Regiospecific preparation of α,α-dihalofluoromethyl perfluoroalkyl ketones via halogenation of perfluoro betaines

Donald J. Burton* and In Howa Jeong†
Department of Chemistry, University of Iowa, Iowa City, IA 52242 (USA)

(Received June 20, 1992; accepted September 11, 1992)

Abstract

Acylation of fluorinated phosphoranium salts with perfluorinated acyl chlorides provided the corresponding (*Z*)-perfluoro betaines in high yield. Subsequent chlorination or bromination of the betaines regiospecifically yields the α,α-dihalofluoromethyl perfluoroalkyl ketones. Halogen specificity is best controlled via use of $CFCl_3/Cl_2$ for the preparation of dichloroketones and $CFBr_3/Br_2$ for the corresponding dibromoketones. The dihalophosphorane by-product can promote a halogen-exchange reaction with ketones.

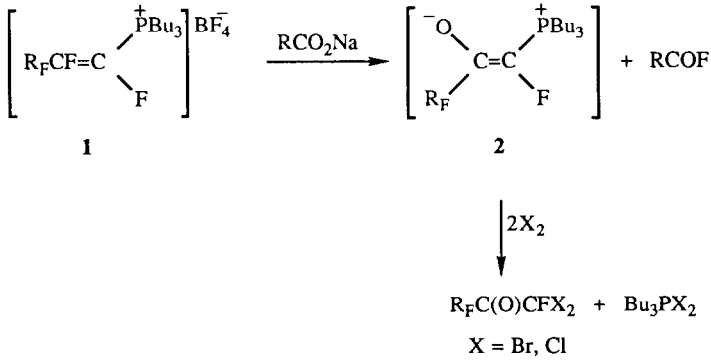
Introduction

Since the Favorskii rearrangement was discovered in 1894, there has been continued interest in the chemistry of halogenated carbonyl compounds. The past two decades have seen a considerable expansion in synthetic procedures and mechanistic studies dealing with α-halogenated ketones [2]. Most notably, the use of enolates [3], which can be derived from the α-halogenated ketones [3], has made a significant impact in synthetic organic chemistry. However, generation [4, 5] and utilization [4–11] of polyfluorinated enolates in organofluorine chemistry has been quite limited because of the lack of general methods for the preparation of suitable polyfluorinated enolate precursors.

Recently, we were interested in the preparation of α,α-dihalofluoromethyl perfluoroalkyl ketones which are potential synthetic intermediates to enol phosphates, enol phosphonium salts, enol silyl ethers and enol acetates. However, there are only limited reports on the synthesis of α,α-dihalofluoromethyl perfluoroalkyl ketones, and these methods either lack regiospecificity [12, 13], utilize expensive [14] or toxic reagents [15], and lack generality [12–15]. Previous work in our laboratory [16] has shown that fluorinated betaines **2**, prepared from vinyl phosphonium salts **1** were readily cleaved by halogen to give α,α-dihalofluoromethyl ketones [16].

*Author to whom all correspondence should be addressed.
†For a preliminary account, see ref. 1.

0022-1139/93/$6.00



This early work involved several steps to obtain **2**, and we sought an easier, more direct route to **2**.

We now report that betaines **2** can be easily prepared by the acylation of fluorinated phosphoranium salts. This reaction provides a general route to α,α-dihalofluoromethyl perfluoroalkyl ketones because of the availability of a wide variety of perfluorinated acyl chlorides.

Results and discussion

The fluorinated phosphoranium salt **3** can be easily prepared in 90–95% ^{19}F NMR spectroscopic yield from the reaction of tri-n-butylphosphine with fluorotrichloromethane or with fluorotribromomethane. A recent report [17] from our laboratory detailed the synthesis of the fluorinated phosphoranium salts and the mechanism of their formation. Among the several solvent systems (methylene chloride, benzonitrile and *o*-chlorotoluene), benzonitrile which is doubly distilled from phosphorus pentoxide was found to be the most useful solvent both for the preparation of **3** as well as for the formation of the betaines.

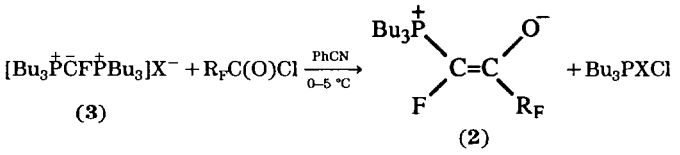
$$3Bu_3P + CFX_3 \xrightarrow[0\text{–}5\ ^\circ C]{PhCN} [Bu_3\overset{+}{P}\overset{-}{C}F\overset{+}{P}Bu_3]X^- + Bu_3PX_2$$

(X = Br, Cl) **(3)**

The acylation of the fluorinated phosphoranium salt **3** with a wide variety of perfluorinated acyl chlorides, which are readily generated from the reaction of the commercially available acids with benzoyl chloride [18] or phosphorus pentachloride [19], is rapid, clean and gives high yields. The results of the acylation are summarized in Table 1. Contrary to the reaction with non-fluorinated acyl chlorides [20], which provides the doubly acylated phosphonium salt, reaction with perfluoroacylchlorides gave only **2**. This result indicates that **2**, when $R = R_F$, is less nucleophilic towards the acyl chloride than **2**, when $R = R_H$.

TABLE 1

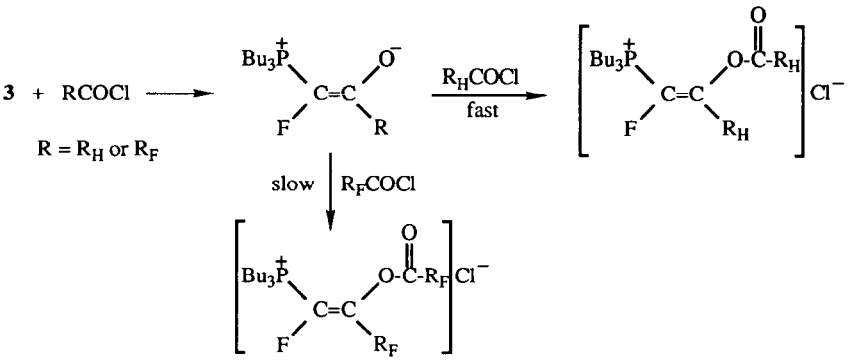
^{19}F NMR yields of (*Z*)-perfluoro betaines



(3) (2)

R_F	Yield (%)[a]	
	X = Br[b]	X = Cl[b]
CF_3	85	90
CF_2Cl	72	70
CF_3CF_2	87	91
$CF_3CF_2CF_2$	90	91
$CF_3(CF_2)_5CF_2$	–	90

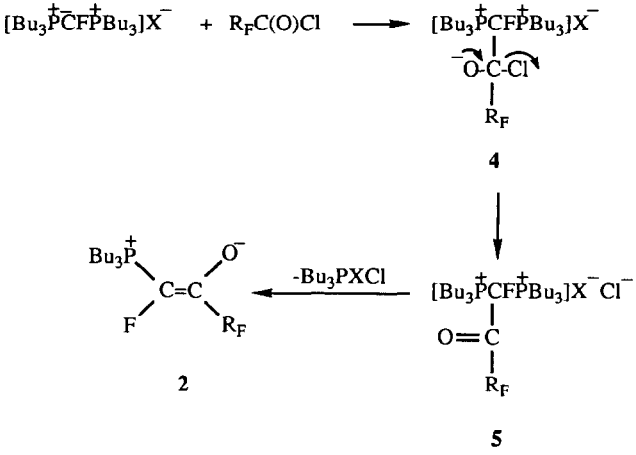
[a]Yields determined by ^{19}F NMR analysis relative to C_6F_6.
[b]Overall yield based on $R_FC(O)Cl$.



The stereochemistry of **2** was assigned as *Z* based on the magnitude of the J_{F,CF_2} coupling constant ($J = 18$–29 Hz) in the ^{19}F NMR spectrum of the betaines, similar to that for (*Z*)-fluoro-olefins ($J_{F,CF_2} = 20$–27 Hz) and greater than for (*E*)-fluoro-olefins ($J_{F,CF_2} = 7$–12 Hz).

The proposed mechanism (Scheme 1) of betaine formation involves initial attack on the perfluorinated acyl chloride by the carbanionic center of the fluorinated phosphoranium salt to produce the intermediate **4**, which quickly collapsed to the β-keto-bis-phosphonium salt **5**. Subsequent attack by halide ion on salt **5** results in the formation of betaine and dihalophosphorane.

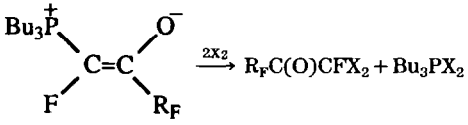
Treatment of 1 equiv. of **2** with 2 equiv. of halogen results in the formation of the α,α-dihalofluoromethyl perfluoroalkyl ketones and dihalophosphorane.



Scheme 1. Mechanism of betaine formation.

TABLE 2

Yields of α,α-dihalofluoromethyl perfluoroalkyl ketones



Product	R_F	X	Yield (%)[a]
6	CF_3	Cl	68(41)
7	CF_2Cl	Cl	56(40)
8	CF_3CF_2	Cl	72(60)
9	$CF_3CF_2CF_2$	Cl	75(62)
10	$CF_3(CF_2)_5CF_2$	Cl	[b](56)
11	CF_3	Br	68(42)
12	CF_2Cl	Br	60(30)
13	CF_3CF_2	Br	77(52)
14	$CF_3CF_2CF_2$	Br	79(53)

[a]Yield determined by ^{19}F NMR analysis relative to C_6F_6; yield in parentheses is the isolated yield based on acyl chloride.
[b]Product was not entirely soluble in the reaction mixture; ^{19}F NMR yield not determined.

$$\mathbf{2} + 2X_2 \longrightarrow R_FC(O)CFX_2 + Bu_3PX_2$$

The ketones were isolated in high purity by flash-distillation under reduced pressure followed by fractional distillation. These results are summarized in Table 2. Although the perfluorinated acyl chlorides function well in the preparation of both dichloro- and dibromo-ketones, halogen specificity is best controlled via the use of $CFCl_3/Cl_2$ for the preparation of dichloroketones

and $CFBr_3/Br_2$ for the corresponding dibromoketones. Otherwise, in the preparation of the fluorinated phosphoranium salt from $CFCl_3$, the dichlorophosphorane by-product can promote halogen-exchange reactions to give mixed halogen products on subsequent bromination. For example, reaction of the fluorinated phosphoranium salt generated from $CFCl_3$ with perfluorobutanoyl chloride followed by treatment with Br_2 provided three different ketones(**14**/**15**/**9** = 53:27:20) in 74% ^{19}F NMR spectroscopic yield.

$$[Bu_3\overset{+}{P}C\overset{-}{F}\overset{+}{P}Bu_3]Cl^- + Bu_3PCl_2$$

$$\downarrow \begin{array}{l}(1)\ C_3F_7C(O)Cl \\ (2)\ 2Br_2\end{array}$$

$$C_3F_7C(O)CFBr_2 + C_3F_7C(O)CFBrCl + C_3F_7C(O)CFCl_2$$

(14) **(15)** **(9)**

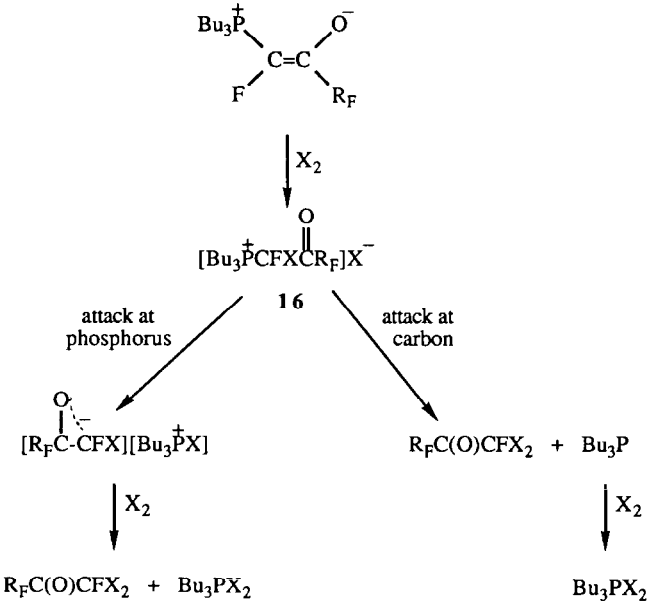
It is well known that the dichlorophosphorane can supply chloride ion via the following equilibrium [21]:

$$Bu_3PCl_2 \rightleftharpoons [Bu_3\overset{+}{P}Cl]Cl^-$$

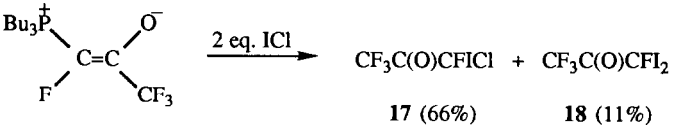
Thus, the chloride ion could attack at the α-brominated carbon atom of the ketone to provide the α-chlorinated ketone via a nucleophilic substitution reaction. In a control experiment, reaction of 1,1-dibromoperfluoro-2-pentanone (**14**) with excess LiCl in triglyme (TG) gave 1-bromo-1-chloroperfluoro-2-pentanone (**15**) and 1,1-dichloroperfluoro-2-pentanone (**9**) (**15**/**9** = 25:75) in 95% ^{19}F NMR spectroscopic yield after 24 h at room temperature.

$$\underset{\textbf{(14)}}{C_3F_7C(O)CFBr_2} \xrightarrow[\substack{TG \\ 24\ h}]{LiCl} \underset{\textbf{(15)}}{C_3F_7C(O)CFBrCl} + \underset{\textbf{(9)}}{C_3F_7C(O)CFCl_2}$$

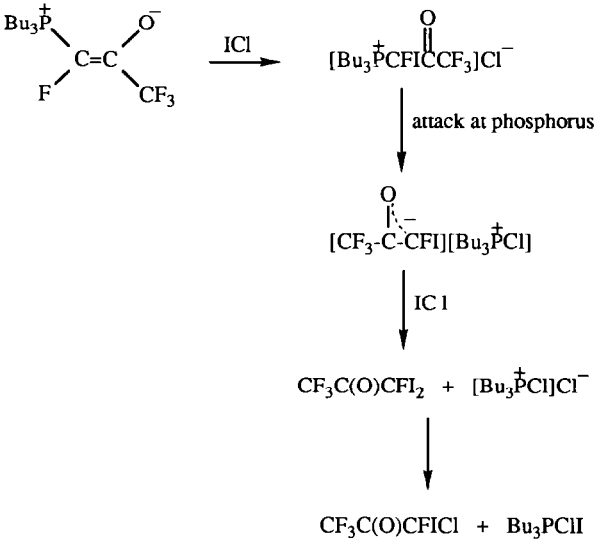
A mechanistic interpretation of the halogenation reaction is outlined in Scheme 2. In the initial step, halogen reacts with **2** to give the β-ketophosphonium salt **16**. The salt **16** may provide α,α-dihalofluoromethyl perfluoroalkyl ketone via two possible pathways. One route is attack of the halide ion at the phosphorus atom to form the halophosphonium enolate which captures a positive halogen from the second mole of elemental halogen. The other pathway is attack of the halide ion at the carbon atom adjacent to the phosphorus atom to produce the ketone plus tri-n-butylphosphine, which further reacts with the second mole of elemental halogen to produce dihalophosphorane. However, the possibility of the latter pathway can be ruled out from the reaction between betaine **2** and ICl [16], in which the formation of 1,1-diiodoperfluoropropanone (**18**) can be achieved only by attack of the halide ion at the phosphorus atom rather than at the carbon atom adjacent to the phosphorus.



Scheme 2. Mechanism of formation of dihalofluoromethyl perfluoroalkyl ketones.



The formation of 1-chloro-1-iodoperfluoropropanone (**17**) is ascribed to halogen exchange between 1,1-diiodoperfluoropropane and the chloride ion produced from the dichlorophosphorane.



In conclusion, this newly developed method provides a general and high yield preparation of α,α-dihalofluoromethyl perfluoroalkyl ketones. The reaction is carried out under mild conditions and with controlled regiochemistry. In addition, all reagents* and transient intermediates can be prepared from readily available commercial materials*. Also, it was found that the α,α-dibromofluoromethyl perfluoroalkyl ketones would undergo a halogen-exchange reaction with the chloride ion.

Experimental

NMR spectra were recorded on a JEOL FX 90-Q multinuclear spectrometer in $CDCl_3$, CCl_4 or C_6H_5CN. ^{19}F NMR spectra were obtained at an operating frequency of 84.26 MHz with $CFCl_3$ as an internal reference. ^{31}P NMR spectra were recorded at 36.20 MHz with 85% H_3PO_4 as an external reference. ^{31}P NMR spectra were broadband decoupled from hydrogen nuclei. IR spectra were obtained on a Beckman Acculab 8 grating IR spectrometer. Mass spectra were obtained on a Hewlett-Packard 5985 GC/MS system at 70 eV. GLPC analysis were performed on a Hewlett-Packard model 5830A gas chromatograph with helium as the carrier gas. The column used was a 3% OV-101, 2 mm i.d. × 6 ft. Boiling points were obtained during distillation using a partial immersion thermometer and are uncorrected.

General procedure for the preparation of the perfluorinated betaines **2**

A 500 ml three-neck round-bottom flask equipped with a stopper, septum, magnetic stir bar and a Dry Ice/isopropyl alcohol condenser connected to a source of nitrogen was charged with dry tri-n-butylphosphine and benzonitrile. The reaction mixture was cooled to 0–5 °C with an ice/water bath. To the cold solution, trihalofluoromethane was added via a cooled syringe in one portion (or dropwise for tribromofluoromethane). The reaction mixture was stirred at 0–5 °C for 1 h and then at room temperature for 3 h to produce the fluorinated phosphoranium salt. The reaction mixture was then cooled to 0–5 °C with an ice/water bath. The perfluorinated acyl chloride was added via a cooled syringe (if the perfluorinated acyl chlorides were liquid at room temperature) or by evaporation from a 15 ml graduated tube after measurement (if the perfluorinated acyl chlorides were gaseous at room temperature). After the solution was stirred at 0–5 °C for 0.5 h and at room temperature for 0.5–1 h, the betaines were obtained. The ^{19}F and ^{31}P NMR data of **2** are tabulated in Table 3.

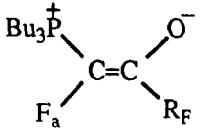
Preparation of 1,1-dichloroperfluoropropanone (**6**)

The fluorinated phosphoranium salt was prepared from tri-n-butylphosphine (60.6 g, 300 mmol) and trichlorofluoromethane (13.7 g, 100 mmol)

*Bu_3P, $CFCl_3$, $CFBr_3$ and several perfluoroacyl chlorides are available from Aldrich, PCR or Fluorochem. Ltd. $CFBr_3$ can also be easily prepared from CBr_4 (Aldrich) via the literature method [22].

TABLE 3

^{19}F and ^{31}P NMR data for **2**



R_F	^{19}F NMR											^{31}P NMR	
	δ (ppm)							J (Hz)				δ (ppm)	J_{PF} (Hz)
	a	b	c	d	e	f	g	FP	ab	ac	bd		
$\underset{b}{CF_3}$	−220.1	−71.1						47.7	18.3			22.6	46.9
$\underset{b}{CF_2Cl}$	−216.3	−58.0						47.7	22.0			23.0	46.9
$\underset{b\ c}{CF_2CF_3}$	−217.1	−120.2	−82.4					44.0	29.3	7.3		23.3	46.9
$\underset{b\ c\ d}{CF_2CF_2CF_3}$	−216.6	−118.0	−127.1	−80.2				51.3	29.3	11.0	11.0	23.3	46.9
$\underset{b\ c\ d\ e\ f\ g}{CF_2CF_2CF_2(CF_2)_2CF_2CF_3}$	−216.5	−117.1	−121.6		(−122.5)	−125.8	−80.7	51.3	25.7	11.0	11.0	23.5	49.8

in 130 ml of dry benzonitrile according to the general procedure. Perfluoroacetyl chloride (12.2 g, 92 mmol) was added dropwise via the Dry Ice/isopropyl alcohol condenser. After the solution was stirred at 0–5 °C for 0.5 h and then at room temperature for 0.5 h, chlorine (14.2 g, 200 mmol) was added dropwise at 0–5 °C via the Dry Ice/isopropyl alcohol condenser. The reaction mixture was stirred at room temperature for 1 h and then flash-distilled at 80 °C/30 mmHg to give a colorless solution. Simple distillation of the flash-distillate from an equal volume of conc. H_2SO_4* provided 7.5 g (41% yield, 95% GLPC purity) of 1,1-dichloroperfluoropropanone, b.p. 43–45 °C (lit. value [12], b.p. 44 °C); the ^{19}F NMR data are listed in Table 4. IR (gas) (cm^{-1}): 1795 (s, C=O); 1295 (s); 1235 (s); 1190 (s); 1130 (s); 1070 (s); 1035 (s); 870 (s); 830 (s); 710 (s). GC/MS (*m/e*) (relative intensity): 165 (12.7, $M^+ - Cl$); 163 (30.1, $M^+ - Cl$); 137 (5.5); 135 (13.3); 105 (7.1); 103 (44.3); 101 (64.5); 87 (6.2); 85 (14.7); 69 (100.0); 68 (6.5); 66 (27.7); 50 (13.8); 37 (5.8); 35 (15.2).

Preparation of 1,1,3-trichloroperfluoropropanone (7)

A similar reaction was conducted with 92 mmol (13.7 g) of chlorodifluoroacetyl chloride. Flash-distillation of the reaction mixture at 45 °C/5 mmHg gave a colorless solution. Simple distillation of the flash-distillate from an equal volume of conc. H_2SO_4 provided 7.9 g (40% yield, 96% GLPC purity) of 1,1,3-trichloroperfluoropropanone, b.p. 78–80 °C (lit. value [12], b.p. 84 °C); the ^{19}F NMR data are listed in Table 4. IR (neat) (cm^{-1}): 1785 (s, C=O); 1230 (s); 1170 (s); 1115 (s); 1070 (s); 1050 (s); 950 (s); 850 (s); 780 (s). GC/MS (*m/e*) (relative intensity): 218 (0.8, M^+); 216 (2.3, M^+); 214 (2.4, M^+); 155, (5.4); 153 (33.7); 151 (51.2); 105 (11.0); 103 (67.0); 101 (100.0); 96 (4.4); 94 (12.5); 87 (16.0); 85 (47.9); 68 (4.8); 66 (13.9).

Preparation of 1,1-dichloroperfluoro-2-butanone (8) (nc)

A similar reaction was conducted with 92 mmol (16.8 g) of perfluoropropanoyl chloride. Flash-distillation of the reaction mixture at 60 °C/10 mmHg gave a colorless solution. Simple distillation of the flash-distillate from an equal volume of conc. H_2SO_4 provided 13.7 g (60% yield, 97% GLPC purity) of 1,1-dichloroperfluoro-2-butanone, b.p. 64–66 °C; the ^{19}F NMR data are listed in Table 4. IR (gas) (cm^{-1}): 1790 (m, C=O); 1340 (m); 1240 (s); 1200 (s); 1160 (s); 1100 (s); 1005 (m); 980 (m); 870 (s); 800 (m); 745 (m); 705 (m). GC/MS (*m/e*) (relative intensity): 250 (0.2, M^+); 248 (0.3, M^+); 215 (3.9); 213 (12.4); 119 (57.6); 105 (10.5); 103 (65.9); 101 (100.0); 97 (39.7); 87 (11.0); 85 (33.4); 69 (35.2).

Preparation of 1,1-dichloroperfluoro-2-pentanone (9) (nc)

A similar reaction was conducted with 92 mmol (21.4 g) of perfluorobutanoyl chloride. Flash-distillation of the reaction mixture at room tem-

*The product is distilled from conc. H_2SO_4 to convert any hydrate formed in work-up to the anhydrous ketone.

TABLE 4

^{19}F NMR data for α,α-dihalofluoromethyl perfluoroalkyl ketones

Substrate	δ (ppm)							J (Hz)			
	a	b	c	d	e	f	g	ab	ac	bd	eg
$CF_3C(O)CFCl_2$ (**6**)	−72.0	−71.2						9.8			
$CF_2ClC(O)CFCl_2$ (**7**)	−69.5	−61.9						11.0			
$CF_3CF_2C(O)CFCl_2$ (**8**)	−71.0	−116.3	−81.6					12.2			
$CF_3CF_2CF_2C(O)CFCl_2$ (**9**)	−71.2	−114.3	−125.7	−80.9				12.2	7.3	9.8	
$CF_3CF_2CF_2(CF_2)_2CF_2CF_2C(O)CFCl_2$ (**10**)	−71.1	−113.5	(−121.4 to −123.1)			−126.6	−81.3	12.2	7.3		9.8
$CF_3C(O)CFBr_2$ (**11**)	−74.4	−70.3						9.8			
$CF_2ClC(O)CFBr_2$ (**12**)	−72.2	−61.4						12.2			
$CF_3CF_2C(O)CFBr_2$ (**13**)	−73.8	−115.8	−82.0					12.2			
$CF_3CF_2CF_2C(O)CFBr_2$ (**14**)	−73.9	−112.9	−125.5	−80.8				12.2	7.3	9.8	

perature and at 11.0 mmHg pressure gave a colorless solution. Simple distillation of the flash-distillate from an equal volume of conc. H_2SO_4 provided 17.2 g (62% yield, 99% GLPC purity) of 1,1-dichloroperfluoro-2-pentanone, b.p. 87–89 °C; the ^{19}F NMR data are listed in Table 4. IR (neat) (cm^{-1}): 1785 (s, C=O); 1350 (s); 1240 (s); 1200 (s); 1135 (s); 1075 (m); 1050 (m); 1030 (w); 960 (w); 930 (m); 860 (m); 790 (w); 745 (w); 710 (w). GC/MS (*m/e*) (relative intensity): 265 (1.8, $M^+ - Cl$); 263 (6.1, $M^+ - Cl$); 169 (26.7); 119 (22.4); 105 (9.4); 103 (59.8); 101 (90.0); 100 (26.9); 96 (5.1); 94 (16.2); 87 (9.4); 85 (28.0); 69 (100.0); 68 (7.6); 66 (23.1).

*Preparation of 1,1-dichloroperfluoro-2-nonanone (**10**) (nc)*

The fluorinated phosphonium salt was prepared from tri-n-butylphosphine (24.3 g, 120 mmol) and trichlorofluoromethane (5.5 g, 40 mmol) in 60 ml of dry benzonitrile according to the general procedure. Perfluorooctanoyl chloride (13.8 g, 32 mmol) was added in several portions via a syringe at 0–5 °C to form the betaine. After the solution was stirred at 0–5 °C for 0.5 h and at room temperature for 1 h, chlorine (5.7 g, 80 mmol) was added via a Dry Ice/isopropyl alcohol condenser at 0–5 °C. The product was not entirely soluble in the reaction mixture. The bottom layer was separated from the benzonitrile (upper layer). Vacuum distillation of the separated solution from an equal volume of conc. H_2SO_4 provided 9.0 g (56% yield, 99% GLPC purity) of 1,1-dichloroperfluoro-2-nonanone, b.p. 82–83 °C/40 mmHg; the ^{19}F NMR data are listed in Table 4. IR (neat) (cm^{-1}): 1790 (m, C=O); 1360 (w); 1325 (m); 1210 (s); 1155 (s); 1110 (m); 1080 (s); 995 (w); 865 (m); 720 (m). GC/MS (*m/e*) (relative intensity): 169 (16.6); 131 (29.6); 119 (32.1); 105 (10.5); 103 (64.0); 101 (100.0); 100 (22.0); 96 (4.3); 94 (13.6); 87 (12.0); 85 (38.9); 69 (72.2); 66 (12.1).

*Preparation of 1,1-dibromoperfluoropropanone (**11**)*

The fluorinated phosphonium salt was prepared from tri-n-butylphosphine (30.3 g, 150 mmol) and tribromofluoromethane (13.6 g, 50 mmol) in 65 ml of dry benzonitrile according to the general procedure. Perfluoroacetyl chloride (5.7 g, 43 mmol) was added dropwise at 0–5 °C via the Dry Ice/isopropyl alcohol condenser to form the betaine. After the solution was stirred at 0–5 °C for 0.5 h and at room temperature for 0.5 h, bromine (16.0 g, 100 mmol) was added dropwise at 0–5 °C via a syringe. The reaction mixture was stirred at room temperature for 1 h and then flash-distilled at room temperature (0.5 mmHg for 2 h) to give a yellow liquid which contained the product and benzonitrile. This liquid was distilled through a short-path distillation apparatus to collect the crude product at 70–120 °C. Fractional distillation of the crude product through a 4 in. Vigreux column from an equal volume of conc. H_2SO_4 provided 5.2 g (42% yield, 95% GLPC purity) of 1,1-dibromoperfluoropropanone, b.p. 78–81 °C (lit. value [15], b.p. 81 °C); the ^{19}F NMR data are listed in Table 4. IR (neat) (cm^{-1}): 1790 (s, C=O); 1300 (s); 1230 (s); 1205–1180 (s); 1130 (s); 1070 (s); 1030 (s); 870 (m); 820 (s). GC/MS (*m/e*) (relative intensity): 290 (0.8, M^+); 288 (1.3,

M^+); 286 (0.7, M^+); 193 (25.1); 191 (50.5); 189 (27.0); 140 (16.9); 138 (17.5); 131 (13.8); 129 (14.2); 112 (28.7); 110 (28.1); 93 (13.3); 81 (27.6); 79 (27.3); 69 (100.0); 50 (12.1).

*Preparation of 1,1-dibromo-3-chloroperfluoropropanone (**12**) (nc)*

A similar reaction was conducted with 45 mmol (6.7 g) of chlorodifluoroacetyl chloride. Flash-distillation of the reaction mixture at room temperature (0.5 mmHg for 2 h) gave a yellow liquid which contained the product and benzonitrile. This liquid was distilled through a short-path distillation apparatus to collect the crude product at 100–170 °C. Vacuum distillation of the crude product through a 4 in. Vigreux column from an equal volume of conc. H_2SO_4 provided 4.1 g (30% yield, 95% GLPC purity) of 1,1-dibromo-3-chloroperfluoropropanone, b.p. 61–63 °C/100 mmHg; the ^{19}F NMR data are listed in Table 4. IR (neat) (cm^{-1}): 1775 (s, C=O); 1240 (m); 1175 (s); 1120 (s); 1075 (s); 945 (s); 835 (s); 810 (m); 775 (m); 740 (m). GC/MS (*m/e*) (relative intensity): 308 (0.5, M^+); 306 (2.7, M^+); 304 (3.7, M^+); 302 (1.7, M^+); 243 (6.1); 241 (11.8); 239 (6.0); 199 (4.0); 197 (19.0); 195 (12.4); 193 (45.3); 191 (100.0); 189 (50.8); 140 (14.2); 138 (14.1); 112 (19.9); 110 (20.0); 87 (9.6); 85 (29.6).

*Preparation of 1,1-dibromoperfluoro-2-butanone (**13**) (nc)*

The fluorinated phosphonium salt was prepared from tri-n-butylphosphine (60.6 g, 300 mmol) and tribromofluoromethane (27.1 g, 100 mmol) in 100 ml of dry benzonitrile according to the general procedure. Perfluoropropanoyl chloride (16.4 g, 90 mmol) was added dropwise at 0–5 °C via a Dry Ice/isopropyl alcohol condenser to form the betaine. After the solution was stirred at 0–5 °C for 0.5 h and at room temperature for 0.5 h, bromine (32.0 g, 200 mmol) was added dropwise at 0–5 °C via a syringe. The reaction mixture was stirred at room temperature for 1 h and then flash-distilled at room temperature (10.5 mmHg for 2 h) to give a yellow liquid which contained the product and benzonitrile. This liquid was distilled through a short-path distillation apparatus to collect the crude product at 80–150 °C. Vacuum distillation of the crude product through a 4 in. Vigreux column from an equal volume of conc. H_2SO_4 provided 15.9 g (52% yield, 95% GLPC purity) of 1,1-dibromoperfluoro-2-butanone, b.p. 50–52 °C/145 mmHg; the ^{19}F NMR data are listed in Table 4. IR (neat) (cm^{-1}): 1770 (m, C=O); 1330 (m); 1225 (s); 1195 (s); 1140 (s); 1090 (s); 985 (m); 945 (m); 835 (w); 800 (m); 770 (w); 725 (m). GC/MS (*m/e*) (relative intensity): 340 (0.1, M^+); 338 (0.2, M^+); 336 (0.2 M^+); 193 (47.6); 191 (100.0); 189 (53.9); 140 (28.7); 138 (29.7); 131 (28.4); 129 (28.5); 119 (71.9); 112 (43.4); 110 (45.8); 100 (21.5); 97 (11.5); 93 (16.0); 91 (10.3); 81 (26.9); 79 (24.5); 69 (78.2).

*Preparation of 1,1-dibromoperfluoro-2-pentanone (**14**) (nc)*

A similar reaction was conducted with 93 mmol (21.6 g) of perfluorobutanoyl chloride. Flash-distillation of the reaction mixture at room tem-

perature (10.5 mmHg for 3 h) gave a yellow liquid containing the product and benzonitrile. This liquid was distilled through a short-path distillation apparatus to collect the crude product at 100–175 °C. Vacuum distillation of the crude product through a 4 in. Vigreux column from an equal volume of conc. H_2SO_4 provided 19.0 g (53% yield, 95% GLPC purity) of 1,1-dibromoperfluoro-2-pentanone, b.p. 65–68 °C/120 mmHg; the ^{19}F NMR data are listed in Table 4. IR (neat) (cm^{-1}): 1775 (m, C=O); 1350 (s); 1235 (s); 1200 (s); 1135 (s); 1065 (m); 1045 (m); 950 (w); 905 (m); 830 (m); 800 (m); 725 (m). GC/MS (*m/e*) (relative intensity): 309 (1.3, $M^+ - Br$); 307 (1.3, $M^+ - Br$); 193 (21.2); 191 (40.3); 189 (20.4); 169 (13.4); 140 (14.1); 138 (15.2); 119 (15.5); 112 (24.0); 110 (23.7); 100 (21.6); 93 (10.7); 81 (13.4); 79 (11.1); 69 (100.0).

Acknowledgement

We thank the National Science Foundation for generous support of our work.

References

1 I. H. Jeong, D. J. Burton and D. G. Cox, *Tetrahedron Lett.*, *27* (1986) 3709.
2 S. Patai and Z. Rappoport, *The Chemistry of Functional Groups, Supplement D*, John Wiley & Sons, New York, 1983, p. 815.
3 D. A. Evans, J. V. Nelson and T. R. Taber, *Top. Stereochem.*, *13* (1982) 1.
4 R. A. Bekker, G. G. Melikyan, E. P. Lur'e, B. L. Dyatkin and I. L. Knunyants, *Dokl. Akad. Nauk SSSR*, *217* (1974) 1320.
5 R. A. Bekker, G. G. Melikyan, B. L. Dyatkin and I. L. Knunyants, *Zh. Org. Khim.*, *11* (1975) 1370.
6 R. A. Bekker, G. G. Melikyan, B. L. Dyatkin and I. L. Knunyants, *Zh. Org. Khim.*, *11* (1975) 1600.
7 R. A. Bekker, G. G. Melikyan, B. L. Dyatkin and I. L. Knunyants, *Zh. Org. Khim.*, *11* (1975) 2370.
8 R. A. Bekker, G. G. Melikyan, B. L. Dyatkin and I. L. Knunyants, *Zh. Org. Khim.*, *11* (1975) 1604.
9 R. A. Bekker, G. G. Melikyan, B. L. Dyatkin and I. L. Knunyants, *Dokl. Akad. Nauk SSSR*, *221* (1975) 1331.
10 R. A. Bekker, G. G. Melikyan, B. L. Dyatkin and I. L. Knunyants, *Zh. Org. Khim.*, *12* (1976) 1377.
11 R. A. Bekker, Sh. O. Badonyan, G. G. Melikyan and I. L. Knunyants, *Zh. Org. Khim.*, *13* (1977) 1582.
12 H. R. Nychka and C. Woolf, *Fr. Pat. 1 369 785* (1965); [*Chem. Abstr.*, *62* (1965) 3940].
13 L. A. Saloutina, A. Ya. Zapevolov, M. J. Kodess, I. P. Kolenko and L. S. German, *Izv. Akad. Nauk SSSR, Ser. Khim.*, (1983) 1434.
14 R. A. Shepard and A. A. Loiselle, *J. Org. Chem.*, *23* (1958) 2012.
15 E. T. McBee, O. R. Pierce and H. W. Kilbourne, *J. Am. Chem. Soc.*, *75* (1953) 4091.

16 S. Shin-Ya, *Ph.D. Thesis*, University of Iowa, 1980.
17 D. G. Cox and D. J. Burton, *J. Org. Chem.*, *53* (1988) 366.
18 A. L. Henne, R. M. Alm and M. Smook, *J. Am. Chem. Soc.*, *70* (1948) 1968.
19 M. Sander, *Monatsh. Chem.*, *95* (1964) 608.
20 D. G. Cox, *Ph.D. Thesis*, University of Iowa, 1984.
21 D. J. Burton and W. M. Koppes, *J. Org. Chem.*, *40* (1975) 3026.
22 J. M. Birchall and R. N. Haszeldine, *J. Chem. Soc.*, (1959) 13.