Acylchlorination and Related Reactions of Fluoroethenes Using AlCl₃ and FeCl₃

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Acylchlorination of mono-, 1,1-di-, and trifluoroethenes with carboxylic acid chlorides using AlCl₃ and FeCl₃ as a Lewis acid was investigated. In AlCl₃-catalyzed reactions, fluorine-chlorine exchange reaction always occurred in part, while in FeCl₃-catalyzed reactions Claisen-type condensation giving β-diketones was observed. Preparations of 2-chloro-2-fluoroethyl, 2-chloro-2,2-difluoroethyl, and 2-chloro-1,2,2-trifluoroethyl ketones are given.
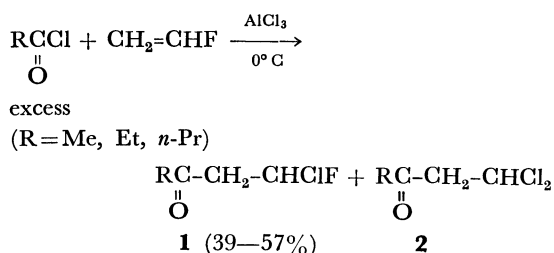
Although the reactivity of fluoroethenes towards electrophiles is lowered by the presence of negative fluorine atoms, several examples of the electrophilic addition across the double bond of mono-, di-, and trifluoroethenes appeared in the literature.[1]

As to the Friedel-Crafts acylhalogenations of the fluoroethenes, the additions of acyl chlorides or acetyl fluoride to 1,1-difluoroethene and trifluoroethene catalyzed by AlCl₃[2] and SbF₅[3] were reported by Soviet workers.

In this paper we wish to report on the reactions of various carboxylic acid chlorides with mono-, di-, and trifluoroethenes using AlCl₃ and FeCl₃ as a Lewis acid, and on the preparations of chlorofluoroethyl ketones and β-diketones, which are expected as useful intermediates for synthesis of fluorine containing organic compounds.

Results and Discussion

Acylchlorination of Fluoroethene. Among fluoroethenes, monofluoroethene is expected to be the most susceptible to the attack of electrophiles, however, only a few electrophilic reactions of fluoroethene, *e.g.* additions of fluorosulfuric acid[4] and arenesulfenyl chlorides,[5] are known. No reports on the acylchlorination of fluoroethene have appeared in literatures so far. We found that fluoroethene was readily acylchlorinated by various carboxylic acid chlorides in the presence of AlCl₃ or FeCl₃ even under mild conditions. For example, when fluoroethene gas was allowed to be absorbed in a mixture of excess acyl chlorides and AlCl₃ (4:1 mole ratio) at 0 °C, 2-chloro-2-fluoroethyl ketones (**1**) were obtained. However, 2,2-dichloroethyl ketones (**2**), formed by a halogen exchange reaction, were always found as a side product in the reaction mixture. Expecting to avoid this dichlo-

$$\underset{O}{RC\!Cl} + CH_2{=}CHF \xrightarrow[0°C]{AlCl_3}$$

excess
(R=Me, Et, *n*-Pr)

$$\underset{O}{RC\!-\!CH_2\!-\!CHClF} + \underset{O}{RC\!-\!CH_2\!-\!CHCl_2}$$

1 (39—57%)   **2**

roethyl ketone formation, dichloromethane was used as a solvent and equimolar amounts of acyl chloride and fluoroethene were made to react under the same conditions. The formation of **2**, however, could not

be controlled by this method, and from benzoyl chloride, in particular, 2,2-dichloroethyl phenyl ketone (**3**) was formed in a yield of 43%. The fluorine-
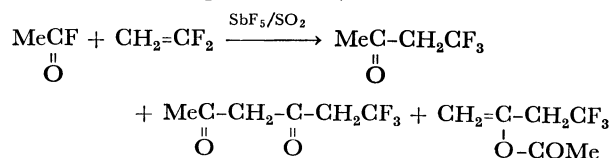
$$\underset{O}{PhC\!Cl} + CH_2{=}CHF \xrightarrow[0°C]{AlCl_3/CH_2Cl_2} \underset{O}{PhC\!-\!CH_2\!-\!CHCl_2}$$

3
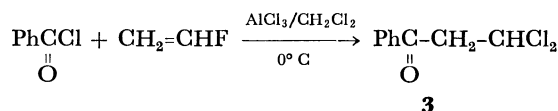
to-chlorine exchange reaction by AlCl₃ forming dichloroethyl ketones in these reactions was confirmed experimentally. For example, when a mixture of equimolar amounts of 2-chloro-2-fluoroethyl propyl ketone **1** (R=*n*-Pr) and AlCl₃ in dichloromethane was stirred at 0 °C for 40 min, **1** and **2** were found in a ratio 68:32, based on the ¹H NMR signal intensities, in the resulting mixture.

Then we carried out the acylchlorination of fluoroethene, using FeCl₃ instead of AlCl₃ in the above procedure, because FeCl₃ is known to be a milder Lewis acid than AlCl₃.[6,7] By this method, the expected 2-chloro-2-fluoroethyl ketones were obtained exclusively in good yields (Table 1). Even aroyl chlorides afforded corresponding ketones in fairy good yields (≈50%). These 2-chloro-2-fluoroethyl ketones

$$\underset{O}{RC\!Cl} + CH_2{=}CHF \xrightarrow[0°C]{FeCl_3/CH_2Cl_2} \mathbf{1}\ (49{-}76\%)$$

(R=alkyl or aryl)
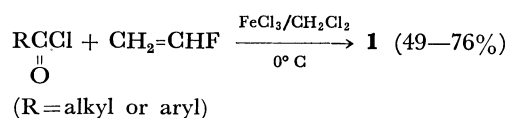
were readily dehydrochlorinated by heat or by a base, giving unstable vinyl ketones.

Acylchlorination of 1,1-Difluoroethene. More than twenty years ago Knunyants and his co-workers reported the addition of acetyl, propionyl, and butyryl chlorides to 1,1-difluoroethene using AlCl₃ in trichloromethane at low temperature (−10——5 °C), affording 2-chloro-2,2-difluoroethyl ketones in rather low yields (33—48%).[2] More recently, Belen'kii and German reported the reaction between acetyl fluoride and 1,1-difluoroethene in sulfur dioxide using SbF₅ as a Lewis acid, obtaining a normal adduct together with condensation products, a β-diketone and an ester.[3]

$$\underset{O}{MeCF} + CH_2{=}CF_2 \xrightarrow{SbF_5/SO_2} \underset{O}{MeC\!-\!CH_2CF_3}$$

$$+ \underset{O\ \ \ \ O}{MeC\!-\!CH_2\!-\!C\!-\!CH_2CF_3} + \underset{O\text{-}COMe}{CH_2{=}C\!-\!CH_2CF_3}$$

By tracing the procedure reported by Knunyants *et al.*, 2,2,2-trichloroethyl ketones (**5**) were formed as well as 2-chloro-2,2-difluoroethyl ketones (**4**) according

TABLE 1. PREPARATION OF $\overset{\alpha}{RC}-\overset{}{\underset{\parallel}{C}}H_2-\overset{\beta}{C}HClF$ (1)

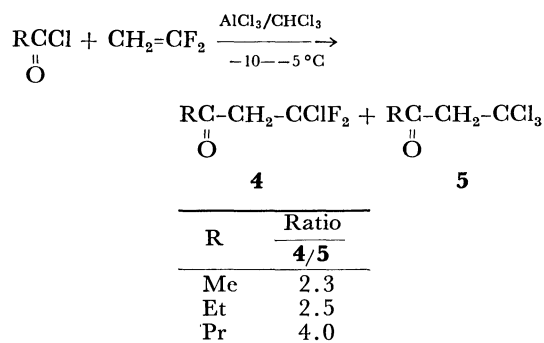| R	Bp °C/mmHg [Mp °C]	Yield (%) (Method)[a]	¹H and ¹⁹F NMR (δ ppm)			IR (C=O) cm⁻¹	Found (Calcd) (%)	
			α-H	β-H (J_{H-F} Hz)	β-F		C	H
Me	38—39/9	(A) 39 (B) 70	3.20 3.27	{6.50 {(50)	54.3	1720	{ 38.84 {(38.58)	4.66 (4.86)
Et	43—45/9	(A) 46	3.20 3.27	{6.53 {(50)	54.0	1720	{ 43.13 {(43.34)	5.46 (5.82)
n-Pr	53—54/5	(A) 57 (B) 76	3.10 3.17	{6.45 {(49)	54.3	1720	{ 47.64 {(47.23)	6.70 (6.61)
i-Pr	55—52/5	(A) 32	3.10 3.17	{6.43 {(49)	54.3	1720	{ 47.64 {(47.23)	6.70 (6.61)
n-C₅H₁₁	55-60/2.5	(B) 65	3.15 3.25	{6.50 {(50)	54.0	1720	{ 53.67 {(53.19)	7.67 (7.81)
Ph	[48.5—50]	(B) 50	3.63 3.72	{6.65 {(50)	53.3	1680	{ 58.19 {(57.93)	4.25 (4.32)
p-MeC₆H₄	[76—77]	(B) 49	3.60 3.70	{6.70 {(50)	53.3	1675	{ 60.27 {(59.86)	4.97 (5.02)

a) Method (A): AlCl₃ in excess RCOCl, (B): FeCl₃ in CH₂Cl₂. b) ¹⁹F NMR was measured in neat and chemical shifts are given in δ ppm from ext. CF₃CO₂H. ¹H NMR was measured in CCl₄.

TABLE 2. PREPARATION OF $\overset{\alpha}{RC}-\overset{}{\underset{\parallel}{C}}H_2-\overset{\beta}{C}ClF_2$ (4)

R	Bp °C/mmHg	Yield (%) (Method)[a]	¹H and ¹⁹F NMR (δ ppm)[b]		IR (C=O) cm⁻¹
			α-H	β-F	
Me	38—40/24[c]	(A) 59[c] (B) 46[f]	3.40	−29.7	1730
Et	59—60/29[d]	(A) 56[d]	3.38	−29.5	1730
n-Pr	60—62/20[e]	(B) 50[f]	3.33	−29.6	1720

a) Method (A): AlCl₃ in CHCl₃, (B): FeCl₃ in CH₂Cl₂. b) See Table 1, footnote b): ¹H NMR was measured in CDCl₃. c) Lit,[2] bp 40—41 °C/25 mmHg, 44.5%. d) Lit,[2] Bp 56—57 °C/30 mmHg, 48%. e) Lit,[2] bp 64—65 °C/22 mmHg, 33%. f) Contaminated with further acylated products (≈10%).
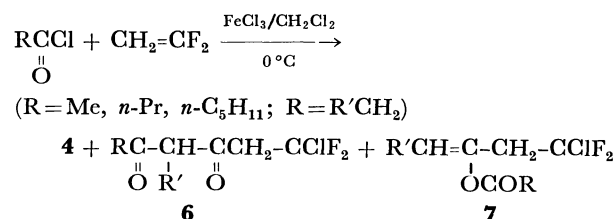
to the ¹H NMR spectra of reaction products, with the ratios shown below.

$$\underset{\underset{O}{\parallel}}{RCCl} + CH_2{=}CF_2 \xrightarrow[-10--5\,°C]{AlCl_3/CHCl_3}$$

$$\underset{\underset{O}{\parallel}}{RC}-CH_2-CClF_2 + \underset{\underset{O}{\parallel}}{RC}-CH_2-CCl_3$$

$$\quad\quad 4 \quad\quad\quad\quad\quad\quad\quad 5$$

R	Ratio 4/5
Me	2.3
Et	2.5
Pr	4.0

Avoiding the halogen exchange between **4** and **5** with AlCl₃, we examined FeCl₃ instead of AlCl₃ in these cases again. Thus 1,1-difluoroethene was allowed to be absorbed into a mixture of acyl chlorides and FeCl₃ in dichloromethane at 0 °C. By this method, chlorodifluoroethyl ketones were obtained in 50% yield, and no formation of trichloroethyl ketone was observed in the reaction mixture (Table 2).

However, other unidentified by-products were always included in the main product and these contaminants were assumed to be further acylated condensation products such as β-diketone (**6**) or enol ester (**7**) as Belen'kii *et al.* observed in their reaction. The forma-

$$\underset{\underset{O}{\parallel}}{RCCl} + CH_2{=}CF_2 \xrightarrow[0\,°C]{FeCl_3/CH_2Cl_2}$$

$$(R{=}Me,\ n\text{-}Pr,\ n\text{-}C_5H_{11};\ R{=}R'CH_2)$$

$$4 + \underset{\underset{O}{\parallel}}{RC}-CH-\underset{\underset{R'}{\vert}}{C}H_2-\underset{\underset{O}{\parallel}}{C}ClF_2 + R'CH{=}C-CH_2-CClF_2$$
$$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\underset{OCOR}{\vert}$$
$$\quad\quad\quad\quad 6 \quad\quad\quad\quad\quad\quad\quad\quad\quad\quad 7$$

tion of these kind of condensation products is reasonable as FeCl₃ is known to accelerate Claisen-type condensation under acidic conditions.[8] Actually, when butyryl chloride was made to react with 2-chloro-2,2-difluoroethyl methyl ketone using FeCl₃, β-diketone was obtained though in a low yield.
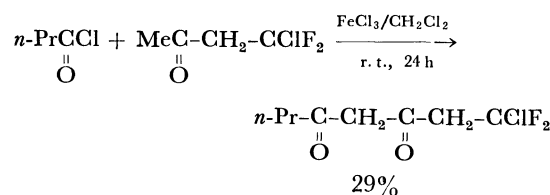
$$n\text{-}\underset{\underset{O}{\parallel}}{PrCCl} + Me\underset{\underset{O}{\parallel}}{C}-CH_2-CClF_2 \xrightarrow[r.\,t.,\ 24\,h]{FeCl_3/CH_2Cl_2}$$

$$n\text{-}Pr-\underset{\underset{O}{\parallel}}{C}-CH_2-\underset{\underset{O}{\parallel}}{C}-CH_2-CClF_2$$

$$29\%$$

TABLE 3. PREPARATION OF $RC-\overset{\alpha}{C}HF-\overset{\beta}{C}ClF_2$ (8)
        $\overset{\parallel}{O}$

R	Bp °C/mmHg	Yield %	¹H and ¹⁹F NMR (δ ppm)ᵃ⁾			IR (C=O) cm⁻¹	Found (Calcd) (%)	
			α-H (J_{H-F} Hz)	α-F	β-F$_2$ (J_{F-F} Hz)		C	H
Me	98—100ᵇ⁾	70ᵇ⁾	{4.83 (50)	116.5	{−13.9, −16.1 (180)	1745	—	—
n-Pr	78.5—79/103	73	{4.85 (48)	117.4	{−14.4, −16.6 (174)	1755	{ 38.62 (38.22)	4.16 (4.28)
n-C₅H₁₁	74—76/12	82	{4.82 (48)	117.6	{−13.9, −16.1 (178)	1765	{ 44.09 (44.35)	5.51 (5.58)
n-C₉H₁₉	92.5—94.5/2.5	82	{4.86 (48)	117.2	{−14.2, −16.4 (173)	1740	{ 53.34 (52.85)	7.31 (7.39)
Ph	58—59/1.5	13	{5.65 (48)	113.3	{−15.8, −16.8 (172)	1710	{ 49.00 (49.00)	2.78 (2.74)

a) See, Table 1, footnote b).   b) Lit,²⁾ bp 99—100 °C, yield 34%.

TABLE 4. PREPARATION OF $RC=CH-C-\overset{\alpha}{C}HF-\overset{\beta}{C}ClF_2$ (9') (R=H)
        $\overset{|}{OH} \quad \overset{\parallel}{O}$

R	Bp °C/mmHg	Yield (%) (Method)ᵃ⁾	¹H and ¹⁹F NMR (δ ppm)				IR (C=O) cm⁻¹	Found (Calcd) (%)	
			OH	α-H α-F (J_{H-F} Hz)		β-F$_2$ (J_{F-F} Hz)		C	H
Me	70—74/23	(A) 40 (B) 70	14.2—15.0	5.00 117.9 (48)		−13.2, −15.5	1600 br	{ 35.83 (35.58)	2.88 (2.99)
n-Pr	89/18	(B) 67	14.1—14.9	4.90 117.6 (47)		−13.9, −15.9	1600 br	{ 41.19 (41.67)	4.37 (4.34)
n-C₅H₁₁	75—76/3	(B) 61	14.2—16.2	4.96 117.1 (46)		−13.7, −15.8	1600 br	{ 46.63 (46.43)	5.35 (5.46)

a) Method (A): RCOCl+C₂HF₃ (FeCl₃), Method (B): RCOCl+MeCOCHFCClF₂ (FeCl₃).

Since, 1,1-difluoroethene is less reactive to electrophiles than fluoroethene, the acylchlorination must be sluggish, and it is natural that other side reactions likely occur. Further, aroyl chlorides, which are weaker electrophiles than aliphatic carboxylic acid chlorides, gave no reaction products either by AlCl₃ or by FeCl₃.

Reaction of Trifluoroethene with Acyl Chlorides. As trifluoroethene is even less susceptible to the Friedel-Crafts acylchlorination than mono- and difluoroethenes, it does not react with acyl chlorides under atmospheric pressure. Knunyants *et al.* made trifluoroethene react with an excess amount of acetyl chloride in a sealed vessel and obtained 2-chloro-1,2,2-trifluoroethyl methyl ketone in 34% yield.²⁾ Belen'kii also reported that the reaction between acetyl fluoride and trifluoroethene with SbF₅ in SO₂ resulted in the formation of the adduct and its further acylated products.
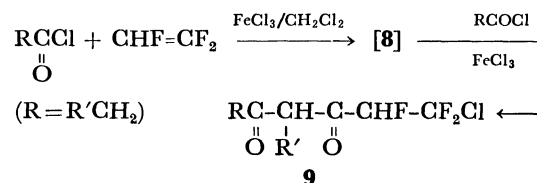
Various carboxylic acid chlorides were tried to use for the reaction with trifluoroethene using AlCl₃ in dichloromethane in a sealed vessel. By making them react at room temperature for a prolonged time, 2-chloro-1,2,2-trifluoroethyl ketones (8) were obtained in rather good yields (Table 3).

$$RCCl + CHF=CF_2 \xrightarrow[\text{r.t., 20—48 h}]{AlCl_3/CH_2Cl_2} RC-CHF-CF_2Cl$$
$$\overset{\parallel}{O} \qquad\qquad\qquad\qquad\qquad \overset{\parallel}{O}$$

(R=Me, n-Pr, n-C₅H₁₁, n-C₉H₁₉)   8 (70—82%)
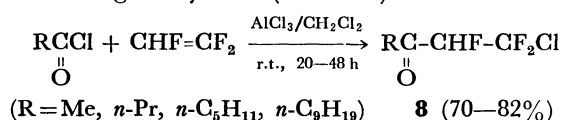
However, a small amount of 1,1,1,2-tetrachloroethane was always formed as a side-product, which was assumed to have been formed by chlorination of trifluoroethene with AlCl₃ followed by hydrochlorination with HCl. This was confirmed experimentally by allowing trifluoroethene and AlCl₃ to react in the presence of a trace of water. Substantial amount of tetrachloroethane was obtained by this reaction.
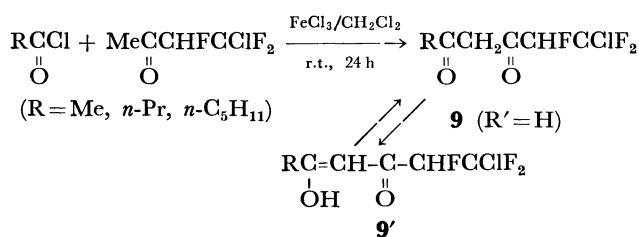
$$CHF=CF_2 + AlCl_3 \longrightarrow [CHCl=CCl_2] \xrightarrow{HCl} CH_2ClCCl_3$$

As a matter of interest, when FeCl₃ was used instead of AlCl₃, β-diketones (9) were obtained as a main product and only a small or trace amount of acyl-chlorinated product was formed (Table 4-Method A).

$$RCCl + CHF=CF_2 \xrightarrow{FeCl_3/CH_2Cl_2} [8] \xrightarrow{RCOCl}_{FeCl_3}$$
$$\overset{\parallel}{O}$$

(R=R'CH₂) $RC-CH-C-CHF-CF_2Cl \longleftarrow$
           $\overset{\parallel}{O} \overset{|}{R'} \overset{\parallel}{O}$
               9

This also means that FeCl₃ worked as an effective catalyst for the Claisen-type condensation.

In order to prepare the β-diketones carrying an active CH₂ group, chlorotrifluoroethyl methyl ketone **8**, obtained by the AlCl₃ catalyzed reaction, was allowed to react with an acyl chloride using FeCl₃. Diketones **9** (R=Me, n-Pr, n-C₅H₁₁; R'=H) were obtained in considerable yields by this method (Table

4-Method B), and they existed in an enol form (**9′**) based on the ^{1}H NMR.

$$RCCl + MeCCHFCClF_2 \xrightarrow[\text{r.t., 24 h}]{FeCl_3/CH_2Cl_2} RCCH_2CCHFCClF_2$$

(R=Me, n-Pr, n-C$_5$H$_{11}$)

$$RC=CH-C-CHFCClF_2$$
$$\underset{OH}{|} \quad \underset{O}{\|}$$

9′

Consequently, it was concluded that trifluoroethene was acylchlorinated by using AlCl$_3$ under more vigorous conditions than the cases of mono- and difluoroethenes, and that when FeCl$_3$ was used, the formation of β-diketone occurred dominantly, presumably because the Claisen-type further acylation proceeded faster than the preceding acylchlorination.

Experimental

2-Chloro-2-fluoroethyl Methyl Ketone **1** *(R=Me).* *(A)*: Into a solution of AlCl$_3$ (13.3 g, 0.1 mol) in acetyl chloride (31.4 g, 0.4 mol), fluoroethene gas was introduced through the bottom of the vessel. The temperature was kept below 0 °C and the introduction was continued until no more absorption was observed ($\approx$40 min). The reaction mixture was then poured into a mixture of ice (50 g) and concd hydrochloric acid (10 ml) and a separated oily material was extracted with diethyl ether. The extract was washed with aqueous solution of NaHCO$_3$ to remove a free carboxylic acid, then with water, and dried over MgSO$_4$. After evaporating the solvent, the residue was subjected to distillation under reduced pressure, giving **1** (R=Me) (5.0 g), bp 38—39 °C/9 mmHg**, in a yield of 39% based on the used AlCl$_3$.

(B): Into a suspension of FeCl$_3$ (19.4 g, 0.12 mol) in dichloromethane (100 ml), acetyl chloride (7.85 g, 0.10 mol) was added dropwise with cooling in an ice-bath. Then fluoroethene gas was introduced to the solution keeping the temperature below 0 °C until no more gas was absorbed (3 h). The reaction mixture was treated similarly as mentioned in (A) and distillation gave **1** (R=Me) (8.70 g) in 70% yield.

The other carboxylic acid chlorides were allowed to react with fluoroethene in similar procedures (Table 1). When the aroyl chlorides were used, the products came out as a solid after removal of the solvent, which were purified by recrystallization from cyclohexane. All of the 2-chloro-2-fluoroethyl ketones were readily dehydrochlorinated by distillation at high temperature. Therefore it was necessary to distill them at lower than 60 °C under reduced pressure. They gradually decomposed even kept in a refrigerator.

2,2-Dichloroethyl Phenyl Ketone **(3)**. Into a mixture of benzoyl chloride (14.1 g, 0.10 mol), AlCl$_3$ (13.3 g, 0.10 mol) and dichloromethane (38 ml), fluoroethene gas was absorbed, and the reaction mixture was worked up as usual. After evaporation of the solvent, the residue was recrystallized from hexane, giving **3** (7.44 g, 43%), mp 58—59 °C; NMR (CCl$_4$): δ 3.82 (2H), 6.27 (H), 7.30—8.00 (5H); $\nu_{C=O}$; 1670 cm^{-1}. Found: C, 53.82; H, 3.95%. Calcd for C$_9$H$_{18}$Cl$_2$O:

_____
**1 mmHg $\approx$ 133.3 Pa.

C, 53.23; H, 3.97%.

2-Chloro-2,2-difluoroethyl Methyl Ketone **(4)** *(R=Me).*
(A): The reactions between acetyl chloride and 1,1-difluoroethene in chloroform were carried out after the Knunyants procedure. Somewhat higher yield was obtained (Table 2).

(B): 1,1-Difluoroethene was absorbed into a mixture of acetyl chloride, FeCl$_3$, and dichloromethane at 0 °C. The procedure was similar to that of fluoroethene mentioned above, though the reaction was sluggish and it took $\approx$5 h. The product, even after distillation, was contaminated with unidentified impurities and the purity of **4** was $\approx$90% from the signal intensities of ^{1}H NMR.

2-Chloro-1,2,2-trifluoroethyl Methyl Ketone **(8)** *(R=Me).*
A mixture of AlCl$_3$ (16.0 g, 0.12 mol), acetyl chloride (7.85 g, 0.10 mol), and dichloromethane (100 ml) was placed in a pressure vessel, and was cooled in a Dry Ice–acetone bath. Liquefied trifluoroethene (9.0 g, 0.11 mol) was introduced into the vessel and the mixture was stirred at room temperature for 48 h and was poured onto a mixture of ice (100 g) and concd hydrochloric acid (10 ml). An oily layer was separated, washed with an aqueous solution of NaHCO$_3$, and dried over MgSO$_4$. After evaporating the solvent, distillation of the residue gave **8** (R=Me) (11.3 g), bp 98—100 °C (lit,[2] bp 99—100 °C), in 70% yield.

The reactions of trifluoroethene with other carboxylic acid chlorides using AlCl$_3$ were carried out in a similar manner. When benzoyl chloride was used, the product was separated by column chromatography on silica gel (solvent : hexane).

6-Chloro-5,6,6-trifluoro-2,4-hexanedione **(9)** *(R=Me; R′=H).*
(A): Into a mixture of FeCl$_3$ (32.4 g, 0.2 mol), acetyl chloride (15.7 g, 0.2 mol), and dichloromethane (100 ml) was introduced liquefied trifluoroethene (8.2 g, 0.1 mol) as described above. The mixture was allowed to react for 20 h at room temperature and the reaction mixture was worked up as usual. β-Diketone **9** (R=Me; R′=H) (8.1 g), bp 70—74 °C/23 mmHg, was obtained in 40% yield.

(B): Into a suspension of FeCl$_3$ (1.95 g, 12 mmol) in dichloromethane (10 ml), a mixture of acetyl chloride (0.40 g, 5 mmol) and 2-chloro-1,2,2-trifluoroethyl methyl ketone (0.80 g, 5 mmol) was dropped and the mixture was stirred for 24 h at room temperature under atmospheric pressure. The reaction mixture was worked up giving a β-diketone **9** (R=Me; R′=H) (0.70 g) in 70% yield.

References

1) B. L. Dyatkin, E. P. Mochalina, and I. L. Knunyants, "Fluorine Chemistry Reviews," Marcel Dekker, New York, N.Y. (1969), Vol. 3, p. 45.

2) I. L. Knunyants, R. N. Sterlin, L. N. Pinkina, and B. L. Dyatkin, *Izv. Akad. Nauk SSSR, Ser. Khim.*, **1958**, 296.

3) G. G. Belen'kii and L. S. German, *Izv. Akad. Nauk SSSR, Ser. Khim.*, **1974**, 942.

4) G. A. Olah, J. Nishimura, and Y. K. Mo, *Synthesis*, **1973**, 661.

5) S. Kondo, T. Akasaka, and K. Tsuda, *Nagoya Kogyo Daigaku Gaku-ho*, **26**, 231 (1974).

6) G. A. Olah, S. J. Kuhn, S. H. Flood, and B. A. Hardie, *J. Am. Chem. Soc.*, **86**, 1044 (1064).

7) G. A. Olah, S. J. Kuhn, and B. A. Hardie, *J. Am. Chem. Soc.*, **86**, 1055 (1964).

8) B. M. Perfetti and R. Levine, *J. Am. Chem. Soc.*, **75**, 626 (1953).