. Neelakantan, and T. R. Seshadri, *Indian J. Chem.*, **4**, 173 (1966).

Mild Oxidation of Alkyl Halides

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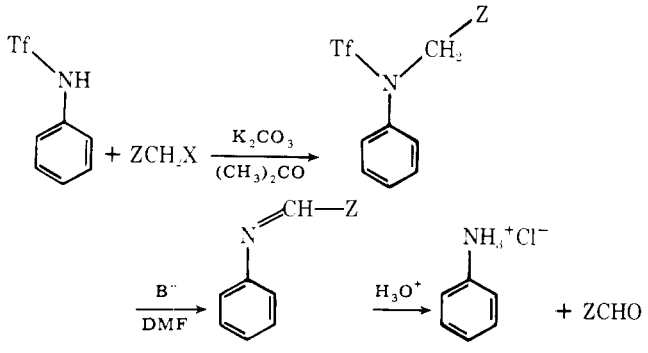
The application of *N*-phenyltrifluoromethanesulfonamide to the oxidation of activated halides (α-halo carbonyl compounds) has been extended and shown to be general. A new reagent, *N*-(4-acetoxyphenyl)trifluoromethanesulfonamide, has been developed for the mild oxidation of unactivated alkyl halides. The reagent was N-alkylated with a number of different alkyl halides. The elements of CF_3SO_2H were then eliminated under mild basic conditions generating imines which were easily hydrolyzed to the corresponding amines and carbonyl compounds. The ease of $CF_3SO_2^-$ elimination was demonstrated to be dependent on intermediate aminoquinone formation.

Although there are a number of techniques currently available for the oxidation of unactivated primary halides to aldehydes, the reaction conditions frequently do not lend themselves to polyfunctional or labile systems. Most of these oxidations employ dimethyl sulfoxide as the oxidant and require temperatures in excess of 100 °C,[2-4] or the presence of strong acids[5-7] or heavy metals.[8-10] We wish to report an oxidation procedure which does not require activated alkyl halides or harsh reaction conditions.

N-Phenyltriflamide is N-alkylated in high yield under very mild conditions with a variety of activated and unactivated electrophiles, including alkyl halides[11-15] (eq 1). These alkylated sulfonamides can be converted to imines by treatment



with base and the imines hydrolyzed under mild acidic conditions to the corresponding aldehydes and amines. However, the conditions required to generate the imine, i.e., to abstract this α proton and eliminate $CF_3SO_2^-$ (Tf), are very harsh. Thus, when Z is *p*-BrC_6H_4CO, potassium carbonate in refluxing acetone is adequate. When Z is C_6H_5, NaH in DMF at 100 °C for 24 h is required, and when Z is $CH_3(CH_2)_2CH_2^-$, elimination is not observed at all.[11]

Because of our interest in the synthesis of 1,2-dicarbonyl compounds, we had the occasion to extend this sequence of reactions to a number of different alkylating agents (Table I). It was determined that activated secondary halides alkylated *N*-phenyltriflamide cleanly and in high yield. Treatment of these intermediates with base under mild conditions followed by acid hydrolysis led to the expected dicarbonyl compounds in good yield. However, as in earlier studies, unless the methylene protons were activated, the conditions necessary for elimination of $CF_3SO_2^-$ were very harsh.

It was clear from these findings that elimination of $CF_3SO_2^-$ required a rather substantial buildup of charge on the methylene carbon, much like the elimination of HF from fluorinated hydrocarbons.[6] This requirement could, of course, be expected to substantially reduce the applicability of an otherwise very useful oxidizing system.

Because of the potential ease of formation of aminoquinones from systems of the type in eq 2 and the driving force

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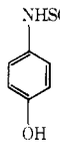
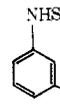
Table I. Reactions of Activated Secondary Halides with *N*-Phenyltriflamide

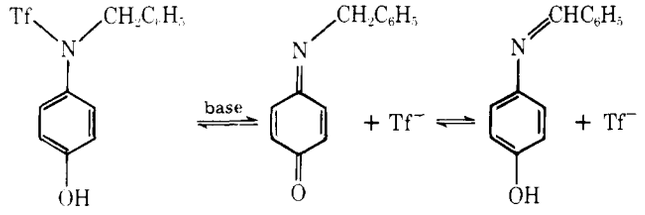
RCHBrCOR′		$C_6H_5NCHRCOR'$ SO_2CF_3	RCOCOR′
CH_3	C_6H_5	91.0%	73%
CH_3	C_8H_{17}	92.5%	79%
C_3H_7	OC_2H_5	89.0%	67%
C_6H_{13}	OC_2H_5	92.0%	62%

Table II. Alkylation of *N*-(3 and 4-Hydroxyphenyl)-triflamide

triflamide	$CH_3(CH_2)_5CH_2I$	$PhCH_2Br$
	59.2% N-alkylation 15.6% N,O-dialkylation 11.0% anil formation[a]	47.1% N-alkylation 7.6% N,O-dialkylation 36.0% anil formation[a]
	42% N-alkylation 49.4% N,O-dialkylation	99% N-alkylation

[a] Identified by hydrolysis to the corresponding aldehyde.

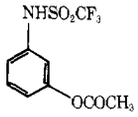
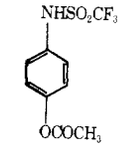
for rearomatization, this reaction sequence was considered as a means to assist in $CF_3SO_2^-$ elimination. In a preliminary experiment the triflamides of 3- and 4-hydroxyaniline were prepared in high yield by reacting 2 mol of the amine with 1 mol of triflic anhydride. The resulting sulfonamides were alkylated with either benzyl bromide or heptyl iodide in refluxing acetone with K_2CO_3 serving as the base. Although alkylation of these compounds with benzyl bromide resulted



in almost exclusive N-alkylation, the alkylation with heptyl iodide gave mixtures of mono- and dialkylated products, i.e., N- and O-alkylated compounds. The 3-hydroxy-N-benzylated and N-heptylated analogues were stable and isolatable. However, under the alkylation conditions the 4-hydroxy-N-benzylated and N-heptylated analogues sustained partial elimination of CF_3SO_2H, forming the anils which were identified from their hydrolysis products (Table II). Although anil formation was spontaneous for both N-benzylated and N-heptylated *N*-(4-hydroxyphenyl)triflamides, this elimination was more complete for the N-benzylated compound. This can be attributed to the lower pK_a of the benzyl vs. the heptyl hydrogens α to the nitrogen and to the extended conjugation observed in the benzyl anil. These relative reactivities, i.e., the stability of the 3-hydroxy-N-alkylated phenyltriflamide to elimination and the spontaneous elimination of $CF_3SO_2^-$ observed in the 4-hydroxy-N-alkylated phenyltriflamide, are in agreement with the proposed aminoquinone scheme. However, it was clear that for this system to be useful in the oxidation of alkyl halides the dialkylation problem had to be alleviated.

Dialkylation was reduced by simply acylating the hydroxyls of the 3- and 4-hydroxyphenyl triflamides with acetic anhydride in the presence of a catalytic amount of H_2SO_4. Monoalkylation of the acetylated compounds with benzyl bromide in refluxing acetone proceeded in high yield. However, the reduced reactivity, and therefore increased reaction time, required for the heptyl iodide alkylation resulted in some cleavage of the acetate group by carbonate followed by O-alkylation. This problem was eliminated by the use of NaH in DMF.

Table III. Reactions of *N*-(3 and 4-Acetoxyphenyl)-triflamide

triflamide	*b*[a]	*c*[a]	*d*	*e*
	72.5 (13.5)	94	0	0
	71.4 (10.2)	92	76	80

[a] Yield based on triflamide. [b] $CH_3(CH_2)_5CH_2I$: % monoalkylation (% dialkylation). [c] $C_6H_5CH_2Br$: % monoalkylation. [d] % yield of $CH_3(CH_2)_5CHO$ from monoalkylated product. [e] % yield of C_6H_5CHO from monoalkylated product.

On treatment with 2 equiv of sodium ethoxide in DMF at 26 °C, the N-alkylated *N*-(3-*O*-acetoxyphenyl)triflamide compound quantitatively deacetylated and no further reaction was observed, again supporting the proposed aminoquinone intermediate. Conversely, the N-alkylated *N*-(4-*O*-acetoxyphenyl)triflamide compounds were smoothly deacylated with concomitant elimination, yielding the imines, which were easily hydrolyzed to the corresponding aldehydes (Table III).

From these data it is clear that $CF_3SO_2^-$ elimination assisted by intermediate aminoquinone formation is a useful modification in the triflamide oxidation of unactivated halides. It is recognized that a limited number of cases have been considered; however, these systems were chosen because they represent the most severe elimination problems. Further experimentation is currently in progress which will expand the number of cases considered.

Experimental Section

All infrared spectra (IR) were taken neat on a Perkin-Elmer 257-grating spectrophotometer. The ^{1}H-NMR spectra were recorded on a Varian EM 360 spectrometer and, unless otherwise noted, utilized $CDCl_3$; the chemical shifts are given in parts per million relative to internal Me_4Si. Mass spectra were taken on a Du Pont 21-490 mass spectrometer at 70 eV. Elemental analyses were done by Galbraith Laboratories, Inc., Knoxville, Tenn. Melting points were taken on a Thomas-Hoover apparatus and are uncorrected. VPC analyses were done either on a Hewlett-Packard 5710A equipped with thermal conductivity detector using a glass column packed with 5% SF96 on Chromosorb W(AW), DMCS, or on a Varian Aerograph 1400 equipped with FID detector using a glass column packed with 10% SE30 on Chromosorb W(AW), DMCS. All preparative TLC was done on 20 × 20 cm, 2000 μm SiO_2 plates supplied by Analtech, Inc. All drying utilized Na_2SO_4.

Materials. Trifluoromethanesulfonic anhydride (triflic anhydride) and *N*-phenyl-*N*-trifluoromethanesulfonamide (phenyltriflamide) were prepared as previously described by Hendrickson and Bergeron.[11]

General Procedure for Alkylation of *N*-Phenyltriflamide with α-Bromo Ketones. Equimolar (25 mmol) portions of α-bromo ketone, *N*-phenyltriflamide, and anhydrous K_2CO_3 were contained in 250 mL of freshly distilled acetone and refluxed for 18 h under a static N_2 atmosphere. The solvent was removed in vacuo and the residue stirred several times with $CHCl_3$. These extracts were washed with water, dried, and concentrated, leaving the product.

***N*-(2-Oxo-1-phenyl-1-propyl)-*N*-phenyltriflamide.** The above procedure gave this material in 91% yield: mp (hexane) 129–131 °C; IR (KBr) 1798 (m), 1220 (s), 1200 (s), 1189 (s), 1149 (s); NMR 8.30–7.20 (m, 10), 5.92 (q, 1, J = 7.4 Hz), 1.30 (d, 3, J = J.4 Hz); mass spectrum *m/e* (rel intensity) 357 (3), 252 (55), 119 (100), 105 (80), 77

(56).

Anal. Calcd for $C_{16}H_{14}NO_3F_3S$: C, 53.78; H, 3.95. Found: C, 53.68; H, 3.90.

***N*-(2-Oxo-3-undecyl)-*N*-phenyltriflamide.** The above procedure gave this material in 92.5% yield after purification by preparative TLC (10% ether in petroleum ether) followed by VPC: IR 2923 (s), 2854 (s), 1729 (m), 1387 (m), 1285 (s), 1191 (s), 1149 (s), 1126 (m); NMR 7.35 (s, 5), 4.71 (t, 1, J = 5.8 Hz), 2.30 (s, 3), 1.90–0.50 (m, 17); mass spectrum m/e (rel intensity) 393 (0), 350 (21), 217 (32), 132 (13), 119 (100), 77 (14), 43 (14).

Anal. Calcd for $C_{18}H_{26}NO_3F_3S$: C, 54.95; H, 6.66. Found: C, 55.11; H, 6.77.

General Procedure for the Alkylation of *N*-Phenyltriflamide with α-Bromo Esters. The α-bromo ester (30 mmol) was combined with 45 mmol of N-phenyltriflamide, 45 mmol of K_2CO_3, and 3 mmol of KI in 250 mL of distilled acetone and refluxed for 4–5 days under a static N_2 atmosphere. The insoluble salts were removed by filtration and the filtrate reduced in vacuo. The resulting oil was taken up in ether, washed with H_2O, and dried. On removing the ether the product was recovered as an oil.

***N*-(1-Ethoxycarbonyl-2-pentyl)-*N*-phenyltriflamide.** Using the above procedure, this material was obtained in 89% yield, after purification by VPC: IR 2966 (s), 2935 (m), 2854 (m), 1747 (s), 1492 (m), 1193 (s), 1153 (s), 1126 (s), 1031 cm^{-1} (m); NMR δ 7.45 (s, 5), 4.27 (t, 1, J = 6 Hz), 4.20 (q, 2, J = 7 Hz), 1.94–0.70 (m, 16); mass spectrum m/e (rel intensity) 395 (4), 322 (100), 189 (30), 119 (91), 104 (16), 77 (16).

Anal. Calcd for $C_{17}H_{24}NO_4F_3S$: C, 51.64; H, 6.12. Found: C, 51.84; H, 6.36.

General Procedure for Elimination and Hydrolysis of α,β-Diketones. During the alkylation of the α-bromo ketones, concurrent elimination was observed; therefore, a synthesis of the anil was developed using additional K_2CO_3. Since the recovered anil proved difficult to isolate and quickly decomposed on standing, it was immediately hydrolyzed. This essentially resulted in a one-step synthesis of the diketone from the α-bromo ketone.

Equimolar amounts (25 mmol) of the α-bromo ketone, N-phenyltriflamide, and K_2CO_3 were combined in 100 mL of distilled acetone and refluxed for 18 h under a static N_2 atmosphere. VPC and MS analyses revealed both addition product and anil. The most probable explanation of this result is the presence of active α-hydrogens and additional base in the form of bicarbonate. The addition of 17 mmol of K_2CO_3 and 18 h of further reflux completed the elimination. The insoluble salts were removed by filtration under N_2. The filtrate was then concentrated and the resulting yellow residue stirred with $MeCl_2$. Filtration of this solution to remove the insoluble potassium triflate, followed by concentration of the filtrate, resulted in a red gum which was immediately dissolved in 100 mL of THF and poured into 50 mL of 10% hydrochloric acid. The THF was removed at reduced pressure and the aqueous residue extracted several times with $MeCl_2$. These extracts were dried and reduced in vacuo to yield the diketone, as a yellow liquid.

1-Phenyl-1,2-propanedione. By the above procedure, this material was produced in 73% yield: bp 98–102 °C (8 mm Hg) (lit. (CRC) 101 °C (11 mm Hg)); IR 1702 (s), 1672 (s), 1283 (m), 1158 (s), 900 (s); NMR δ 8.07–7.18 (m, 5), 2.42 (s, 3); mass spectrum m/e (rel intensity) 148 (3), 105 (11), 77 (70), 51 (20), 43 (20); identical to authentic sample.

2,3-Undecandione. This compound was obtained by the general procedure in 79% yield after purification by preparative TLC (10% ether in petroleum ether): IR 2927 (s), 2853 (s), 1710 (s), 1459 (m), 1348 (m), 1220 (m), 1120 (m), 1061 (m), 911 cm^{-1} (m); NMR δ 2.70 (t, 2, J = 7.0 Hz), 2.30 (s, 3), 1.95–0.60 (m, 15); mass spectrum (rel intensity) 184 (1), 141 (42), 71 (72), 57 (100), 43 (97), identical to authentic sample.

General Procedure for the Elimination and Hydrolysis of α-Keto Esters. The N-phenyltriflamide-substituted ester (25 mmol) was dissolved in 150 mL of distilled DMF and placed under a static N_2 atmosphere. Pentane washed sodium hydride (29 mmol) was gradually added over an 8-h period, foaming being allowed to subside between additions. The reaction mixture was heated at 80 °C for an additional 8 h, cooled, and poured into 300 mL of cold 10% hydrochloric acid. This mixture was then extracted with pentane and the extracts were dried and reduced in vacuo. Distillation of the resulting residue at reduced pressure separated the liquid keto ester from unreacted starting material.

Ethyl 2-Oxooctanoate. Based on recovered starting material, the outlined procedure resulted in 62% yield of this material: bp 101–102 °C (8 mm Hg) (lit.[17] bp 106–107 °C (11 mm Hg)); IR 2929 (s), 2857 (m), 1726 (s), 1457 (m), 1365 (m), 1261 (s), 1123 (m), 1065 cm^{-1} (s); NMR δ 4.29 (q, 2, J = 6.8 Hz), 2.81 (t, 2, J = 7.0 Hz), 1.91–0.61 (m, 14); mass spectrum m/e (rel intensity) 186 (1), 113 (55), 85 (25), 43 (100), 29 (28).

Preparation of *N*-(Hydroxyphenyl)triflamide. The aminophenol (100 mmol) was suspended in 200 mL of dry ether and cooled to −5 °C. A solution of the triflic anhydride (50 mmol) in 40 mL of ether was then added over a 90-min period. The reaction mixture was stirred at −5 °C for 1 h, allowed to warm to 26 °C, and stirred overnight. After washing the reaction mixture with 10% HCl, H_2O, and saturated aqueous NaCl, the organic phase was dried and reduced in vacuo to yield the solid product.

***N*-(3-Hydroxyphenyl)triflamide.** Using the procedure described, this material was produced in 98.4% yield: mp (hexane/ether) 93–95 °C; IR (KBr) 3266 (s), 1593 (m), 1481 (m), 1420 (m), 1353 (m), 1308 (m), 1268 (m), 1191 (s), 1133 (s), 1091 (m), 973 (m), 919 (m), 791 (m), 753 (m), 689 cm^{-1} (m); NMR (acetone-d_6) δ 10.18 (s, 1, D_2O exchangeable), 8.72 (s, 1, D_2O exchangeable), 7.46–6.63 (m, 4); mass spectrum m/e (rel intensity) 241 (42), 108 (100), 81 (38), 80 (17), 53 (15).

Anal. Calcd for $C_7H_6NO_3F_3S$: C, 34.86; H, 2.51. Found: C, 34.92; H, 2.52.

***N*-(4-Hydroxyphenyl)triflamide.** The above procedure resulted in 88% yield of this compound: mp (hexane) 105–107 °C; IR (KBr) 3345 (s), 3260 (s), 1422 (m), 1358 (m), 1224 (s), 1204 (s), 1194 (s), 1134 (s), 1106 (m), 954 (m), 938 (m), 836 cm^{-1} (m); NMR (acetone-d_6) δ 9.00–6.00 (s, 2, D_2O exchangeable), 7.20 (d, 2, J = 8.2 Hz), 6.84 (d, 2, J = 8.2 Hz); mass spectrum m/e (rel intensity) 241 (35), 108 (100), 81 (26).

Anal. Calcd for $C_7H_6NO_3F_3S$: C, 34.86; H, 2.51. Found: C, 35.13; H, 2.68.

General Procedure for the Alkylation of Hydroxyphenyltriflamides. The alkyl halide (5 mmol), hydroxyphenyltriflamide (5 mmol), and K_2CO_3 (5 mmol) were combined in 25 mL of acetone and stirred at 27 °C for several days or refluxed 24 h. After VPC indicated that all alkyl halide was consumed, the reaction mixture was filtered to remove the inorganic salts and the filtrate concentrated in vacuo. The resulting residue was extracted by stirring with ether and the combined ether extracts washed with H_2O and saturated NaCl solution. After drying, the extracts were reduced in vacuo to yield the crude product.

***N*-(3-Hydroxyphenyl)-*N*-benzyltriflamide.** By this procedure this material was obtained in 99% yield, after purification by preparative TLC (1:1 ether–petroleum ether) followed by recrystallization from hexane: mp 66–68 °C; IR (KBr) 3360 (s), 1594 (m), 1462 (m), 1224 (s), 1182 (s), 1160 (s), 1146 (s), 1086 (m), 783 cm^{-1} (m); NMR δ 7.38–6.42 (m, 9), 5.20 (s, 1, D_2O exchangeable), 4.81 (s, 2); mass spectrum m/e (rel intensity) 331 (14), 91 (100).

Anal. Calcd for $C_{14}H_{12}NO_3F_3S$: C, 50.75; H, 3.65. Found: C, 51.00; H, 3.80.

Alkylation of *N*-(4-Hydroxyphenyl)triflamide with Benzyl Bromide (Concurrent Elimination). The material isolated from this reaction proved unstable; therefore, it was immediately taken up in DMF and hydrolyzed with cold 10% hydrochloric acid. Extraction with pentane VPC analysis indicated a 36% yield of benzaldehyde based on benzyl bromide. Upon cooling of the pentane solution a white precipitate formed. The pentane was decanted and reduced in vacuo to leave a liquid spectroscopically identical to benzaldehyde, while the white precipitate was taken up in ether and dried. Upon removal of the ether, an oil resulted. NMR and TLC analyses indicated a mixture of products. Separation by preparative TLC (25% ether in petroleum ether) showed it to contain N-benzyl-N-(4-hydroxyphenyl)triflamide and N-benzyl-N-(4-benzoxyphenyl)triflamide in yields of 7.2 and 7.6%, respectively, based on starting halide.

The original acidic aqueous solution was extracted with ether and the ether extracts combined, washed with saturated NaCl, and dried. Upon concentration, these extracts gave an oil identified as N-benzyl-N-(4-hydroxyphenyl)triflamide in 39.9% yield, based on starting halide. Thus, a total yield of 47.1% mono N-alkylated product was realized.

***N*-Benzyl-*N*-(4-hydroxphenyl)triflamide:** yield 47.1%; mp 73–75 °C; IR (KBr) 3431 (s), 1595 (m), 1368 (m), 1192 (s), 1136 (s), 1107 (m), 1084 (s), 1072 (s), 1026 (m), 1010 (m), 871 (m), 696 cm^{-1} (m); NMR δ 7.34–7.19 (m, 5), 6.97 (d, 2, J = 8.8 Hz), 6.50 (d, 2, J = 8.8 Hz), 5.38 (s, 1, D_2O exchangeable), 4.82 (s, 2); mass spectrum m/e (rel intensity) 331 (14), 198 (6), 120 (5), 92 (8), 91 (100).

Anal. Calcd for $C_{14}H_{12}NO_3F_3S$: C, 50.75; H, 3.65. Found: C, 50.85; H, 3.76.

***N*-Benzyl-*N*-(4-benzoxyphenyl)triflamide:** yield 7.6%; mp 119.5–120.8 °C; IR (KBr), 1497 (m), 1287 (m), 1246 (s), 1225 (s), 1199 (s), 1187 (s), 1139 (s), 1108 (m), 1057 (s), 1022 (s), 836 (m), 694 cm^{-1}

(m); NMR δ 7.37 (s, 5), 7.22 (s, 5), 7.05 (d, 2, J = 10 Hz), 6.81 (d, 2, J = 10 Hz), 4.99 (s, 2), 4.84 (s, 2); mass spectrum m/e (rel intensity) 421 (6), 91 (100), 65 (8).

Anal. Calcd for $C_{21}H_{18}NO_3F_3S$: C, 59.85; H, 4.30. Found: C, 60.04; H, 4.37.

Alkylation of *N*-(3-Hydroxyphenyl)triflamide with Heptyl Iodide. Separation and purification of the product oil by preparative TLC (10% ether in petroleum ether) recovered two products.

***N*-Heptyl-*N*-(3-hydroxyphenyl)triflamide:** yield 42% based on heptyl iodide; IR 3517 (m), 2932 (s), 2859 (m), 1594 (s), 1482 (m), 1377 (s), 1225 (s), 1192 (s), 1151 (s), 1130 (s), 1073 (s), 983 (s), 695 cm^{-1} (m); NMR δ 7.48–6.63 (m, 4), 5.90 (s, 1, D_2O exchangeable), 3.77 (t, 2, J = 6.0 Hz), 1.85–0.60 (m, 13); mass spectrum m/e (rel intensity) 339 (74), 254 (39), 241 (43), 206 (59), 122 (93), 121 (100), 43 (36).

Anal. Calcd for $C_{14}H_{20}NO_3F_3S$: C, 49.55; H, 5.94. Found: C, 49.57; H, 5.98.

***N*-Heptyl-*N*-(3-heptoxyphenyl)triflamide (dialkylation):** yield 49.4% based on heptyl iodide; mp 39–42 °C; IR (KBr) 2923 (s), 2853 (s), 1585 (m), 1380 (m), 1220 (s), 1179 (s), 1160 (s), 1129 cm^{-1} (s); NMR δ 7.47–6.57 (m, 4), 4.12–3.40 (m, 4), 2.07–4.41 (m, 26); mass spectrum m/e (rel intensity) 437 (89), 339 (100), 304 (25), 254 (24), 241 (60), 206 (76), 122 (60), 121 (55), 57 (92).

Anal. Calcd for $C_{21}H_{34}NO_3F_3S$: C, 57.64; H, 7.83. Found: C, 57.91; H, 8.00.

Alkylation of *N*-(4-Hydroxyphenyl)triflamide with Heptyl Iodide. The mixture of products isolated from the acetone reaction was taken up in DMF and hydrolyzed with cold 10% HCl. The mixture was extracted with pentane and the extracts analyzed by VPC (heptanal yield 11%; spectral properties identical to an authentic sample). The pentane was dried and concentrated to an oil which was separated and purified by preparative TLC (20% ether in petroleum ether) recovering two products.

***N*-Heptyl-*N*-(4-hydroxyphenyl)triflamide:** yield 59.2% oil; IR 3507 (m), 2929 (m), 1500 (m), 1378 (m), 1225 (s), 1191 (s), 1153 (m), 1136 (m), 1074 cm^{-1} (m); NMR δ 7.12 (d, 2, J = 9.0 Hz), 6.76 (d, 2, J = 9.0 Hz), 5.72 (s, 1, D_2O exchangeable), 3.93–3.40 (m, 2), 1.85–0.59 (m, 13); mass spectrum m/e (rel intensity) 339 (27), 206 (100), 122 (59), 121 (20), 55 (30), 43 (18).

Anal. Calcd for $C_{14}H_{20}NO_3F_3S$: C, 49.55; H, 5.94. Found: C, 49.62; H, 5.96.

***N*-Heptyl-*N*-(4-heptoxyphenyl)triflamide (dialkylation):** yield 15.6% oil; IR 2932 (s), 2861 (m), 1605 (m), 1505 (m), 1464 (m), 1295 (m), 1264 (s), 1229 (s), 1191 (s), 1155 (m), 1078 (m), 836 cm^{-1} (m); NMR δ 7.18 (d, 2, J = 8.8 Hz), 6.85 (d, 2, J = 8.8 Hz), 4.13–3.40 (m, 4), 1.98–0.55 (m, 26); mass spectrum m/e (rel intensity) 437 (13), 304 (100), 57 (14), 55 (17), 43 (13).

Anal. Calcd for $C_{21}H_{34}NO_3F_3S$: C, 57.64; H, 7.83. Found: C, 57.56; H, 7.92.

Preparation of *N*-(3 or 4-Acetoxyphenyl)triflamide. These compounds were prepared by standard phenol acetylation. The N-(hydroxyphenyl)triflamide was suspended in a slight excess of freshly distilled acetic anhydride and a drop of concentrated sulfuric acid added with swirling. After the initial exothermic reaction the solid mass was dissolved in ether and stirred for 18 h. The reaction mixture was diluted further with ether and washed with H_2O, 10% HCl, H_2O, and saturated NaCl solution. After drying, the ether was removed in vacuo, leaving a solid which was used as is for further reactions or recrystallized from 5–10% ether in hexane.

***N*-(3-Acetoxyphenyl)triflamide:** yield 94.4%; mp (hexane) 88–89 °C; IR (KBr) 3097 (s), 1727 (s), 1592 (m), 1418 (m), 1203 (s), 1176 (s), 1136 (s), 1006 (m), 979 (s), 901 (m), 790 cm^{-1} (m); NMR (acetone-d_6) δ 7.69–6.70 (m, 5, 1 proton D_2O exchangeable), 2.21 (s, 3); mass spectrum m/e (rel intensity) 283 (8), 240 (100), 108 (89), 81 (20), 80 (13), 43 (76).

Anal. Calcd for $C_9H_8NO_4F_3S$: C, 38.17; H, 2.85. Found: C, 38.27; H, 2.88.

***N*-(4-Acetoxyphenyl)triflamide:** yield 96.4%; mp 95 °C; IR (KBr) 3167 (s), 1737 (s), 1514 (m), 1247 (s), 1236 (s), 1191 (s), 1140 (s), 1021 (m), 952 (s), 926 cm^{-1} (m); NMR (acetone-d_6) δ 7.38 (d, 2, J = 8.8 Hz), 7.10 (d, 2, J = 8.8 Hz), 6.70 (s, 1, D_2O exchangeable), 2.22 (s, 3); mass spectrum m/e (rel intensity) 283 (8), 241 (13), 240 (100), 108 (100), 81 (15), 43 (88).

Anal. Calcd for $C_9H_8NO_4F_3S$: C, 38.17; H, 2.85. Found: C, 38.26; H, 2.90.

General Procedure for Alkylation of *N*-(3 or 4-Acetoxyphenyl)triflamide. Benzylation was achieved when equimolar amounts (10 mmol) of benzyl bromide, the appropriate N-(acetoxyphenyl)triflamide, and K_2CO_3 were combined in 100 mL of acetone, stirred at 26 °C for 18 h, and then refluxed 2 h for the para derivative and 18 h for the meta compound. Alkylation with heptyl iodide (10 mmol) required a slight excess of the appropriate N-(acetoxyphenyl)triflamide (11 mmol) and K_2CO_3 (11 mmol) and additional refluxing (48 h). The benzylation reaction mixtures were filtered and the filtrate concentrated in vacuo. The heptylation reactions were filtered, the filtrate concentrated to an oil, and the oil taken up in $MeCl_2$. This solution was washed with H_2O, dried, and concentrated in vacuo.

***N*-Benzyl-*N*-(3-acetoxyphenyl)triflamide.** The product, an oil, was purified by preparative TLC (10% ether in petroleum ether) in 94% yield: IR 1771 (s), 1597 (m), 1385 (m), 1225 (s), 1195 (s), 1145 (s), 1023 (m), 695 cm^{-1} (m); NMR δ 7.46–6.81 (m, 10), 4.88 (s, 2), 2.22 (s, 3); mass spectrum m/e (rel intensity) 373 (4), 330 (21), 91 (100).

Anal. Calcd for $C_{16}H_{14}NO_4F_3S$: C, 51.47; H, 3.78. Found: C, 51.51; H, 3.63.

***N*-Benzyl-*N*-(4-acetoxyphenyl)triflamide:** yield 92%; mp (hexane) 97–100 °C; IR (KBr) 1769 (s), 1493 (m), 1224 (s), 1180 (s), 1137 (s), 1085 (s), 1061 (s), 1023 (m), 909 (m), 851 (m), 711 cm^{-1} (m); NMR δ 7.21 (m, 5), 7.13 (s, 4), 4.86 (s, 2), 2.23 (s, 3); mass spectrum m/e (rel intensity) 373 (3), 330 (12), 91 (100), 43 (12).

Anal. Calcd for $C_{16}H_{14}NO_4F_3S$: C, 51.47; H, 3.78. Found: C, 51.60; H, 3.97.

Alkylation of *N*-(3-Acetoxyphenyl)triflamide with Heptyl Iodide. The crude product was purified by preparative TLC (10% ether in petroleum ether). Two pure products (mono- and dialkylated) resulted.

***N*-Heptyl-*N*-(3-acetoxyphenyl)triflamide:** yield 72.5% oil; IR 2927 (m), 1701 (s), 1591 (m), 1387 (m), 1228 (s), 1195 (s), 1147 (s), 1131 (s), 1074 cm^{-1} (m); NMR δ 7.61–6.99 (m, 4), 3.77 (t, 2, J = 6 Hz), 2.29 (s, 3), 1.79–0.61 (m, 13); mass spectrum m/e (rel intensity) 381 (8), 338 (100), 249 (22), 206 (26), 122 (26), 121 (28), 43 (39).

Anal. Calcd for $C_{16}H_{22}NO_4F_3S$: C, 50.38; H, 5.81. Found: C, 50.45; H, 5.80.

***N*-Heptyl-*N*-(3-heptoxyphenyl)triflamide:** yield 13.5%; spectral properties identical to previously isolated compound.

Alkylation of *N*-(4-Acetoxyphenyl)triflamide with Heptyl Iodide. The oily mixture obtained from this reaction was separated and purified by preparative TLC (10% ether in petroleum ether). Two pure products were recovered.

***N*-Heptyl-*N*-(4-acetoxyphenyl)triflamide:** yield 71.4% oil; IR 2927 (m), 1769 (s), 1368 (m), 1225 (s), 1186 (m), 1131 (s), 1074 (m), 1017 (m), 912 cm^{-1} (m); NMR δ 7.32 (d, 2, J = 8.8 Hz), 7.10 (d, 2, J = 8.8 Hz), 3.77 (t, 2, J = 6.4 Hz), 2.30 (s, 3), 1.90–0.60 (m, 13); mass spectrum m/e (rel intensity) 381 (5), 338 (66), 207 (15), 206 (100), 122 (30), 55 (17), 43 (24).

Anal. Calcd for $C_{16}H_{22}NO_4F_3S$: C, 50.38; H, 5.81. Found: 50.51; H, 6.02.

***N*-Heptyl-*N*-(4-heptoxyphenyl)triflamide:** yield 10.2%; spectral properties identical to the previously isolated compound.

Elimination of Dialkylation. It was determined that forming the anion using NaH in DMF in the presence of the alkyl halide followed by heating for 2 h at 80 °C gave the best conversion (80% based on recovered N-(4-acetoxyphenyl)triflamide) and dialkylation could not be detected. On workup, two products were isolated, N-heptyl-N-(4-acetoxyphenyl)triflamide and the deacylated N-heptyl-N-(4-hydroxyphenyl)triflamide, both useful for synthesis of heptanal.

Alkylation of *N*-(4-Acetoxyphenyl)triflamide with Heptyl Iodide Using Sodium Hydride. Equimolar amounts (1 mmol) of N-(4-acetoxyphenyl)triflamide and heptyl iodide were combined in 10 mL of dry, distilled DMF (CaH). Pentane-washed NaH (1.1 mmol) was added in portions over 1.5 h. The solution was then heated 2 h at 80 °C, cooled, poured into cold 10% HCl, and stirred with a layer of pentane gradually warming to 26 °C. The pentane was removed and the aqueous layer extracted with pentane and ether. The pentane extracts were combined and dried as were the ether extracts. The crude mixture recovered from the pentane was separated and purified by preparative TLC (10% ether in petroleum ether) recovering two products and starting material. The starting material recovered from this plate near the origin was combined with material recovered from the ether extraction and purified by additional preparative TLC (15% absolute ethanol in petroleum ether) recovering 0.055 g of N-(4-acetoxyphenyl)triflamide (80% conversion). The two products and their yields based on recovered reagent were N-heptyl-N-(4-acetoxyphenyl)triflamide (0.23 g, 75.5%) and N-heptyl-N-(4-hydroxyphenyl)triflamide (0.05 g, 18.9%).

General Procedure for Deacetylation, Elimination, and Hydrolysis. To a 5–10% solution of the N-alkylated N-(3 or 4-acetoxyphenyl)triflamide in DMF was added 2 equiv of NaOEt. The heptyl reactions were stirred overnight at 26 °C while the benzylations were stirred only 4 h. (The reaction in both cases appears to be instantaneous and 1 h is probably sufficient.) The reaction mixture was poured

into 50 mL of cold 10% HCl, stirred with a layer of pentane, and allowed to warm to 26 °C. After 3 h, the pentane layer was removed and the aqueous layer extracted with pentane. The combined pentane solutions were analyzed by VPC and the heptanal, benzaldehyde, and *N*-heptyl-*N*-(3-hydroxyphenyl)triflamide products were isolated by drying the pentane and removing in vacuo. The pentane extracts from the N-benzylated meta reaction contained no product; thus, the aqueous phase was extracted with $MeCl_2$. These organic extracts were then dried and concentrated to the crude product.

***N*-Heptyl-*N*-(4-acetoxyphenyl)triflamide.** The reaction gave a 76% yield of heptanal. The isolated material had spectral properties identical with an authentic sample.

***N*-Benzyl-*N*-(4-acetoxyphenyl)triflamide.** The reaction yielded 80% benzaldehyde, the material isolated having spectral properties identical with literature.

***N*-Heptyl-*N*-(3-acetoxyphenyl)triflamide.** The reaction gave *N*-heptyl-*N*-(3-hydroxyphenyl)triflamide in 100% yield after purification by preparative TLC (25% ether in petroleum ether). Spectral properties were identical to those of an authentic sample.

***N*-Benzyl-*N*-(3-acetoxyphenyl)triflamide.** The reaction yielded 97% *N*-benzyl-*N*-(3-hydroxyphenyl)triflamide after purification by preparative TLC (50% ether in petroleum ether). Spectral properties were identical to those of an authentic sample.

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Registry No.—*N*-Phenyltriflamide, 456-64-4; *m*-aminophenol, 591-27-5; *p*-aminophenol, 123-30-8; triflic anhydride, 358-23-6.

References and Notes

(1) This work was done in partial fulfillment of a degree at the University of Maryland.
(2) W. W. Epstein and F. W. Sweat, *Chem. Rev.*, **67**, 247 (1967).
(3) V. J. Traynelis and R. H. Ode, *J. Org. Chem.*, **35**, 2207 (1970).
(4) A. Markovac, C. L. Stevens, A. B. Ash, and B. E. Hackley, *J. Org. Chem.*, **35**, 841 (1970).
(5) T. M. Santosusso and D. Swern, *Tetrahedron Lett.*, 4261 (1978).
(6) J. R. Pakkh and W. von E. Doering, *J. Am. Chem. Soc.*, **89**, 5505 (1967).
(7) R. E. Harman, C. V. Zenarosa, and S. K. Gupta, *J. Org. Chem.*, **35**, 1936 (1970).
(8) W. W. Epstein and J. Ollinger, *Chem. Commun.*, 1338 (1970).
(9) J. M. Epstein and J. Ollinger, *Chem. Commun.*, 1338 (1970).
(10) D. P. Bauer and R. S. Macomber, *J. Org. Chem.*, **40**, 1990 (1975).
(11) J. B. Hendrickson, R. Bergeron, A. Giga, and D. Sternbach, *J. Am. Chem. Soc.*, **95**, 3412 (1973).
(12) J. B. Hendrickson and R. Bergeron, *Tetrahedron Lett.*, 3839 (1973).
(13) J. B. Hendrickson, R. Bergeron, and D. D. Sternbach, *Tetrahedron*, **31**, 2517 (1975).
(14) J. B. Hendrickson, K. W. Bair, R. Bergeron, A. Giga, P. L. Shapper, D. D. Sternbach, and J. A. Wareing, *Org. Prep. Proced. Int.*, **9** (11), 173 (1977).
(15) J. B. Hendrickson, D. D. Sternbach, and K. W. Bair, *Acc. Chem. Res.*, **10**, 306 (1977).
(16) J. Bunnett, *Angew. Chem., Int. Ed. Engl.*, **1**, 222 (1962).
(17) T. Cuvigny, *C. R. Hebd. Seances Acad. Sci.*, **240**, 206 (1955).
(18) R. W. Wynn and A. H. Corwin, *J. Org. Chem.*, **15**, 203 (1950).

Phenylcinnamalones. 4. An Oxidation Reaction[1]

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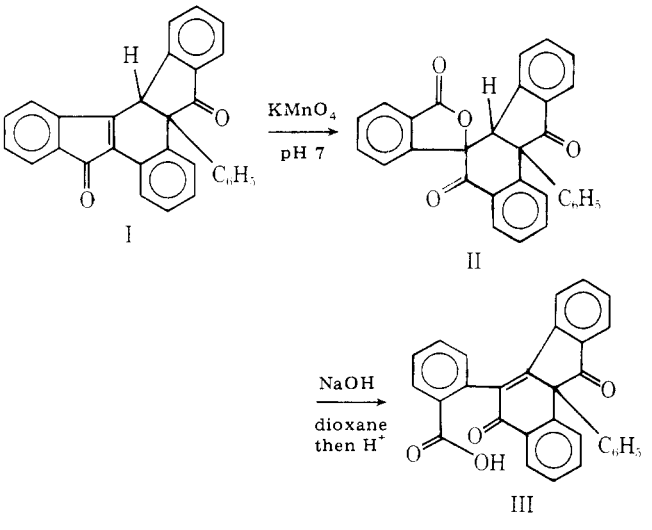
Mild oxidation of phenylcinnamalone (I) with neutral potassium permanganate gave the spiro lactone 6a′-hydro-11a′-phenylspiro[isobenzofuran-3(1*H*),6′-benzo[*a*]fluorene]-1,5′,11′-trione (II). Hydrolysis of II yielded 6-(*o*-carboxyphenyl)-11a-phenyl-5*H*-benzo[*a*]fluorene-5,11-dione (III) rather than the hydroxy acid which might be expected. The characterization of II and III is reported along with some ideas concerning possible reaction mechanisms.

Prior reports in this series have been concerned with the preparation and characterization of I,[4] its analogues and derivatives,[4,5] the scope of the preparative reaction,[5] and the nature of the potential reaction intermediates.[5] One of the intriguing aspects of the phenylcinnamalone (I) ring system is the ease with which it can be converted into other complex polycyclic compounds by simple single-step gentle procedures. In the most recent of the previous publications,[6] we described one method of entry into the benzo[*a*]fluorene system from phenylcinnamalone via an initial hydrolytic cleavage of one of the five-membered rings. In this report we shall describe an oxidative cleavage of the other five-membered ring of phenylcinnamalone to yield additional derivatives of benzo[*a*]fluorene (see Scheme I).

Scheme I



I II III

Reaction of phenylcinnamalone (I) with neutral potassium permanganate leads to a single white crystalline material (II) in good yield. A molecular formula of $C_{30}H_{18}O_4$ is consistent with the elemental analysis and with the isotopic analysis of the mass spectrum of II. Also, the infrared spectrum of II displays no hydroxyl-stretching band. These data rule out the possible formation of a glycol such as IV.

A tetraketone (V), analogous to the triketone (VI) prepared by Daleo[7] from 2,3-diphenylindone, does fit the observed molecular formula. However, the infrared spectrum of II shows, in addition to two strong carbonyl absorptions at 1710

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