phase was dried (Na_2SO_4) and concentrated, and the residue was distilled under nitrogen to yield 3.6 g (89%) of 1-cyanooctane having ^1H NMR and IR spectra indistinguishable from those of an authentic sample. Reuse of recovered **18** in an identical experiment led to an 84% yield of 1-cyanooctane.
(16) Bromide ion liberated in the reaction may compete effectively with acetate for phosphonium sites on the polymer and act as a catalyst poison.
(17) S. L. Regen, J. J. Besse, and J. McLick, *J. Am. Chem. Soc.*, in press.
(18) M. Cinquini, S. Colonna, H. Molinari, F. Montanari, and P. Tundo, *J. Chem. Soc., Chem. Commun.*, 394 (1976).
(19) S. L. Regen, *J. Am. Chem. Soc.*, **98,** 6270 (1976).
(20) T. M. Fyles and C. C. Leznoff, *Can. J. Chem.*, **54,** 935 (1976).
(21) J. A. Patterson in "Biochemical Aspects of Reactions on Solid Supports", G. R. Stark, Ed., Academic Press, New York, 1971, p 183.

Free-Radical Addition of Iodo-*F*-alkanes to Isomeric 5-Norbornene-2,3-dicarboxylic Acid Derivatives

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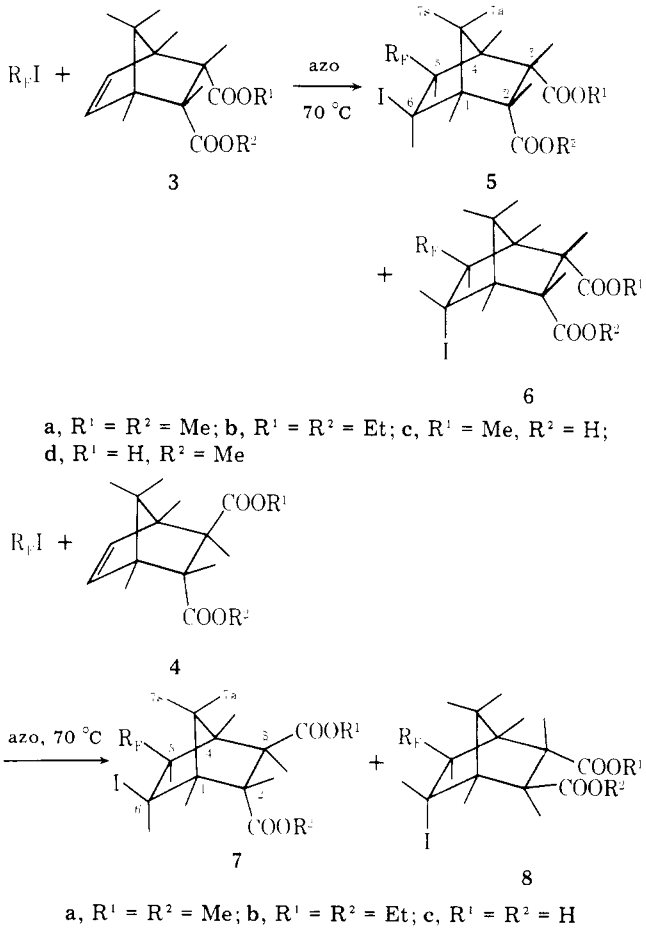
Free-radical addition of linear iodo-*F*-alkanes (R_FI) to isomeric 5-norbornene-2,3-dicarboxylic acids and derivatives occurred stereoselectively. The anhydrides gave trans addition of R_FI exclusively, while exo-cis addition was the principal mode of reaction of *endo*-2,3-dicarboxylic esters. Nonstereoselective addition of the branched 2-*F*-propyl iodide took place as the result of steric crowding in the intermediate radical. Azonitrile, peroxide, or ultraviolet initiation was used as required. Chemical transformation of the resulting adducts was profoundly affected by their structure, particularly by the position of the iodine atom. Heating of *exo*-6-iodo-*exo*-*F*-alkyl-2,3-norbornanedicarboxylic esters gave a lactone, with loss of alkyl iodide; the *endo*-6-iodo compounds remain unchanged. Similarly, base-induced cyclization of the *exo*-6-iodo derivatives to a nortricyclene product took place and the *endo*-6-iodo isomer again was unaffected. This stereospecificity sheds new light on these reactions. Spectroscopic properties of these *F*-containing compounds were extensively studied, and a new area of derivative chemistry was opened.

Historical Background. Reaction of norbornene with various addenda has been frequently reported. My early work[1] showed that trans addition of iodo-*F*-alkanes (R_FI) occurred, the *F*-alkyl group taking an exo position and the iodine atom exclusively adding in an endo position. Ludwick and Martin[2] explored radical additions of polyhalomethanes to *endo*-norbornene anhydride (bicyclo[2.2.1]hept-5-ene-*endo*-2,3-dicarboxylic anhydride) (**1**) and discovered temperature dependent rotation of the dibromofluoromethyl group in the exo-cis adduct from tribromofluoromethane. Smart[3] examined radical addition of halogens and 1-iodo-*F*-propane to 5,5,6,6-tetrafluoro-2-norbornene, and Osborn, Van Auken, and Trecker[4] studied the effects of steric factors on the addition of carbon tetrachloride to norbornene derivatives. From a theoretical standpoint, radical addition of R_FI to *endo*- and *exo*-norbornene anhydrides (**1** and **2**) was of great interest since steric and electronic factors should have a pronounced effect. Additionally, a rich derivative chemistry of the products could be envisioned. The starting 5-norbornene anhydrides were readily available as the *endo*-anhydride is isomerized into the *exo*-anhydride by simple heating.[5] A convenient preparative procedure was recently reported.[6]

It is the purpose of this paper to describe the free-radical addition of R_FI to **1** and **2** and their derivatives and to report some significant new reactions of the adducts.

Scheme I. Stereoselective Free-Radical Addition of 1-Iodo-*F*-alkanes to Isomeric 5-Norbornene-2,3-dicarboxylic Acids and Esters



a, R¹ = R² = Me; b, R¹ = R² = Et; c, R¹ = Me, R² = H; d, R¹ = H, R² = Me

a, R¹ = R² = Me; b, R¹ = R² = Et; c, R¹ = R² = H

Results

Free-radical addition of R_FI ($R_F = CF_3(CF_2)_n$, $n = 3, 5, 7$) to dimethyl 5-norbornene-*endo*-2,*endo*-3-dicarboxylate (**3a**) occurred smoothly at 70 °C using an azonitrile initiator and afforded chiefly (90–97%) the *exo*-6-iodo isomer **5a** and only 3–10% of *endo*-6-iodo adduct **6a.**[7] The R_F group added exclusively in the exo position, as observed previously.[1] By contrast, the branched 2-iodo-*F*-propane did not react stereoselectively, but gave both *exo*- and *endo*-iodo products in about equal amounts. These reactants and products, together with the analogous reaction of the diethyl ester **3b,** the stereoisomeric *trans*-diesters **4a** and **4b,** and the diacid **4c,** are summarized in Scheme I. The half-esters **3c** and **3d** behaved similarly to the diesters **3a** and **3b.** Esterification of the adducts **5c** and **5d** gave principally the same diester **5a** as was isolated from addition of R_FI to **3a.** The *trans*-diester **4a** gave

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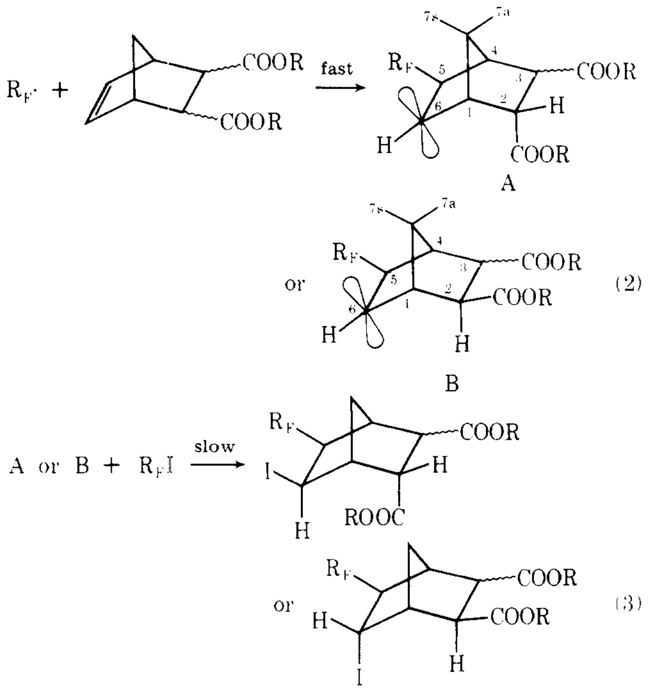
Scheme II. Free-Radical Chain Addition of 1-Iodo-*F*-alkanes. Stereochemistry of the Intermediate Radicals

$$R_FI \xrightarrow[\text{heat}]{\text{initiator}} R_F\cdot + R{-}I \qquad (1)$$



three products from reaction with 1-iodo-*F*-hexane or 1-iodo-*F*-octane. Two of these adducts were **7a** and **8a**, and the third was a substance with the carboxylate ester groups switched in position. The *trans*-diacid **4c** also reacted nonstereoselectively with 1-iodo-*F*-octane to give about equal amounts of *exo*- and *endo*-6-iodo isomers **7c** and **8c**. The *endo*-iodo adduct **8c** was isolated in pure condition and enabled the configuration of the molecule to be ascertained by NMR study. Radical addition of R_FI to 5-norbornene-*endo*-2,*endo*-3-dicarboxylic acid did not occur.

Stereochemistry of Intermediate Radicals. These results point to a free-radical reaction which is under kinetic control; that product is isolated which is formed at a faster rate in the slow radical-transfer step of the three-step chain reaction (Scheme II). The intermediate radicals A or B from diesters or diacids differ in their accessibility to approach by the iodo-*F*-alkane in the transfer step (eq 3), depending on the orientation of the carboxylate groups. Under conditions where selectivity is at a maximum (low temperature, mild initiator reactivity), the large electron-rich R_FI molecule reacts chiefly with radical A or B in a manner which presents the least steric (or electronic) interference. Thus, addition of 1-iodo-*F*-octane to **3a** (*endo*-diester) occurred slowly in ligroine solution at 25 °C under ultraviolet irradiation and gave only exo adduct **5a**. An uncontrolled, exothermic reaction (caused by peroxide initiation) gave, however, *both* exo and endo adducts **5a** and **6a** (and a little isomerized product) in excellent yield. Accordingly, at a sufficiently high temperature radical transfer was not stereoselective. For reasons which are given below, it was not possible to equilibrate exo and endo isomers, by heating them directly, in order to determine relative product stability.

In *exo*-iodo adducts **5a** the H_{6n} resonance appeared at 4.63 ppm and was coupled to protons H_{7a} and H_{5n}. This coupling of H_6 to H_{7a} only exists[3,8,9] if H_6 is endo. The signal for H_6 at 4.63 ppm was a clean doublet of doublets ($J_{6n,5n}$ = 7.2 Hz, $J_{6n,7a}$ = 2.5 Hz). Irradiation at H_{7a} (1.64 ppm) confirmed its coupling to H_{6n}.

From these results it can be seen that when both ester groups are in an endo position, transfer of the iodine atom from R_FI normally takes place from the exo direction. However, the bulky branched *F*-isopropyl group, when present in the radical A, hinders exo approach of 2-iodo-*F*-propane. This results in slower reaction and formation of a stereoisomeric mixture. In conformity with this idea, NMR studies (see below) showed restricted rotation of the 2-*F*-propyl group in adducts **5a** and **6a**.

The situation is different for *trans*-diesters **4a** and **4b** and diacid **4c**. The intermediate radicals (A or B, Scheme II) actually have two possible positions for an *exo*-carboxylate group: on the side opposite to the R_F group which has already added exo, or on the side opposite to the radical at C-6. Thus, endo approach of R_FI to radical B (which has an *exo*-carboxylate group at C-2) gives *endo*-iodo adducts **8a** to **8c**. This conforms to the stereochemistry observed for norbornene itself.[1] Alternatively, transfer of the intermediate radical A takes place chiefly in the exo direction, resulting in adducts **7a–c**. Since the R_F radical adds first (and only in an exo direction) but nonselectively with respect to the carboxylate groups, approximately equal amounts of radical A and B are formed from *trans*-esters or the *trans*-diacid.

A careful study of the NMR spectra of adducts **5–8** (see below) revealed a significant interaction of carboxylic acid and ester groups on the R_F side of the molecules. This is probably caused by free rotation of the carboxylate groups.[8]

Addition to Anhydrides. Reaction of iodo-*F*-alkanes with 5-norbornene-*endo*-2,*endo*-3-dicarboxylic anhydride (**1**) required a peroxide initiator and a reaction temperature of 100–140 °C and resulted in a single product, *exo*-5-*F*-alkyl-*endo*-6-iodonorbornane-*endo*-2,*endo*-3-dicarboxylic acid anhydride (**9**), having an *exo*-R_F group and an *endo*-iodine atom. The *exo*-anhydride **2** also gave stereoselectively the *endo*-6-iodo adduct **10** (Scheme III). Surprisingly, Ludwick and Martin[2] found that bromotrichloromethane added nonstereoselectively to *endo*-anhydride **1**. The CCl_3 group added exo; cis and trans adducts were isolated in a ratio of 60:40.

There is evidence from NMR spectra that the anhydride linkage in R_FI adducts from **1** (or **2**) has significantly less effect on the R_F side of the molecule than do the (presumably) freely rotating carboxylic acid or ester groups. If this is so, then the unusual selectivity could be the result of a faster rate of transfer of the intermediate radical in the endo position, just like norbornene itself. This helps to explain why the *endo*-diesters gave principally the *exo*-iodo adducts. Azonitriles did not initiate the reaction of R_FI with anhydrides, but this was no disadvantage as **1** and **2** are solids which melt well above useful initiation temperatures of azonitriles. Solvents inhibited the addition reaction and could not be used. Careful addition of benzoyl peroxide to a well-stirred mixture of R_FI and

Scheme III. Stereoselective Radical Addition of Iodo-*F*-alkanes to Isomeric 5-Norbornene-2,3-dicarboxylic Anhydrides

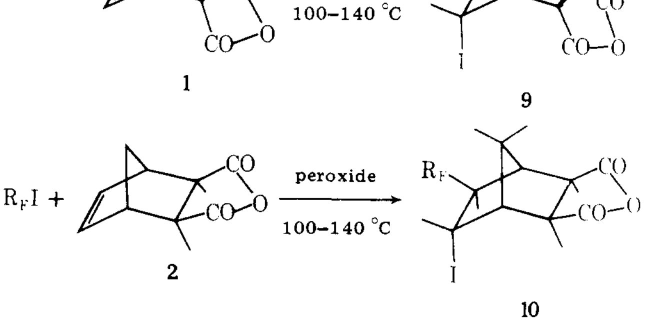


Table I. Preparation of *exo*-5-*F*-Alkyl-*endo*-6-iodonorbornane-*endo*-2,*endo*-3-(or *exo*-2,*exo*-3)dicarboxylic Acid Anhydrides (9 and 10)

	R_FI						anhydride 9 or 10		
	R_F	wt, g (mmol)	wt of 1, g (mmol)	wt of BPO,[a] g	time, h	temp, °C	% of theory	mp, °C	solvent
9a	$(CF_3)_2CF$	29.6 (100)	13.47 (80.00)	0.3633	5	110	70	141	ligroine/EtOAc
9b	$CF_3(CF_2)_3$	34.6 (100)	13.47 (80.00)	0.3633	4	110	85	115–117	ligroine/EtOAc
9c	$(CF_3)_2CFOCF_2CF_2$	41.2 (100)	13.46 (80.00)	0.3633	4.5	110	90	158–161	ligroine/EtOAc
9d	$CF_3(CF_2)_5$	20.7 (46.0)	4.10 (25.0)	0.1500	1.5	105	100	144–146	benzene
9e	$CF_3(CF_2)_7$	19.1 (35.0)	4.10 (25.0)	0.2000	2	110	100	157–159	ligroine/EtOAc
10d	$CF_3(CF_2)_5$	17.84 (40.00)	4.10[b] (25.0)	0.2000	5.5	110	95.8	69–71	ligroine
10e	$CF_3(CF_2)_7$	16.4 (30.0)	4.10[b] (25.0)	0.100	1.5	105–118	100	111–113	benzene

[a] BPO is benzoyl peroxide. [b] *exo*-Anhydride 2 was used.

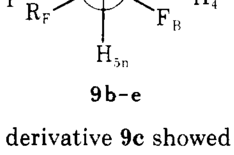
Table II. Chemical Shift Changes Accompanying Transformation of Anhydride to Diacid

	chemical shift, ppm				chemical shift, ppm	
	anhydride[a]		diacid		anhydride[b]	diacid
proton	9b	9c	12b	12c	10e	11e
7a	1.64	1.68	1.43	1.40	1.90	1.66
7s	1.87	1.88	1.66	1.65	1.40	2.20
5n	2.48	2.43	3.80	3.75	2.48	2.40
4	2.91	2.83	2.56	2.50	3.06	2.80
1	3.11	3.13	2.91	2.89	3.06	2.80
2x	3.67	3.66	3.33	3.30	3.75[c]	2.80[c]
3x	3.29	3.89	2.91	2.89	3.06[d]	3.40[d]
6x	4.59	4.55	4.40	4.46	4.38	4.50

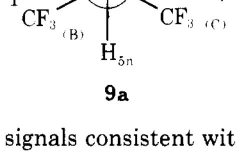
[a] *endo*-anhydrides. [b] *exo*-anhydride. [c] 2n. [d] 3n.

the anhydride at 110 °C gave rapid and complete reaction. Adducts **9** and **10** from a variety of different iodo-*F*-alkanes and **1** are listed in Table I. These products were readily recrystallized from common solvents and were not difficult to obtain in pure condition.

The *endo*-anhydrides **9a–e** exhibited a resonance pattern (doublet of doublets) at 4.4–4.6 ppm for an exo proton at C-6, which was coupled to protons at C-5 and C-1. Protons H_2 and H_3 were similarly coupled to each other and to the bridgehead protons. In *F*-2-propyl derivative **9a**, ^{19}F spectra showed *three* fluorine resonances (3:3:1 intensity), indicating two different CF_3 environments for the $(CF_3)_2CF_A$ group: $CF_{3(B)}$ and $CF_{3(C)}$. F_A was far upfield from the CF_3 signals and was also coupled to H_{5n} (J_{F_A,H_N} = 18.5 Hz, $J_{F_A,F_{B,C}}$ = 7.5 Hz). The CF_3 signals appeared as a doublet of quartets ($J_{F_A,F_{B,C}}$ = 7.5 Hz, J_{F_B,F_C} = 8 Hz).



9b–e



9a

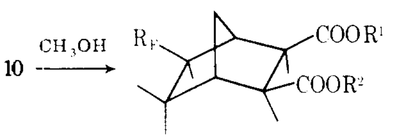
The derivative **9c** showed ^{19}F signals consistent with the more complex R_F group. In **9b–d** a clean splitting pattern at 2.48 ppm was seen for proton H_{5n}, resulting from coupling to the CF_2 fluorine atoms ($J_{5n,6x}$ = 7.5 Hz, J_{5n,F_B} = 7.5 Hz, J_{5n,F_A} = 22.5 Hz).

Most interesting were the changes observed in the NMR spectra in going from the anhydrides **9** to the diacids **12**. For example, data for **9b** and **12b**, listed in Table II, show that the most pronounced differences occur on the side of the molecule substituted by the R_F group. As the anhydride is opened up the carboxylic acid group becomes free to rotate, altering its influence on H_{5n}, H_{3x}, and H_4. The chemical shift of H_{5n} in **9b** at 2.48 ppm becomes 3.80 ppm in **12b**. Proton resonance for H_4 in **9b** is at 2.91 ppm; in **12b** it is at 2.56 ppm. By inspection of models it is evident that this is due to rotation of the anisotropic group and not a change in position of the carbon atom of the carboxylic acid function. Because the *endo*-iodine atom at C-6 hinders rotational change on this side of the molecule, H_{6x} is little affected.

exo-Anhydrides **10d** and **10e** gave NMR spectra very similar to those of the *endo*-anhydrides. Notable differences occurred upon conversion to diacid **11e**, as shown in Table II. Since the exo-linked carboxyl groups cannot rotate into the R_F side of the molecule, little effect on H_5 and H_6 was observed. However, substantial changes in chemical shift of endo protons H_2 and H_3 and syn and anti $H_{7a,7s}$ were observed.

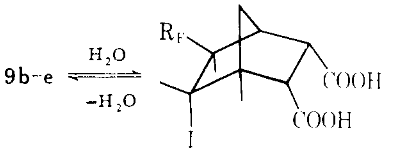
Reactions of Adducts. A few simple reactions of the anhydrides **9** and **10** were carried out. *endo*-Anhydride **9e** gave with methanol a single monoester, mp 172–174 °C (either **6c** or **6d**). Further reaction with thionyl chloride and methanol/pyridine gave *endo*-6-iodo isomer **6a**, confirmed by its melting point and NMR spectrum and differing from isomeric ester **5a**. Analogous steps using **10** gave a mixture of *endo*-6-iodo isomers **11a** and **11b**, and then **11c**, nicely confirming the stereochemical integrity of these reactions.

Hydrolysis of **9** or **10** afforded the diacids **12** and **11e**, respectively, again with complete retention of iodine. Both acids

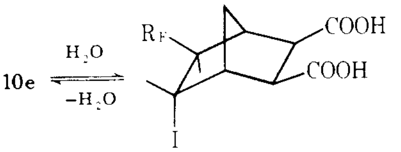


11a, R^1 = H; R^2 = Me
b, R^1 = Me; R^2 = H
c, R^1 = R^2 = Me

evolved water on heating and reverted to the anhydrides.

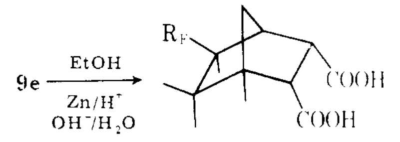


12b–e

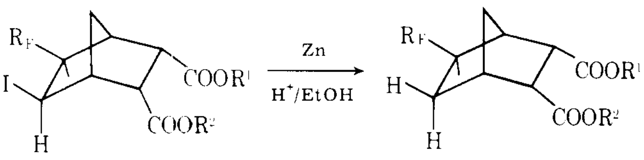


11e

Iodine was removed by reduction with zinc and acid. Boiling anhydride **9e** (R_F = $CF_3(CF_2)_7$) in aqueous ethanol gave, after suitable workup, the diacid **13a**, mp 166–167.5 °C, in 90% yield. The diester **5b** in anhydrous ethanol gave the iodine-free ester **13b**. Methyl ester **5a** gave reduced product **13c** (R = Me) and some isomerized material which was not further characterized.



13a



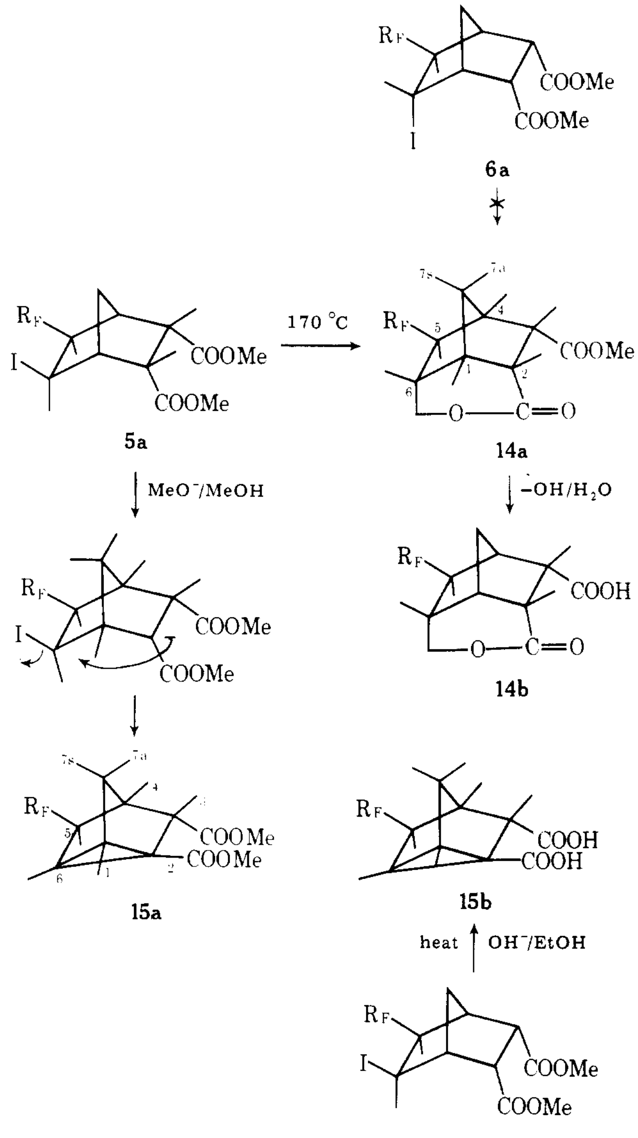
5a or 5b

13b,c

Lactone Formation. Heating diesters **5a** or **5b** above 120 °C and especially under reduced pressure caused alkyl iodide to be lost by what appears to be a homolytic process. A lactone **14a** was formed in excellent yield (Scheme IV). The stereoisomeric ester **6a** (*endo*-iodine) did not react or give lactone under these conditions. Displacement must take place from the endo side of the ring, therefore, and does not involve prior loss of an iodine atom. Lactonization by thermal means is well known, but this reaction provides new insight into the stereochemistry of the process.[10,11]

Heating of lactone ester **14a** in alkaline solution gave crystalline lactone acid **14b** in 80% yield (R_F = C_8F_{17}). NMR spectra of **14a** showed doublets for H_{7a} and H_{7s} at 1.84 ppm as part of an AB quartet; in **14b** these were shifted to 1.56 and 1.86 ppm. The *exo*-6 proton in **14a** was at 5.06 and in **14b** at 4.97 ppm. This resonance was coupled to H_1 at 3.55 ppm in **14a** and at 3.34 ppm in **14b**. Irradiation of **14b** at 5.0 ppm caused the H_1 triplet (J = 4.4 Hz) to collapse to a doublet. Because of additional strain imposed on the ring by the lactone group, the H_{6x} proton appears to be at an unfavorable dihedral angle for coupling to H_{5n} (about 100° instead of the anticipated 130°). An infrared spectrum of lactone **14a** gave sharp carbonyl stretching bands at 1780 and 1725 cm^{-1}. The diester **5a** has three sharp bands at 1750, 1735, and 1710 cm^{-1}.

Scheme IV. Thermal and Base-Induced Reactions of Dimethyl *exo*-6-Iodo-*exo*-5-*F*-alkyl-*endo*-2,*endo*-3-norbornanedicarboxylate (5a)



Base-Induced Cyclization to Nortricyclene Derivatives. When an *exo*-6-iodo ester **5a** was heated with a base such as methoxide in methanol or with an amine such as *N,N,N'*-trimethylpropanediamine, loss of HI occurred and a nortricyclene diester **15a** was formed in excellent yield. A carbanion intermediate is strongly suspected (Scheme IV). A small amount of *endo*-6-iodo isomer **6a** present in the reaction mixture was recovered unchanged (GC analysis). Hence, stereospecific reaction was again observed as in the lactone preparation above. The nortricyclene diacid **15b** was obtained directly from the iodo ester **5a** by heating with sodium hydroxide in aqueous alcohol. The infrared spectrum of both **15a** and **15b** showed cyclopropyl CH stretching bands at 3120 and 3095 cm^{-1}, and the carbonyl stretch was at 1745 and 1735 cm^{-1} in **15a** and at 1700 cm^{-1} in **15b**. NMR spectra were consistent with the assigned structures, taking into account the highly strained condition of the fused ring system.

Experimental Section

Source of Materials and Physical Measurements. *F*-Alkyl iodides were obtained from Ciba-Geigy Corp., Ardsley, N.Y., as a gift

Table III. Preparation of Dialkyl *exo*-6-Iodo-*exo*-5-*F*-alkyl-*endo*-2,*endo*-3-norbornanedicarboxylates

R_F	wt, g (mmol)	wt of **3a**, g (mmol)	wt of ABN, g (mmol)	time, h	temp, °C	total product, %	rel. amount, % **5a**	rel. amount, % **6a**	mp, °C
$(CF_3)_2CF$	14.80 (50.0)	8.33 (39.6)	0.246 (1.50)	7.5	70	79[a]	41	38	
$CF_3(CF_2)_3$	17.3 (50.0)	8.33 (40.0)	0.246 (1.50)	21.2	70	93	>95		95–96.5
$CF_3(CF_2)_5$	53.52 (120.0)	22.90 (108.9)	0.493 (3.00)	17	70	86.9[b]	95	5	94.5–95.5
$CF_3(CF_2)_7$	49.14 (90.0)	15.78 (75.0)	0.492 (3.00)	16	70	92[c]	96	2	84–86
$CF_3(CF_2)_7$	27.3 (50.0)	5.96[d] (25.0)	0.328 (2.00)	16	70	96[e]	>95		56

[a] An oil; heated to 125 °C (0.4 mm) but could not be distilled without decomposition, and gave an inaccurate elemental analysis. GC showed five impurities at 4–6%, 41% of **5a**, and 38% of **6a**. [b] GC showed 96% of **5a**, 2% of **6a**, and 2% of an unknown substance. [c] GC showed 4% of **3a**, 1–2% of 4 impurities, 90% of **5a**, and 2% of **6a**. [d] Used the *diethyl* ester **4b**. [e] NMR showed that both the total product and the recrystallized sample had the same structure. The OC_2H_5 groups were nonequivalent as they are affected to a different degree by the iodine atom.

Table IV. Preparation of Dialkyl *endo,exo*-6-Iodo-*exo*-5-*F*-alkylnorbornane-*endo,exo*-2,*endo,exo*-3-dicarboxylates

R_F	wt of R_FI, g (mmol)	ester, wt (g, mmol)	wt of ABN, g (mmol)	time, h	temp, °C	adducts % of theory	adducts configuration
C_6F_{13}	104.5 (220)	**3c** (16.41, 100.0)[a]	0.500 (3.00)	16	70	98	**5c**
C_8F_{17}	54.6 (110)	**3c** (6.60, 50.0)	0.350 (2.13)	24	72	90	**5c**
C_6F_{13}	13.4 (30.0)	**4a** (13.4, 25.0)	0.164 (1.00)	21.5	70	100[b]	**7a, 8a**
C_8F_{17}	18.4 (33.6)	**4a** (5.26, 25.0)	0.164 (1.00)	16.5	70	93[c]	**7a, 8a**
C_8F_{17}	19.11 (35.0)	**4b** (5.96, 25.0)	0.164 (1.00)	18.5	70	94[d]	**7b, 8b**

[a] Added a twofold excess of methanol to **1**; formed **3c** in situ. [b] GC showed 1% of **4a**, 48% of **7a**, 24% of **8a**, and 25% of an isomer of **7a**; NMR showed H_6 in the exo and endo configurations at 4.2–4.4 ppm. [c] GC showed 11% of 1-iodo-*F*-octane, no **4a**, and 35, 23, and 29% of isomeric adducts **7a**, **8a**, and an isomer of **7a**. A solid mixture was obtained from ligroine solution. NMR was as in *b*. [d] GC showed 63, 29, and 3% of isomeric adducts; NMR was as in *b* above.

from Dr. E. K. Kleiner. The physical constants were those previously given.[12] Infrared spectra were recorded on a Perkin-Elmer Model 337 spectrophotometer, and NMR spectra were obtained at 100 MHz for ^1H and at 94.1 MHz for ^{19}F. Gas chromatographic analyses were performed using a 4 ft × 1/4 in. column packed with 3% OV-17 silicone oil on "Supelcoport" 80–100 mesh, temperature programmed from 50 to 250 °C at 2.5 °C/min with helium at 60 mL/min. Distillations were done in a 16-in. spinning band column.

cis-Dimethyl ester **3a** was prepared from anhydride **1** and methanol (8 mol)[13,14] with *p*-toluene sulfonic acid (0.5%) as catalyst (83% yield, 99% purity by GC): bp 138 °C (11.5 mm); $n^{25}{}_D$ 1.4845; NMR 1.4 ppm (AB quartet for $H_{7a,s}$, J = 9 and 19 Hz, with differential small couplings which characterize the endo configuration).[8] *trans*-Diester **4a** was prepared from the *endo-cis*-ester **3a** by the method of Bauer and Nambury (75% yield, 97% purity):[14] bp 126 °C (11 mm); $n^{25}{}_D$ 1.4755; NMR 1.52 (AB quartet for $H_{7a,s}$), 2.6 (doublet for H_1 or H_4, J = 5 and 2 Hz), 3.0–3.5 [multiplet for H_2, H_3, and H_1 (or H_4)], 3.6 (singlet for one OCH_3), 3.72 (singlet for the other OCH_3), 6.15 (doublet and multiplet for CH═CH) ppm. **4a** was prepared from cyclopentadiene and dimethyl fumarate (63% yield, 93% purity) or in benzene solution at 50–76 °C for 4 h (87% yield, 90% purity). The diethyl ester **4b** was similarly prepared (90% yield, 98% purity): bp 139 °C (12 mm); $n^{25}{}_D$ 1.4461. Heating a sample of **3a** at 182–188 °C for 2 h gave about 10% isomerization to several other substances, but was not a suitable method for the preparation of *exo-cis*-diester, as it was for the anhydrides.[5] Monomethyl ester **3c**[15] and *trans*-diacid **4c**[16] were obtained by published procedures. Elemental analyses of all new compounds are listed in Table V.

Preparation of Dimethyl *exo*-6-Iodo-*exo*-5-*F*-alkyl-*endo*-2,*endo*-3-norbornanedicarboxylates (5a). (a) Azonitrile Initiation. 1-Iodo-*F*-octane (49.14 g, 90.0 mmol), **3a** (15.78 g, 75.0 mmol, 99% pure), and azobis(isobutyronitrile) (ABN, 0.492 g, 3.00 mmol) were charged to a Fischer-Porter pressure tube which was evacuated and filled with nitrogen at −78 °C. After heating at 70 °C for 15 min, during which time the tube was occasionally shaken, the two layer mixture became miscible. After 16.5 h at 70 °C the cloudy solution was poured and scraped out of the tube (63.76 g), mp 66–74 °C. A 1.00-g sample of **5a** was recrystallized from a carbon tetrachloride/ligroine mixture and gave 0.9 g in three fractions: all mp 84–86 °C; NMR 1.64 (doublet for H_{7a}), 2.45 (doublet for H_{7s}), 2.88–3.22 (broad peaking region for five protons, H_{2x}, H_{3x}, H_1, H_4, and H_{5n}), 3.66 and 3.72 (two singlets for nonequivalent OCH_3 groups), 4.63 (doublet of doublets for H_{6n}, $J_{6n,5n}$ = 8 Hz and $J_{6n,7a}$ = 3 Hz) ppm. $J_{6n,7a}$ was confirmed by irradiation of H_{7a} at 1.64 ppm. Reactions of **3a** with various iodo-*F*-alkanes are listed in Table III.

(b) Benzoyl Peroxide Initiation. 1-Iodo-*F*-octane (16.4 g, 30.0 mmol), **3a** (5.25 g, 25.0 mmol), and benzoyl peroxide (0.1000 g, 0.4219 mmol) were heated in an oil bath at 93 °C while stirring rapidly with a magnetic bar under nitrogen. As the mixture reached 85 °C the temperature shot up to 150 °C. The colorless solution turned pink in color and was quickly cooled in a bath of cold water. After 1 min the flask was returned to the oil bath at 108 °C and a sample was removed. GC analysis showed 1% of **3a**, 3% of an unknown at 11.2 min, 34% of **6a** at 18.3 min, and 58% of **5a** at 20.6 min. The isomers were separated by preparative TLC. From 5.106 g of mixture was obtained 0.7815 g (15.30%) of **6a** (R_f 6.0), 2.8723 g (56.25%) of **5a** (R_f 8.5), and 1.4523 g (28.44%) of a mixture of two new substances, probably **7a** and **8a**, according to NMR analysis. Thus, four OCH_3 peaks were observed and the CHI region (~4.00 ppm) gave two doublets of doublets, having relative areas of 2:1 and a total area of one proton.

(c) Ultraviolet Light Initiation. 1-Iodo-*F*-octane (16.4 g, 30.0 mmol), **3a** (5.26 g, 25.0 mmol), and 25 mL of ligroine (bp 60–70 °C) were charged to a mercury vapor ultraviolet light reactor, fitted with a reflux condenser and a nitrogen gas inlet at the bottom of the vessel.

Table V. Elemental Analyses

substance	R_F group	calcd, %				found, %			
		C	H	F	I	C	H	F	I
5a	$(CF_3)_2CF$	33.22	2.79	26.28	25.07	35.24	3.19	22.71	26.18
5a	$CF_3(CF_2)_3$	32.39	2.54	30.75	22.82	32.01	2.48	30.56	22.81
5a	$CF_3(CF_2)_5$	31.11	2.15	37.84	19.34	31.13	2.15	37.71	19.03
5a	$CF_3(CF_2)_7$	30.18	1.86	42.71	16.78	30.31	1.85	42.79	16.39
5c, 5d	$CF_3(CF_2)_5$	29.92	1.88	38.46	19.76	31.30	1.90	37.45	18.8
6a	$CF_3(CF_2)_7$	30.18	1.86	42.71	16.78	30.29	1.84	42.52	16.60
7a, 8a	$CF_3(CF_2)_5$	31.11	2.15	37.64	19.34	31.32	2.18	37.53	18.61
7a, 8a	$CF_3(CF_2)_7$	30.18	1.86	42.71	16.78	30.15	1.84	43.93	16.76
7b, 8b	$CF_3(CF_2)_7$	32.16	2.31	41.19	16.18	32.37	2.34	41.48	16.08
5b	$CF_3(CF_2)_7$	32.16	2.31	41.19	16.18	32.67	2.26	40.61	15.53
9a	$(CF_3)_2CF$	31.32	1.75	28.91	27.58	31.46	1.82	28.68	27.68
9b	$CF_3(CF_2)_3$	30.61	1.58	33.52	24.88	30.63	1.51	33.54	24.52
9c	$(CF_3)_2CFO(CF_2)_2$	29.18	1.40	36.28	22.03	29.21	1.43	36.23	22.13
9d	$CF_3(CF_2)_5$	29.53	1.32	40.48	20.80	29.75	1.30	40.84	20.53
9e	$CF_3(CF_2)_7$	28.75	1.13	45.48	17.87	28.65	1.06	45.49	17.74
10d	$CF_3(CF_2)_5$	29.53	1.32	40.48	20.80	29.59	1.11	40.98	20.49
10e	$CF_3(CF_2)_7$	28.75	1.13	45.48	17.87	28.79	1.18	45.31	17.86
6c/6d	$CF_3(CF_2)_7$	29.13	1.63	43.52	17.10	29.14	1.1	43.29	16.77
7c, 8c	$CF_3(CF_2)_7$	28.04	1.38	44.36	17.43	29.14	1.61	42.38	
8c	$CF_3(CF_2)_7$	28.04	1.38	44.36	17.43	28.15	1.41	44.14	
11a, 11b	$CF_3(CF_2)_7$	29.13	1.63	43.52	17.10	29.02	1.75	42.85	16.45
11c	$CF_3(CF_2)_7$	30.18	1.87	42.71	16.78	30.45	1.87	42.22	16.53
11d	$CF_3(CF_2)_7$	28.04	1.38	44.36	17.43	28.07	1.52	44.4	17.13
12b	$CF_3(CF_2)_3$	29.56	1.91	32.38	24.03	31.14	2.24	31.41	22.91
12c	$(CF_3)_2CFO(CF_2)_2$	28.30	1.70	35.18	21.36	28.9	1.65	34.80	21.19
12e	$CF_3(CF_2)_7$	28.04	1.38	44.36	17.43	28.05	1.26	43.84	17.04
13a	$CF_3(CF_2)_7$	33.90	1.84	53.63		33.80	1.56	54.09	
13b	$CF_3(CF_2)_7$	38.31	2.91	49.06		38.70	2.95	48.33	
13c	$CF_3(CF_2)_5$	38.50	2.85	46.58		38.51	2.83	46.38	
14a	$CF_3(CF_2)_5$	37.38	2.16	48.03		37.55	1.99	47.95	
14a	$CF_3(CF_2)_7$	35.19	1.80	52.58		35.07	1.84	52.34	
14b	$CF_3(CF_2)_7$	34.01	1.51	53.81		34.08	1.55	53.89	
15a	$CF_3(CF_2)_7$	36.32	2.09	51.41		36.21	2.22	51.06	
15b	$CF_3(CF_2)_7$	34.01	1.51	53.82		33.34	1.64	53.61	

The mixture was irradiated at ambient temperature (25–35 °C) for 15 h. A dark green colored solid precipitated in the lower part of the reactor to give 8.00 g (42% of theory), mp 82–87 °C, of **5a**. The filtrate was a mixture of mostly **3a** and a little **5a**.

Preparation of Dialkyl *endo,exo*-5-Iodo-*exo*-6-*F*-alkylnorbornane-*endo,exo*-2,*endo,exo*-3-dicarboxylates. Reactions of R_FI with half methyl ester **3a** and *trans*-diesters **4a** and **4b** are summarized in Table IV. The product from reaction of **3a** with R_FI was further reacted with thionyl chloride, and the acid chloride was treated with methanol (3 mol) and pyridine (1 mol) at 50 °C for 2 h. After being washed and dried, pure diester **5a** was isolated in 90% yield.

Addition of 1-Iodo-*F*-octane to 5-Norbornene-*endo*-2,*exo*-3-dicarboxylic Acid (4c). 1-Iodo-*F*-octane (13.65 g, 25.00 mmol), **4c** (3.64 g, 20.0 mmol, mp 186 °C), ethyl acetate (25 mL), and ABN (0.1200 g, 0.7000 mmol) were stirred by a magnet bar under nitrogen at 80 °C for 22 h. Unchanged **4c** was recovered (2.0364 g, mp 183–186 °C). Removal of volatile material and further evaporation gave 6.2312 g (97% of theory) of product mixture, melting range 104 to 180 °C. Recrystallization from ligroine (100 mL) and ethyl acetate (15 mL) gave pure **8c** (0.8971 g), mp 198–199 °C, and lower melting point fractions. NMR showed that the original mixture contained 10% of unchanged **4c** and equal parts of *exo*- and *endo*-6-iodo adducts. Adduct **8c** was the *endo*-iodo adduct in one of the two possible forms (*exo*- and *endo*-carboxyl groups).

Preparation of *endo*-6-Iodo-*exo*-5-*F*-alkyl-*exo*-2,*exo*-3-norbornanedicarboxylic Acid Anhydrides. (a) 10 (R_F = $CF_3(CF_2)_5$). A round-bottom flask was fitted with a nitrogen inlet, a reflux condenser, and a magnetic stirring bar and heated by an oil bath. 1-Iodo-*F*-hexane (17.84 g, 40.00 mmol), **2** (bp 139–142 °C, 4.10 g, 25.0 mmol), and benzoyl peroxide (0.200 g, 0.826 mmol) formed a clear solution at 110 °C. After 5.5 h unreacted 1-iodo-*F*-hexane was removed at the water pump and **10** was recrystallized from 50 mL of ligroine (bp 60–70 °C) to give three fractions (mp 69–71 °C), 14.62 g (95.84% of theory). An infrared spectrum gave absorption bands due to C=O at 1770 and 1790 cm^{-1}.

(b) 10 (R_F = $CF_3(CF_2)_7$). 1-Iodo-*F*-octane (16.4 g, 30.0 mmol), **2** (4.10 g, 25.0 mmol), and benzoyl peroxide (0.100 g, 0.413 mmol) were heated for 1.5 h at 105–112 °C. Unreacted 1-iodo-*F*-octane was removed by distillation at the water pump to give 17.78 g of adduct **10** (100% of theory), mp 105–110 °C. A 2.00-g portion of **10** was recrystallized from benzene, mp 111–113 °C. Heating the reaction mixture at 100–106 °C for 1 h using 0.164 g (1.00 mmol) of azobis(isobutyronitrile) as the initiator gave no reaction (two immiscible layers).

Preparation of *endo*-6-Iodo-*exo*-5-*F*-alkyl-*endo*-2,*endo*-3-norbornanedicarboxylic Acid Anhydrides. (a) R_F = $CF_3(CF_2)_7$ by Di-*tert*-butyl Peroxide Initiation. Anhydride **1** (8.21 g, 50.01 mmol), 1-iodo-*F*-octane (56.6 g, 104 mmol), and ABN (0.164 g, 1.00 mmol) under nitrogen were stirred by a magnet bar and heated to 75–98 °C in an oil bath. No reaction occurred in 1 h. The mixture was heated to 135 °C, and di-*tert*-butyl peroxide (0.32 g, 2.2 mmol) was added. An exothermic reaction occurred, and at 140 °C the solid dissolved. After 4 h at 140–142 °C, another 0.16-g portion of di-*tert*-butyl peroxide was added and the mixture was kept at 142 °C for 1 h. The solution became dark red in color. 1-Iodo-*F*-octane was removed [bp 70 °C (35 mm), 28.0 g], leaving 35.0 g (99% of theory) of **9**. Recrystallization from ligroine and ethyl acetate gave pure **9**, mp 157–159 °C.

(b) By Benzoyl Peroxide Initiation. Table I lists preparations of adducts **9** having various R_F groups, at 105–110 °C, using benzoyl peroxide initiation.

Hydrolysis of Anhydrides 9 and 10 to Diacids. (a) 11e (R_F = $CF_3(CF_2)_7$). Anhydride **10** (1.000 g, 1.41 mmol) and 10 mL of water were heated on a steam bath at 90 °C for 0.5 h. A thick paste formed; it was cooled to 20 °C and collected (1.00 g), mp 133–134 °C. The sample reverted to the anhydride (mp 113 °C) upon drying in an oven at 90 °C for 24 h. A Nujol mull gave a broad band at 1710 cm^{-1} for the carbonyl group.

(b) 12e (R_F = $CF_3(CF_2)_7$). Anhydride **9** (7.4036 g, 10.40 mmol), 75 mL of water, and 10.00 mL (60.00 mmol) of 6 N sodium hydroxide were heated for 6.0 h at 63–70 °C while being stirred. The clear alkaline solution was cooled, and the sodium salt precipitated as shiny flakes. The slurry was diluted with 75 mL of ethanol, heated to 55 °C, and acidified with 14.00 mL of 6 N HCl while being stirred. The precipitated paste was diluted further with 200 mL of water and collected. After being dried the solid diacid **12e** weighed 7.23 g (98.9% of theory), mp (sinter) 147 and 150–154 °C dec. It was recrystallized from 100 mL of benzene containing enough 95% ethanol to dissolve it at boiling (3.30 g), mp 167–168 °C dec. A second fraction, mp 165–166 °C dec, of 1.18 g was isolated and some lower melting material. The infrared spectrum showed a bonded OH and a strong band at 1700 cm^{-1} for the carbonyl group. In the NMR spectrum the proton resonance for the exo proton at C-6 appeared at 4.38 ppm as a doublet of doublets ($J_{6,1}$ = 3.2 Hz and $J_{6,5}$ = 8 Hz). Other NMR data are collected in Table II. Elemental analyses also showed that the iodine remained intact.

(c) 12b ($R_F = CF_3(CF_2)_3$). In the same way diacid **12b,** mp 189–190 °C, was isolated from a ligroine/ethyl acetate solution.

(d) 12c ($R_F = (CF_3)_2CFOCF_2CF_2$). Hydrolysis of the anhydride **9c** in an acetone/water solution gave **12c,** mp 168–175 °C.

Preparation of Dimethyl *endo*-6-Iodo-*exo*-5-*F*-octylnorbornane-2,3-dicarboxylates from the Anhydrides via the Mono Ester and Acid Chloride. (a) *exo*-Esters 11a–c from *exo*-Anhydride 10. Anhydride **10** (7.10 g, 10.0 mmol) and methanol (30 mL, 24 g, 740 mmol) were heated at reflux for 18 h, and the excess methanol was removed by distillation. The products **11a** and **11b** were a gummy solid: NMR, 4.35 ppm (doublet of doublets, H_{6x}, J = 6.2 and 4 Hz); IR showed carbonyl stretching at 1735 and 1710 cm^{-1} for the ester and acid, respectively. Thionyl chloride (29 mL, 37.5 g, 320 mmol) was added, the mixture was kept at 59–68 °C for 2.5 h, and excess thionyl chloride was pumped away: IR showed a carbonyl stretching at 1790 and 1740 cm^{-1} for the acid chloride and ester, respectively. Methanol (20 mL, 15.8 g, 500 mmol) was added, and the solution was heated under reflux for 16 h. Removal of excess methanol gave dimethyl ester **11c:** 7.0 g (93% of theory); mp (sinter) 53 and 54–57 °C (Fisher-John's block); IR showed a carbonyl stretch at 1735 cm^{-1} and bands differing from **5a;** NMR 1.76 (H_{7s} coupled to H_{2n}), 2.17 (H_{7a}, broadened doublet), 2.40 (H_{5n}, multiplet), 2.83 (H_1, H_4, and H_{3n}, broadened multiplets), 3.50 (H_{2n}, doublet of doublets, $J_{2n,3n}$ = 10.0 Hz and $J_{2n,7s}$ = 1.5 Hz), 4.34 (H_{6x}, doublet of doublets, $J_{6x,5n}$ = 6 Hz and $J_{6x,1}$ = 4 Hz), 3.68 (singlet for two equivalent OCH_3 groups) ppm.

The NMR spectrum of **11b** showed proton resonance for H_{7s} at 1.77 ppm (doublet), for H_{7a} at 2.17 ppm (doublet), for H_{5n} at 2.40 ppm (multiplet), broad overlapping peaks at 2.84 ppm for three protons (H_1, H_4, and H_{3n}), for H_{2n} at 3.56 ppm (doublet, J = 9 Hz), for H_{6x} at 4.35 ppm (doublet of doublets, $J_{6x,5n}$ = 6.2 Hz, and $J_{6x,1}$ = 4 Hz), for OCH_3 at 3.70 ppm (singlet), and for COOH at 9.59 ppm (broad singlet). The NMR spectrum of **11c** was nearly identical with that of **11b,** without the COOH resonance.

(b) *endo*-Esters 6c/6d and 6a from *endo*-Anhydride 9. Using anhydride **9** (7.10 g, 10.0 mmol) and the same procedure, as above, pure isomer **6c** or **6d,** mp 172–174 °C, was obtained (100% of theory): IR showed carbonyl bands at 1755 and 1705 cm^{-1}; NMR showed a single OCH_3 resonance at 3.58 ppm, H_{6x} at 4.38 ppm, and a doublet of doublets as in **6a.** The diester **6a** (8.04 g; mp 82–90 °C; IR 1735 cm^{-1} band only) was recrystallized from ligroine (25 mL) and methanol (2 mL): mp 90–93 °C; NMR 1.40 (H_{7a}, doublet), 1.86 (H_{7s}, doublet), 2.83 (singlet for H_4), 2.90 (H_{2x} or H_{3x}, dd with arms hidden in the 2.90- and 3.06-ppm signals), 3.06 (H_1, triplet poorly resolved), 3.41 [H_{3x} or H_{2x}, dd, $J_{2x,3x}$ = 11 Hz and $J_{2x,1}$ = 4.2 ppm (decoupling would indicate the signal to be H_{2x}, but not unequivocally)], 3.90 (H_{5n}, multiplet), 4.31 (H_{6x}, dd, $J_{6x,5n}$ = 8 Hz and $J_{6x,1}$ = 3.6 Hz), 3.72 and 3.77 (two singlets for nonequivalent OCH_3 groups) ppm.

Reduction of *endo*-6-Iodo-*exo*-5-*F*-octylnorbornane-*endo*-2,*endo*-3-dicarboxylic Anhydride (9) to *exo*-5-*F*-Octylnorbornane-*endo*-2,*endo*-3-dicarboxylic Acid (13). Zinc (Baker's, 30 mesh, 3.00 g, 46.0 mmol), water (75 mL), hydrochloric acid (20 mL, concentrated 12 M), ethanol (20 mL), and **9** (16.7 g, 23.5 mmol) were stirred and heated near the boiling point for 2 h; during this time two further additions of zinc (3.00 g) were made. Hydrochloric acid (12 M, 6 mL) and ethanol (100 mL) were added to give a clear, colorless solution, which was kept near boiling for 1 h. The solution was decanted into water (200 mL), extracted with ether (three times, 25 mL), dried over $MgSO_4$, and evaporated off to a gummy solid, 17.3 g (100% of theory). The impure ester was hydrolyzed in ethanol (75 mL) containing sodium hydroxide (2.00 g, 50.0 mmol) and water (10 mL) by heating for 4 h at 58–63 °C, acidified with hydrochloric acid (6 N, 10.0 mL), and poured into water (300 mL). The precipitated solid **13** was dried to give 13.62 g (96% of theory), mp 152–161 °C; a small portion recrystallized from a benzene/alcohol solution gave pure *exo*-5-*F*-octylnorbornane-*endo*-2,*endo*-3-dicarboxylic acid (**13**)**:** 1.00 g; mp 166–167.5 °C (gas, dec). A lower melting impure product (1.87 g) was obtained from the filtrate.

Lactone 14a by Heating Dimethyl Ester 5a. In a flask fitted with a condenser leading to a dry ice cooled trap was placed **5a** (73.8 g, 97.7 mmol), and the flask was evacuated to 20 mm at the water pump. The flask was heated to 171 °C in an oil bath and stirring by a magnet bar gave a smooth evolution of iodomethane during 2 h at 170–174 °C (9.8 g, 71%). The residue (61.52 g, 100%) was dissolved in benzene (400 mL), treated with decolorizing carbon, and gave **14a** in three fractions [45.54, 5.37, and 1.82 g (87.8%)], mp 127–127.5 and 125–127 °C. The residue contained **5a** and **14a** by NMR analysis. An IR spectrum of **14a** gave carbonyl bands at 1725 and 1780 cm^{-1} (ester and lactone, respectively); NMR gave proton resonances in dimethyl-d_6 sulfoxide at 1.84 (collapsing AB pattern for H_{7a} and H_{7s}, with lines broadened by small interaction with H_1, H_4, and H_{5n}), 3.55 (a multiplet for H_1 coupled to H_{6x} (shown by double irradiation) and to H_{2x} and other small interactions), 2.80–3.52 (series of multiplets for H_4, H_{2x}, H_{3x}, and H_{5n}, four proton area), 3.64 (sharp singlet for OCH_3), and 5.06 (doublet for H_{6x} coupled to H_1, J = 5 Hz) ppm. That H_{5n} was not coupled to H_{6x} probably can be explained by an unfavorable dihedral angle caused by additional strain imposed on the bicyclic ring system by the lactone ring. The dihedral angle (from an examination of models) appears to be about 100° instead of the usual 130°.

Conversion of Lactone Ester 14a to Lactone Acid 14b. To a solution of sodium hydroxide (1.2 g, 30 mmol) in water (2 mL) and methanol (18 mL) was added **14a** (5.34 g, 8.69 mmol), and the mixture was heated at 60–85 °C for 3 h. Acetic acid (15 mL) was added, and the mixture was diluted with water (25 mL). The precipitated sodium salt (4.36 g, 83.6%) was suspended in 95% ethanol (70 mL), 3 mL of 2 N HCl was added at the boil, and the mixture was filtered. The cool, clear solution gave **14b** (1.89 g), mp 174–175 °C. Crystal fractions of 1.761 and 0.463 g (total recovery, 79%) of lower melting point material were isolated: IR (Nujol mull) showed 1780–1740 cm^{-1}. An NMR spectrum (dimethyl-d_6 sulfoxide) at 100 MHz gave resonances at 1.56 (doublet for H_{7a}, J = 12 Hz, arms broadened somewhat by interactions with H_1, H_4, and H_{5n}), 1.86 (doublet for H_{7s} coupled to H_{7a}), 3.34 (triplet for H_1, $J_{1,6n}$ = 4.4 Hz, spin decoupled at 5.00 ppm), 2.6–3.2 (complex of lines for H_2, H_{3x}, H_4, and H_{5n}), 4.97 (doublet for H_{6x}, $J_{6x,1}$ = 4.4 Hz), and 13.0 (broadened singlet for COOH) ppm.

Preparation of *endo*-6-Iodo-*exo*-5-*F*-octylnorbornane-*endo*-2,*endo*-3-dicarboxylate (6a). *endo*-Anhydride **9** gave the half-ester by reaction with methanol and the dimethyl ester **6a** by subsequent treatment with thionyl chloride, followed by methanol as above with anhydride **10.** The product **6a,** mp 78–83 °C, obtained in 87% yield, was recrystallized from ligroine and methanol, mp 90–93 °C. An IR spectrum showed bands at 1745 and 1750 cm^{-1}. The NMR spectrum gave proton resonances for H_{7a} at 1.40 ppm (doublet), for H_{7s} at 1.86 ppm (doublet), for H_4 at 2.83 ppm (broadened singlet), for H_{3x} at 2.90 ppm (doublet of doublets), for H_{3x} at 3.41 ppm (doublet of doublets, $J_{2x,3x}$ = 11 Hz and $J_{2x,1}$ = 4.2 Hz), for H_{5n} at 3.90 ppm (complex multiplet), and for H_{6x} at 4.31 ppm (doublet of doublets, $J_{6x,5n}$ = 8 Hz and $J_{6x,1}$ = 3.6 Hz).

Thermal Treatment of *endo*-Iodo Ester 6a but No Lactone Formation. Ester **6a** (5.00 g, 6.61 mmole) in a flask was heated at 170–180 °C and 20 mm pressure for 2 h. The sample darkened but there was no loss in weight, and an IR spectrum gave only the 1735-cm^{-1} band. The lactone band at 1780 cm^{-1} was missing, and more than 20 bands of **6a** were present.

Methyl *exo*-5-*F*-Octylnortricyclene-*endo*-3-(methoxycarbonyl)-2-carboxylate (15a). 5a (15.13 g, 18.00 mmol, contained about 10% of **6a**) was suspended in methanol (50 mL) and stirred by a magnet bar in an oil bath at 40 °C. As sodium methoxide (1.222 g, 21.00 mmol) was added the clear solution gave a thick precipitate. After 5 h at 40 °C, the mixture was allowed to stand for 15 h at 25 °C and slurried with 35 mL of chloroform and 25 mL of water and 5 mL of 6 N HCl were added. The aqueous layer was extracted twice with 15 mL of chloroform, in turn with dilute bisulfite solution, and dried over $MgSO_4$. The chloroform solution was evaporated off to a soft solid, 13.56 g (100%). Analysis by NMR showed **6a** (10%, CHI signal at 4.42 ppm), an olefinic compound, perhaps **3a** or a new product from **5a** (5%), and **15a** (85%). GC analysis run under the conditions used to separate **5a** and **6a** gave the following: 14.4 min, 1.3%; 17.9 min, 83.9% of **15a;** 18.4 min, 3.4%; 19.2 min, 1.7%; and 21.7 min, 5.3%. The product (10.36 g), recrystallized from carbon tetrachloride (50 mL), gave 0.5384 g of **15a,** mp 79–82.5 °C. Ligroine (25 mL, bp 70 °C) was added to the filtrate (25 mL) and gave 5.0 g of **15a,** mp 77–80 °C. Successive crystal fractions totalling 7.20 g were obtained. Recrystallization of **15a** (1.00 g) from 20 mL of ligroine (bp 60–70 °C) gave 0.640 g, mp 83.5–84.5 °C. Infrared bands (Nujol mull) at 3120, 3095, 1745, and 1735 cm^{-1} were noted; other bands not in **5a** were 1082, 1030, 990, 975, 890, and 760 cm^{-1}. A KBr pellet gave bands at 3120, 3020, 2960, 1735, and 1720 cm^{-1}; deformation and other vibrations appeared at 1449, 1435, 1370, 1350, 1320, 1310, and 1250–1100 cm^{-1} and at 1095, 1080, 1050, 1040, 1020, 1010, 990, 970, 942, 925, 882, 865, 795, 770, 758, 700, 685, 645, and 625 cm^{-1}. NMR gave proton resonances at 1.61 and 2.05 ppm for $H_{7a,s}$ (doublets with arms broadened), at 2.15 ppm for H_1 (or H_6) and 2.41 ppm (both doublets, $J_{1,6}$ = 5 Hz, with fine splitting), at 2.60 ppm for H_4, at 2.87 ppm for H_3 (singlet), and at 2.97 ppm for H_5 (doublet of doublets with large coupling to

***exo*-5-*F*-Octylnortricyclene-2,*endo*-3-dicarboxylic Acid (15b).** To a stirred solution of sodium hydroxide (1.70 g, 40.0 mmol) in ethanol (40 mL, 90%) at 60 °C was added **5a** (8.00 g, 9.52 mmol, 90%, in 10 mL of ethanol), and the mixture was kept at 50–60 °C for 3 h. Solid **15b** was precipitated in water (100 mL) and hydrochloric acid (0.10 mol), redissolved in base, extracted with ether, reprecipitated with acid, collected, washed, and air-dried to give 4.42 g (82%), mp 132–142 °C. Recrystallization from acetone (20 mL) and benzene (20 mL) gave **15b** (2.34 g), mp 157–158 °C, and subsequent fractions of lower and higher melting point. However, infrared spectra of these materials did not differ from those of pure **15b**. An NMR spectrum gave resonances at 1.76 (AB quartet for $H_{7a,s}$), 2.13 (AB quartet for H_1 and H_6), 2.50 (singlet for H_4), 2.80 (broadened singlet for H_3), 2.99 (doublet of doublets for H_5), and 12.38 (broad resonance for $(COOH)_2$) ppm.

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Registry No.—**1**, 129-64-6; **2**, 2746-19-2; **3a**, 39589-98-5; **3b**, 7288-32-6; **3c**, 4883-79-8; **4a**, 3014-58-2; **4b**, 26272-67-3; **4c**, 1200-88-0; **5a** ($R_F = (CF_3)_2CF$), 69653-62-9; **5a**, ($R_F = CF_3(CF_2)_3$), 69653-63-0; **5a** ($R_F = CF_3(CF_2)_5$), 69653-64-1; **5a** ($R_F = CF_3(CF_2)_7$), 69685-73-0; **5b** ($R_F = CF_3(CF_2)_7$), 69653-65-2; **5c** ($R_F = CF_3(CF_2)_5$), 69653-66-3; **5c** ($R_F = CF_3(CF_2)_7$), 69685-74-1; **5d** ($R_F = CF_3(CF_2)_5$), 69686-92-6; **6a** ($R_F = (CF_3)_2CF$), 69685-75-2; **6a** ($R_F = CF_3(CF_2)_3$), 69653-67-4; **6a** ($R_F = CF_3(CF_2)_5$), 69685-76-3; **6a** ($R_F = CF_3(CF_2)_7$), 69685-77-4; **6c** ($R_F = CF_3(CF_2)_7$), 69685-78-5; **6d** ($R_F = CF_3(CF_2)_7$), 69685-79-6; **7a** ($R_F = CF_3(CF_2)_5$), 69685-80-9; **7a** ($R_F = CF_3(CF_2)_7$), 69685-81-0; **7b** ($R_F = CF_3(CF_2)_7$), 69685-82-1; **7c** ($R_F = CF_3(CF_2)_7$), 69685-83-2; **8a** ($R_F = CF_3(CF_2)_5$), 69685-84-3; **8a** ($R_F = CF_3(CF_2)_7$), 69685-85-4; **8b** ($R_F = CF_3(CF_2)_7$), 69685-86-5; **8c** ($R_F = CF_3(CF_2)_7$), 69685-87-6; **9a**, 69686-95-9; **9b**, 69686-96-0; **9c**, 69653-68-5; **9d**, 69653-50-5; **9e**, 69653-51-6; **10d**, 69744-59-8; **10e**, 69685-71-8; **11a** ($R_F = CF_3(CF_2)_7$), 69653-52-7; **11b** ($R_F = CF_3(CF_2)_7$), 69653-53-8; **11c** ($R_F = CF_3(CF_2)_7$), 69653-54-9; **11e** ($R_F = CF_3(CF_2)_7$), 69653-55-0; **12b**, 69653-56-1; **12c**, 69686-97-1; **12e**, 69685-72-9; **13a** ($R_F = CF_3(CF_2)_7$), 69667-92-1; **13b** ($R_F = CF_3(CF_2)_7$), 69686-98-2; **13c** ($R_F = CF_3(CF_2)_5$), 69667-93-2; **14a** ($R_F = CF_3(CF_2)_5$), 69653-57-2; **14a** ($R_F = CF_3(CF_2)_7$), 69653-58-3; **14b** ($R_F = CF_3(CF_2)_7$), 69653-59-4; **15a** ($R_F = CF_3(CF_2)_7$), 69653-60-7; **15b** ($R_F = CF_3(CF_2)_7$), 69653-61-8; $CF_3(CF_2)_7I$, 507-63-1; $CF_3(CF_2)_5I$, 355-43-1; $CF_3(CF_2)_3I$, 423-39-2; $(CF_3)_2CFI$, 677-69-0.

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Influence of the Heteroatom in the Addition of BH_4^- to the Carbonyl Group in Amino and Thio 4-Ketones

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The nucleophilic addition reaction of BH_4^- has been studied in the case of heterocyclic ketones such as various substituted 4-piperidones (1-methyl, 1-ethyl, 1-*tert*-butyl, 2,6-diphenyl, 3-methyl-2,6-diphenyl, 3,5-dimethyl-2,6-diphenyl and the corresponding 1-methyl compounds, and 2,2,6,6-tetramethyl), 4-tetrahydrothiopyranone, and aliphatic compounds [(dimethylamino)acetone, 4-(dimethylamino)-2-butanone, and 4-(dimethylamino)-3-methyl-2-butanone]. The kinetic results show, for example, an acceleration of 6.2 and 11.2 by N and S in the 4 position compared to the reactivity of the cyclohexanone. On the other hand, throughout this series the replacement of NH by NCH_3 causes an increase of 1.6 in the ratio of rate constants.

The participation of heteroatoms in reactions which occur across a ring or further along a chain has been the subject of numerous studies.[1–13] As part of our continuing studies[13–16] of the mechanism of the nucleophilic addition at carbonyl carbons, we investigated cases in which heteroatom (N or S) participation in the nucleophilic addition reaction is possible. As models we chose substituted 4-piperidones, for which stereochemical analyses have been reported,[17–20] 4-tetrahydrothiopyranone, and aliphatic ketones which contain nitrogen in the chain.

Results and Discussion

The results are given in Tables I, II, and III.

Heteroatom Effect. We found that the presence of the heteroatom increases the reactivity of the 4-piperidones and of 4-tetrahydrothiopyranone relative to the corresponding cyclanones. It is assumed that all ketones react in the same conformation:[10–12] $k_7/k_1 = 11.2$, $k_3/k_1 = 6.2$, $k_6/k_2 = 5.5$, and $k_{10}/k_9 = 5.6$.

In the case of substrates **3**, **6**, **7** (preferential axial attack) and **10** (preferential equatorial attack), the difference in reactivity may be attributed to a transannular dipolar "through space effect" which destabilizes the ground state because of the interaction of partial positive charges, but which stabilizes the transition state where the reacting carbon goes from sp^2 to sp^3 and carries a partial negative charge[16] (Chart I).

This explanation is equally valid for the aliphatic compounds, but in this case the ratio of the rate constants is lower, $k_{18}/k_{16} = 3.2$, presumably because here only inductive effects are possible.

If we go from cyclic to aliphatic compounds, the ratio of the rate constants decreases dramatically, from 88.0 to 0.17 in cases **4** and **18** (Chart II). The effect of the heteroatom is much less pronounced in the aliphatic series because rotation of the