The Preparation of 9-Fluoroanthracenes[1]

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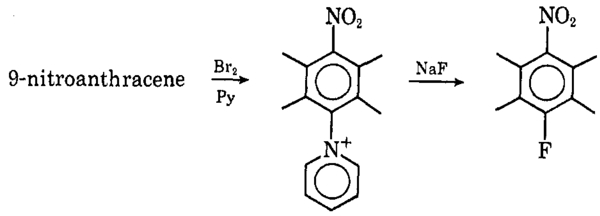
The preparation of 10-substituted 9-fluoroanthracenes and their Diels–Alder adducts are described.

Several procedures are available for the preparation of 9-fluoroanthracene.[2–4] However, few methods have been reported for the synthesis of 10-substituted 9-fluoroanthracenes. Need for these compounds in an investigation of ^{19}F substituent chemical shifts[5] prompted this study.

9-Fluoroanthracene was prepared from 9-aminoanthracene by diazotization of the amine with nitric oxide.[2] 10-Bromo- and 10-chloro-9-fluoroanthracene were prepared from 9-fluoroanthracene by reaction with the appropriate molecular halogen in acetic acid at ambient temperature. Decomposition of the initial adduct occurred with preferred elimination of hydrogen bromide (in bromination) and hydrogen chloride (in chlorination), thereby enabling the preparation of the mixed haloanthracenes in excellent yields. 10-Bromo-9-fluoroanthracene was converted to 10-carboxy-9-fluoroanthracene by treatment with butyllithium followed by carbonation. Esterification of 10-carboxy-9-fluoroanthracene by the mixed trifluoroacetic anhydride approach[6] proceeded smoothly to give 10-carbomethoxy-9-fluoroanthracene.

10-Cyano-9-bromoanthracene was converted to 10-cyano-9-fluoroanthracene by reaction with anhydrous potassium fluoride in tetramethylene sulfone.[7] Our failure to prepare 10-bromo-9-nitroanthracene eliminated the possibility of a similar conversion of this compound to 10-nitro-9-fluoroanthracene. Early work indicates that 10-bromo-9-nitroanthracene is difficult to prepare by an electrophilic substitution reaction.[8] The general features of this work were confirmed in this study. Thus, the bromination of 9-nitroanthracene with molecular bromine in acetic acid gave 9,10-dibromoanthracene. Efforts to nitrate 9-bromoanthracene, even with nitronium tetrafluoroborate, were also unsatisfactory, since 9,10-dibromoanthracene, in addition to several other unidentified products, was obtained. The difficulties in the electrophilic reactions were circumvented by the adoption of another approach. 10-Nitro-9-fluoroanthracene was prepared by the reaction of 9-nitroanthracene-10-pyridinium tetrafluoroborate with sodium fluoride. The necessary pyridinium bromide was prepared by the method of Barnett, *et al.*[8a] Preliminary work revealed that the decomposition of the pyridinium bromide in tetramethylene sulfone yielded both 10-bromo- and 10-fluoro-9-nitroanthracene. However, conversion of the pyridinium bromide to the pyridinium tetrafluoroborate prior to the reaction with sodium fluoride enabled the exclusive formation of 10-nitro-9-fluoroanthracene.



Several attempts were made to prepare 10-amino-9-fluoroanthracene by the reduction of 10-nitro-9-fluoroanthracene. The compound was successfully reduced by the conventional reagents, but, unfortunately, 10-amino-9-fluoroanthracene is quite unstable, similar in this respect to 10-methoxy-9-aminoanthracene[9] and 9,10-diaminoanthracene,[10] and the free amine was isolated in only one experiment as described in the Experimental Section. However, the amine could be readily trapped as the stable 10-acetylamino-9-fluoroanthracene when the reduction was performed with zinc dust in a buffered solution of acetic acid containing acetic anhydride.[11]

The reduction of 10,10-difluoroanthrone[12] was studied briefly. The reduction of this compound with sodium borohydride in monoglyme or methanol did not yield 10-hydroxy-9-fluoroanthracene. This substance, as the amine, is presumably unstable. Accordingly, the hydroxy derivative was trapped as formed by reducing 10,10-difluoroanthrone with zinc dust in acetic anhydride containing pyridine to yield 10-acetoxy-9-fluoroanthracene.

Base-catalyzed hydrolysis of 10-acetoxy-9-fluoroanthracene in a nitrogen atmosphere followed by immediate treatment with dimethyl sulfate yielded 10-methoxy-9-fluoroanthracene. The ^{19}F signal of the intermediate salt was observed, but no attempt was made to isolate the salt or to obtain the unstable hydroxide.

10-Bromo-9-fluoroanthracene was converted to 10-methyl-9-fluoroanthracene by the reaction of "lithium copper methylide" as described by Corey and Posner.[13] The reaction product in several instances was contaminated with 9-fluoroanthracene.

The synthesis of 9,10-difluoroanthracene presented considerable difficulty. The compound has been pre-

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(1) Chemistry of the Bicyclo[2.2.2]octanes. X. This research was supported by a grant, GP 7448, from the National Science Foundation.

(2) J. Rigaudy and J. Barcelo, *C. R. Acad. Sci.*, **258**, 4799 (1964).

(3) M. J. S. Dewar and J. Michl, *Tetrahedron*, **26**, 375 (1970).

(4) 9-Fluoroanthracene may also be prepared by the reaction of 9-anthryllithium with perchloryl fluoride. However, the simultaneous formation of anthracene in the reaction introduces a serious purification problem. R. C. Parish, Dissertation, The University of Chicago Libraries, 1965.

(5) G. L. Anderson and L. M. Stock, *J. Amer. Chem. Soc.*, **91**, 6804 (1969).

(6) R. C. Parish and L. M. Stock, *J. Org. Chem.*, **30**, 927 (1965).

(7) F. W. Baker, R. C. Parish, and L. M. Stock, *J. Amer. Chem. Soc.*, **89**, 5677 (1967).

(8) (a) E. de B. Barnett, J. W. Cook, and H. H. Grainger, *J. Chem. Soc.*, 2059 (1922); (b) E. de B. Barnett and J. W. Cook, *ibid.*, 1084 (1924).

(9) J. Meisenheimer and E. Connerade, *Justus Liebigs Ann. Chem.*, **330**, 133 (1904).

(10) T. W. Campbell, V. E. McCoy, J. C. Kauer, and V. S. Foldi, *J. Org. Chem.*, **26**, 1422 (1961).

(11) A. G. Anderson, Jr., J. A. Nelson, and J. J. Tazuma, *J. Amer. Chem. Soc.*, **75**, 4980 (1953).

(12) A generous sample was provided by Dr. R. C. Parish.

(13) E. J. Corey and G. H. Posner, *J. Amer. Chem. Soc.*, **89**, 3911 (1967).

pared in low yield previously.[14-16] The finding that aryl fluorides are obtained in the reactions of aryllithium compounds with perchloryl fluoride[4,17] prompted the preparation of 9,10-difluoroanthracene from the reaction of 9-fluoroanthryl-10-magnesium bromide with perchloryl fluoride. Some 9-fluoroanthracene was produced simultaneously.

The Diels–Alder adducts of the anthracenes were prepared without major problems. The ethylene adducts were formed when the addition reaction was performed at about 3000 psi in toluene solution at 150°.[7] The maleic anhydride and dimethyl acetylenedicarboxylate adducts were prepared in the customary way.[18,19]

Experimental Section

9-Fluoroanthracene.—9-Nitroanthracene[20] was converted to 9-aminoanthracene by the method of Meisenheimer.[21] The compound was stored in a nitrogen atmosphere. Anthracene-9-diazonium tetrafluoroborate was prepared from the amine according to the procedure of Rigaudy and Barcelo.[2] Yields varied dramatically. In a typical experiment, the diazonium salt (3.87 g) was diluted with sand (40 g) and decomposed in a vacuum sublimator. 9-Fluoroanthracene [yellow needles with green fluorescence, 1.2 g, mp 102–103° (lit.[2] mp 102–103°)] was recrystallized from methanol.

10-Bromo-9-fluoroanthracene.—9-Fluoroanthracene (2.5 g, 12.7 mmol) was dissolved in glacial acetic acid (185 ml). Bromine (2.0 g, 12.7 mmol) in acetic acid (75 ml) was added dropwise to the stirred solution. Stirring was continued for 7 hr during which time the product precipitated. The crude product (2.7 g) was collected and recrystallized from ethanol to yield 10-bromo-9-fluoroanthracene (2.5 g, mp 171–172°).

Anal. Calcd for $C_{14}H_8BrF$: C, 61.09; H, 2.91; Br, 29.09; F, 6.91. Found: C, 61.34; H, 3.04; Br, 28.86; F, 7.20; parent ions (mass spectrum), 273.98 and 275.98.

Oxidation of the product provided anthraquinone in good yield.

10-Chloro-9-fluoroanthracene.—9-Fluoroanthracene (1.0 g, 4.1 mmol) was dissolved in glacial acetic acid (50 ml). An equivalent amount of chlorine in glacial acetic acid was added dropwise to the stirred solution. The reaction was allowed to proceed for 12 hr during which time the product precipitated. The crude product (0.85 g) was collected and recrystallized from ethanol to give 10-chloro-9-fluoroanthracene (0.62 g, mp 185–185.5°).

Anal. Calcd for $C_{14}H_8ClF$: C, 72.89; H, 3.47; Cl, 15.40; F, 8.24. Found: C, 72.91; H, 3.74; Cl, 15.25; F, 8.47; parent ions (mass spectrum), 230.03 and 232.03.

10-Carboxy-9-fluoroanthracene.—10-Bromo-9-fluoroanthracene (2.0 g, 73 mmol) was added as a solid to a stirred solution of *n*-butyllithium (19.2 mmol) in ether (45 ml) under nitrogen. The reaction was allowed to proceed for 15 min at −15° (ice–acetone bath) and 3 hr at room temperature. Carbon dioxide was introduced for 45 min. The crude product was collected in the usual way and recrystallized from ethanol (85%) to give 10-carboxy-9-fluoroanthracene (0.70 g, mp 235–237°).

Anal. Calcd for $C_{15}H_9O_2F$: C, 75.00; H, 3.75. Found: C, 75.66; H, 4.01.

10-Carbomethoxy-9-fluoroanthracene.—10-Carboxy-9-fluoroanthracene (0.4 g, 1.7 mmol) was suspended in benzene (15 ml) and trifluoroacetic anhydride (1.5 ml) was added. Methanol (3 ml) was added and the reaction was allowed to proceed for a few minutes. Aqueous sodium hydroxide solution (10%) was added and the benzene layer was washed with water and dried. The solvent was removed *in vacuo* and the residue was recrystallized from hexane to give 10-carbomethoxy-9-fluoroanthracene (0.31 g, mp 134.5–135.5°).

10-Nitro-9-fluoroanthracene.—A suspension of 9-nitroanthracene-10-pyridinium bromide[8] (25 g, 66 mmol) in fluoroboric acid (150 ml, 48%) was stirred for 5 hr. The product was collected, washed with water, ethanol, and ether, and recrystallized from water to give 9-nitroanthracene-10-pyridinium tetrafluoroborate (18.7 g, 74%, mp 259–260°). A mixture of 9-nitroanthracene-10-pyridinium tetrafluoroborate (16.0 g, 42 mmol), anhydrous sodium fluoride (15.4 g, 420 mmol), and tetramethylene sulfone (100 ml) was heated for 5 hr at about 180° under nitrogen. The reaction mixture was poured, while still hot, into water. After standing, the crude product was collected, washed with hot water, and then dissolved in benzene. After drying, the benzene solution was concentrated and chromatographed on alumina. The crude product was recrystallized from benzene–cyclohexane (1:4) to yield 10-nitro-9-fluoroanthracene (2.01 g, mp 200–201° after sublimation).

Anal. Calcd for $C_{14}H_8O_2NF$: C, 69.71; H, 3.32; N, 5.81; F, 7.88. Found: C, 70.53; H, 3.47; N, 5.35; F, 7.44; parent ion (mass spectrum), 241.05.

A mixture of 9-nitroanthracene-10-pyridinium tetrafluoroborate (22.8 g, 58.7 mmol) and anhydrous sodium fluoride (22.8 g) was heated with flame for about 30 min. The residue was extracted with benzene. The benzene solution was chromatographed to give 10-nitro-9-fluoroanthracene (2.6 g, 18% yield).

10-Acetylamino-9-fluoroanthracene.—10-Acetylamino-9-fluoroanthracene was prepared according to the procedure of Anderson, *et al.*[11] Zinc dust (6.67 g, 90%) was added to a stirred solution of 10-nitro-9-fluoroanthracene (1.0 g, 4.1 mmol), sodium acetate (2.67 g), and acetic anhydride (67 ml) in glacial acetic acid (67 ml). The reaction mixture was stirred for 1 hr and filtered. Water was added to the filtrate and the crude product was extracted into methylene chloride. The methylene chloride extract was washed with water and dilute aqueous ammonia, and dried over calcium sulfate. The methylene chloride was removed *in vacuo* and the residue was crystallized from ethanol to give 10-acetylamino-9-fluoroanthracene (0.5 g, mp 289–291°).

Anal. Calcd for $C_{16}H_{12}NOF$: C, 75.89; H, 4.74; N, 5.53. Found: C, 75.92; H, 4.80; N, 5.33; parent ion (mass spectrum), 253.09.

9-Fluoroanthracene-10-pyridinium Bromide and Fluoroborate.—Bromine (0.4 g) was added to a solution of 9-fluoroanthracene (0.44 g, 2.2 mmol) in pyridine (2 ml) cooled to 0°. After 12 hr, the crude product was collected, washed with pyridine and ether, and recrystallized from water to give 9-fluoroanthracene-10-pyridinium bromide (0.25 g). A suspension of 9-fluoroanthracene-10-pyridinium bromide (0.2 g) in fluoroboric acid (10 ml) was stirred for 1 hr. The product was collected, washed with water and ether, and dried to give 9-fluoroanthracene-10-pyridinium tetrafluoroborate (0.12 g, mp 268–271°).

10-Cyano-9-fluoroanthracene.—A mixture of 9-bromo-10-cyanoanthracene[22] (2.0 g, 7.2 mmol), potassium fluoride (5.76 g, 99.6 mmol), and tetramethylene sulfone (25 ml) was heated at 200° under nitrogen for 4 hr. The product was isolated by the method described for 10-nitro-9-fluoroanthracene. Recrystallization from benzene–cyclohexane (1:4) gave 10-cyano-9-fluoroanthracene [0.52 g, mp 222° after sublimation (lit.[6] mp 218–219.5°)].

10-Acetoxy-9-fluoroanthracene.—Zinc dust (5.86 g, 90%) was added in portions to a solution of 10,10-difluoroanthrone (3.0 g, 13 mmol) in acetic anhydride (50 ml) containing pyridine (3 ml). The reaction was allowed to proceed for 3 hr. The mixture was filtered and water was added to the cooled filtrate. The crude product was collected, dried, and recrystallized from benzene–cyclohexane (1:4) to give 10-acetoxy-9-fluoroanthracene (0.98 g, mp 125–128°).

The proton resonance signal for the methyl group was observed as a singlet at δ 2.45 ppm.

Anal. Calcd for $C_{16}H_{11}O_2F$: C, 75.29; H, 4.33; F, 7.48. Found: C, 75.49; H, 4.47; F, 7.22.

10-Methoxy-9-fluoroanthracene.—Methyl sulfate (1.0 g) was added dropwise to a solution of 10-acetoxy-9-fluoroanthracene (0.5 g, 2.0 mmol) in methanolic sodium hydroxide (5 ml, 5%) under nitrogen. The precipitate was collected after 15 min. The product was extracted into methanol and reprecipitated with

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(14) G. Wittig and H. Harle, *Justus Liebigs Ann. Chem.*, **623**, 17 (1959).

(15) A. L. Logothetis and G. N. Sausen, *J. Org. Chem.*, **31**, 3689 (1966).

(16) W. R. Hasek, W. C. Smith, and V. A. Engelhardt, *J. Amer. Chem. Soc.*, **82**, 543 (1960).

(17) R. D. Schuetz, D. D. Taft, J. P. O'Brien, J. L. Shea, and H. M. Mork, *J. Org. Chem.*, **28**, 1420 (1963).

(18) P. D. Bartlett and S. G. Cohen, *J. Amer. Chem. Soc.*, **62**, 1183 (1940).

(19) O. Diels and K. Alder, *Justus Liebigs Ann. Chem.*, **486**, 191 (1931).

(20) C. E. Braun, C. D. Cook, C. Merritt, Jr., and J. E. Rousseau, *Org. Syn.*, **31**, 77 (1951).

(21) J. Meisenheimer, *Ber.*, **33**, 3547 (1900).

(22) L. F. Fieser and J. L. Hartwell, *J. Amer. Chem. Soc.*, **60**, 2555 (1938).

water to give 10-methoxy-9-fluoroanthracene (0.15 g, mp 81–82°).

The proton resonance signal for the methyl appeared at δ 3.90 ppm in carbon tetrachloride.

Anal. Calcd for $C_{15}H_{11}OF$: C, 79.65; H, 4.87. Found: C, 79.63; H, 4.82.

10-Amino-9-fluoroanthracene.—Zinc dust (1.5 g, 90%) was added to a suspension of 10-nitro-9-fluoroanthracene (0.5 g, 2.1 mmol) in glacial acetic acid (10 ml) under nitrogen. After 5 min, the reaction mixture was filtered and water was added to the filtrate. The precipitate was collected, washed with water, and vacuum dried to give unstable 10-amino-9-fluoroanthracene (0.15 g, mp 114–117°).

The amine (0.5 g) was added to anhydrous ether (10 ml) saturated with hydrogen chloride. The mixture was stirred for 5 min and the solid product was isolated. The amine was regenerated by treatment of the salt with aqueous ammonium hydroxide. Treatment of the amine with acetic anhydride gave a compound with properties identical with those of 10-acetylamino-9-fluoroanthracene.

10-Methyl-9-fluoroanthracene.—A mixture of methyllithium (30 mmol) and cuprous chloride (1.49 g, 15 mmol) was allowed to react for 20 min in ether (15 ml) under nitrogen cooled to 0°. 10-Bromo-9-fluoroanthracene (1.24 g, 4.5 mmol) was added and the mixture was stirred for 1 day under nitrogen at room temperature.[13] Water (5 ml) was added to quench the reaction. The ether layer was decanted and the aqueous phase was extracted with ether. The ether solution was dried over calcium sulfate and the solvent was evaporated. The crude product (0.72 g, mp 70–85°) was chromatographed on alumina. The proton and ^{19}F nmr spectra indicated that 9-fluoroanthracene and 10-methyl-9-fluoroanthracene were formed. The mixture was not purified further.

1-Fluorodibenzobicyclo[2.2.2]octa-2,5-diene.—9-Fluoroanthracene (0.33 g, 1.6 mmol) was dissolved in toluene (50 ml) and heated with ethylene (initial pressure 1000 psi) for 3 days at 150°. The reaction mixture was dried over calcium sulfate and concentrated by distillation. 1-Fluorodibenzobicyclo[2.2.2]-octa-2,5-diene (0.15 g, 40%, mp 104–104.5° after sublimation) was isolated by vpc.

Anal. Calcd for $C_{16}H_{13}F$: C, 85.72; H, 5.80. Found: C, 86.03; H, 5.92.

4-Bromo-1-fluorodibenzobicyclo[2.2.2]octa-2,5-diene.—10-Bromo-9-fluoroanthracene (0.50 g, 1.8 mmol) was dissolved in toluene (75 ml) containing a trace of 2,6-*tert*-butylcatechol and heated with ethylene (initial pressure 925 psi) for 3 days. The product, 4-bromo-1-fluorodibenzobicyclo[2.2.2]octa-2,5-diene (mp 94–95° after sublimation), was isolated by vpc.

Anal. Calcd for $C_{16}H_{12}BrF$: C, 63.37; H, 3.96; Br, 26.40; F, 6.27. Found: C, 63.22; H, 3.82; Br, 26.52; F, 6.30.

Maleic Anhydride Adducts.—The adducts of the 10-substituted 9-fluoroanthracenes were prepared by the method of Bartlett and Cohen.[18] Pertinent data are presented in Tables I and II.

Dimethyl Acetylenedicarboxylate Adducts.—These adducts were prepared by the procedure of Diels and Alder. The crude product was collected, washed with methanol, and recrystallized from methanol. A summary of the adducts prepared in this manner is given in Table III.

TABLE I

MALEIC ANHYDRIDE ADDUCTS

Substituent	Registry no.	Reaction time,[a] hr	Yield, %	Mp, °C
H	26306-24-1	2.5	70.0	243–244
Br	20277-45-6	2.5	83.0	268–268.5
Cl	20277-44-5	5.7	67.6	253.5–254
CN	20277-43-4	10.5	62.4	252.5–253.5
$COOCH_3$	26964-10-3	8.8		265.5–266
NO_2	20277-47-8	13.0	29.8	261–263
$NHCOCH_3$	20277-46-7	3.0	79.4	293–295
$OCOCH_3$	20277-41-2	2.0		224–225
OCH_3	26964-15-8	1.0		259–260

[a] At reflux in xylene.

TABLE II

ANALYTICAL DATA FOR MALEIC ANHYDRIDE ADDUCTS

Substituent	Calcd, %		Found, %	
	C	H	C	H
H	73.5	3.74	73.45	3.92
Br	57.9	2.68	58.02	2.83
Cl	65.7	3.04	65.13	3.10
CN	71.5	3.14	71.68	3.63
NO_2	63.7	2.95	63.91	2.94

TABLE III

DIMETHYL ACETYLENEDICARBOXYLATE ADDUCTS

Substituent	Registry no.	Mp, °C
H	26306-23-0	158–160
Br	26964-14-7	167–170
OCH_3	26964-17-0	94–96
$OCOCH_3$	27128-30-9	196–201
NO_2	26964-15-8	178–179

Registry No.—10-Bromo-9-fluoroanthracene, 27705-22-2; 10-chloro-9-fluoroanthracene, 27705-23-3; 10-carboxy-9-fluoroanthracene, 27705-24-4; 10-carbomethoxy-9-fluoroanthracene, 27705-25-5; 10-nitro-9-fluoroanthracene, 27705-26-6; 10-acetylamino-9-fluoroanthracene, 27705-27-7; 9-fluoroanthracene-10-pyridinium (fluoroborate), 27704-98-9; 10-acetoxy-9-fluoroanthracene, 27705-28-8; 10-methoxy-9-fluoroanthracene, 27705-29-9; 10-amino-9-fluoroanthracene, 27705-30-2; 10-methyl-9-fluoroanthracene, 27705-31-3; 1-fluorodibenzobicyclo[2.2.2]octa-2,5-diene, 26306-25-2; 4-bromo-1-fluorodibenzobicyclo[2.2.2]octa-2,5-diene, 20277-48-9.