Chem. Pharm. Bull.
34(4)1546—1552(1986)

Studies on Organic Fluorine Compounds. IL.[1)]
The Ene Reaction of Trifluoroacetone[2)]

TAKABUMI NAGAI,[a] ITSUMARO KUMADAKI,*[,a] TAKUICHI MIKI,[a]
YOSHIRO KOBAYASHI,*[,b] and GINJIRO TOMIZAWA[b]

Faculty of Pharmaceutical Sciences, Setsunan University,[a] Nagaotoge-cho, Hirakata, Osaka 573–01, Japan and Tokyo College of Pharmacy,[b] Horinouchi, Hachioji, Tokyo 192–03, Japan

(Received September 9, 1985)

The ene reaction of 1,1,1-trifluoroacetone with various olefinic compounds proceeded in the presence of aluminum chloride at low temperature to give allylmethyl (trifluoromethyl)carbinols. Olefinic compounds with a terminal vinyl group reacted smoothly, but some olefins with an inner double bond did not react at all. Trifluoroacetone was also found to undergo a Friedel–Crafts type reaction with aromatic compounds.

Keywords——trifluoroacetone; trifluoromethyl; ene reaction; homoallyl alcohol; trifluoromethylcarbinol; Lewis acid-catalyzed reaction; aluminum chloride; allyl; olefin; diethylaluminum chloride

Hexafluoroacetone has two electronegative trifluoromethyl groups. Therefore, its carbonyl group undergoes many peculiar reactions. For example, hexafluoroacetone reacts as a good enophile with terminal olefins without any catalyst to give allylbis(trifluoromethyl)carbinols in good yields.[3,4)] (Chart 1) 1,1,1-Trifluoroacetone has only one trifluoromethyl group, but if it shows a similar reactivity to hexafluoroacetone, it may be useful for the synthesis of many kinds of trifluoro analogues of natural products. To examine possible applications of this reaction, 1,1,1-trifluoroacetone (**1**) was treated with olefins under conditions similar to those used for the reaction of hexafluoroacetone, but **1** did not react at all with olefinic compounds in the absence of a catalyst. For example, when allylbenzene was heated with **1** in a stainless steel tube, no products by the ene reaction were detected.

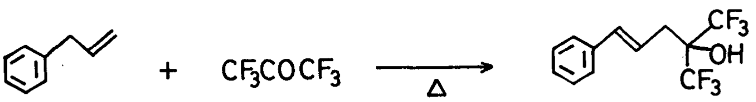

Chart 1

Recently, successful ene reactions using a Lewis acid as a catalyst have been reported by several authors.[5)] First, we examined zinc chloride as a catalyst. When zinc chloride was added to a solution of allylbenzene and **1** in benzene, the only isolated product was 2,2-diphenyl-1,1,1-trifluoropropane (**2**), the Friedel–Crafts reaction product of **1** with benzene. This result showed that the Friedel–Crafts reaction of **1** with benzene occurred in preference to the ene reaction with allylbenzene. The primary product of the Friedel–Crafts reaction, 2-phenyl-1,1,1-trifluoro-2-propanol (**3**), was not detected at all. Thus, **3** is more reactive than **1** in the Friedel–Crafts reaction and presumably reacted with another mole of benzene. This is in marked contrast to the very low reactivity of the hexafluoro analogue of **3** in the Friedel–Crafts reaction. To avoid reaction of the solvent, dichloromethane was used as a solvent, but no ene reaction products were obtained in this case. Diethylaluminum chloride was reported to be a good catalyst for the ene reaction.[5] Therefore, we examined the reaction in the presence of this compound, but the starting material was recovered. Boron trifluoride did not work as a catalyst, either. Next, aluminum chloride was tried. The addition of aluminum chloride to a solution of **1** and allylbenzene in dichloromethane at 40 °C caused a very drastic reaction to give tarry substances. Therefore, the reaction was examined at a lower temperature. Allylbenzene was added to a mixture of **1** and aluminum chloride in methylene chloride cooled at −15 °C. Even at this temperature, however, the only product obtained was a tarry mixture. This reaction was next attempted at −78 °C, and separation of the resulting products by high-performance liquid chromatography (HPLC) afforded 5-phenyl-2-(trifluoromethyl)-4-penten-2-ol (**4**), 2-methyl-5-phenyl-2-(trifluoromethyl)tetrahydrofuran (**5**), and 4-chloro-5-phenyl-2-(trifluoromethyl)pentan-2-ol (**6**) in the ratio of 65 : 21 : 14. Compound **4** was obtained as a colorless oil; bp 110 °C (4 mmHg). In the proton nuclear magnetic resonance (^{1}H-NMR) spectrum of **4**, the signal of the terminal methyl group appears at 1.40 ppm, while the two methylenic protons are not equivalent, and their signals appear at 2.50 and 2.64 ppm. The two olefinic protons appeared at 6.23 and 6.51 ppm, and the coupling constant between them was 15.7 Hz, which suggests that **4** is a *trans* isomer. In this case, no peak assignable to the *cis*-isomer was observed. This was supported by the fact that the fluorine-19 nuclear magnetic resonance (^{19}F-NMR) shows only one singlet at 19.53 ppm. Compound **5** was obtained as a colorless oil; bp 120 °C (17 mmHg). This is a mixture of ($2R^*,5R^*$)- and ($2R^*,5S^*$)-form. In the ^{1}H-NMR spectrum of the ($2R^*,5S^*$)-form, the signals of all the aromatic protons appear at a lower field than usual phenyl protons, while those of the ($2R^*,5R^*$)-form appear in a wide range. The signal of the methyl protons of the ($2R^*,5R^*$)-form appears at lower field than that of the ($2R^*,5S^*$)-form. This can be explained by the anisotropic effect of the benzene ring. Neither of the isomers shows a hydroxylic proton signal. Compound **6** was obtained as a colorless oil. The mass spectrum of **6** shows the presence of one chlorine atom. The parent peak was observed at *m/e* 266 and 268 in a ratio of 3 : 1. The chemical shifts and coupling pattern in the ^{1}H-NMR of **6** support the proposed structure. The treatment of **4** with aluminum chloride gave a mixture of **4** and **5** (approximate ratio of 4 : 1), while **6** was not formed from **4** under these conditions. Thus, **5** is derived from **4** by an acid-catalyzed cyclization, while **6** should be formed directly from the starting materials.

Next, the reaction of α-methylstyrene with **1** was examined in the presence of aluminum chloride at −78 °C. In this case, a small amount of 4-phenyl-2,6-bis(trifluoromethyl)-3-heptene-2,6-diol (**7**) was obtained with a large amount of tarry substances. Compound **7** was obtained as a mixture of *Z*/*E* isomers (*ca.* 20/1). The major isomer, *E*-4-phenyl-2,6-bis(trifluoromethyl)-3-heptene-2,6-diol (**7a**) was isolated as colorless crystals (6.3%). Its mass spectrum shows the parent peak at *m/e* 342, which suggests that this compound is a 1 : 2 adduct. Its ^{1}H-NMR spectrum shows the presence of two terminal methyl groups, two methylenic protons, one vinyl proton and two hydroxylic protons. The ^{19}F-NMR spectrum shows two trifluoromethyl signals. The NMR spectra of the minor isomer, *Z*-4-phenyl-2,6-bis(trifluoromethyl)-3-heptene-2,6-diol (**7b**), are quite similar to those of the major isomer, but the signal of the trifluoromethyl group at the 2-position of **7b** appears at lower field than that of **7a**. This may be attributed to the anisotropic effect of the benzene ring. This result suggested that α-methylstyrene is much more reactive than allylbenzene. Thus, we tried this reaction in the presence of diethylaluminum chloride as a catalyst. In this case, 4-phenyl-2-(trifluoromethyl)-4-penten-2-ol (**8**) was obtained in a yield of 51% together with a small amount of the 3-penten-1-ol isomer (**9**). Compound **8** was obtained as a colorless oil. Its mass spectrum shows the parent peak at *m/e* 230. Its ^{1}H-NMR spectrum shows presence of one methyl group, two olefinic protons, and two methylenic protons. On the other hand, the minor product (**9**) has two methyl groups and only one vinyl proton. Compound **8** has a terminal vinyl group, but it did not react with another mole of **1**. This result indicates that diethylaluminum chloride is a mild catalyst.

On the other hand, the reaction of β-methylstyrene with **1** did not proceed at all in the presence of diethylaluminum chloride, while the use of aluminum chloride caused the formation of a mixture of tarry substances. These results are summarized in Chart 2.

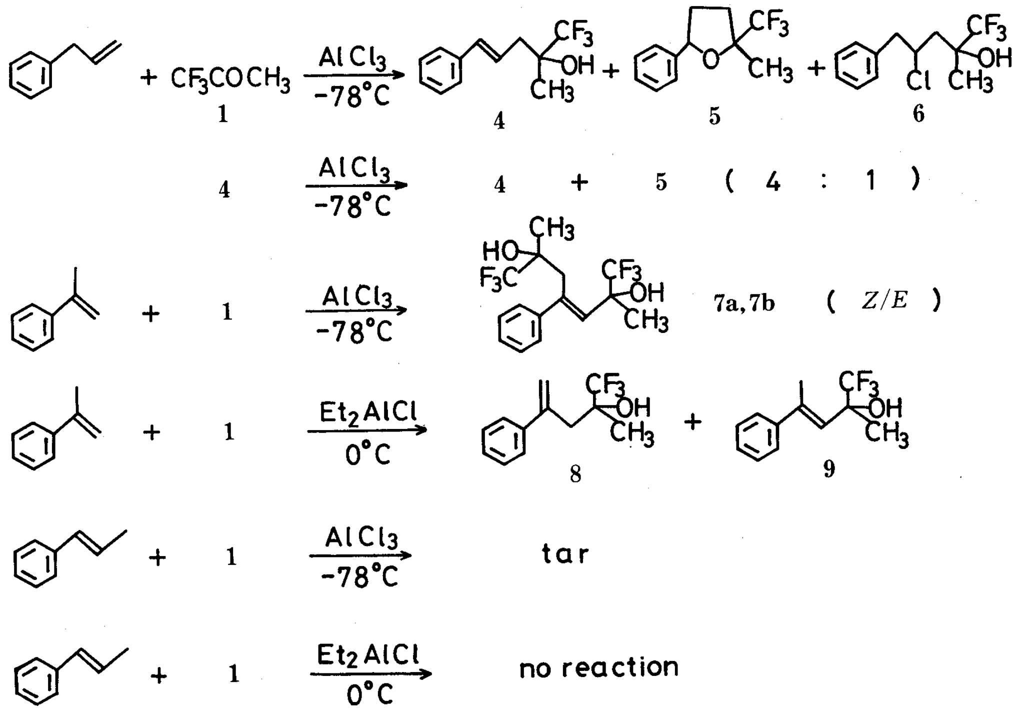

Chart 2

This chart shows that **1** is much less reactive than hexafluoroacetone, but that aluminum chloride is a good catalyst for the ene reaction of **1**. A terminal vinyl group is necessary for the ene reaction of **1**, as in the case of hexafluoroacetone.[4)]

Next, we examined the reaction with olefinic compounds lacking a benzene ring. The reaction of 1-octene with **1** in the presence of aluminum chloride at −78 °C gave 2-(trifluoromethyl)-4-decen-2-ol (**10**), the desired product, in a yield of 79.2% with 11.0% of 5-pentyl-2-methyl-2-(trifluoromethyl)tetrahydrofuran (**11**), while diethylaluminum chloride did not work at all as a catalyst. Compound **10** was obtained as a colorless oil (bp 99—101 °C (50 mmHg)). The ^{1}H-NMR spectrum shows that **10** has two methyl groups and two olefinic protons. The large coupling constant between the olefinic protons suggests that **10** is the *E*-form. The ^{19}F-NMR spectrum shows a sharp singlet at 19.38 ppm with another small singlet, suggesting that **10** contains a small amount of an isomer (probably *Z*-, about 10% of the isolated oil). Compound **11** was obtained as a colorless oil. The ^{1}H-NMR spectrum of **11** does not show any olefinic or hydroxylic protons. Treatment of **10** under the same reaction conditions gave a mixture of **10** and **11**. The reactions of 1-hexene and 1-decene gave results similar to that with 1-octene. Interestingly, the reaction of cyclohexene with **1** in the presence of aluminum chloride at −78 °C gave 2-(2-cyclohexen-1-yl)-1,1,1-trifluoro-2-propanol (**16**) in a yield of 53%, though cyclohexene has no terminal vinyl group. Further, 2-octene reacted with **1** under similar conditions but with a longer reaction time to give 3-methyl-2-(trifluoromethyl)-4-nonen-2-ol (**17**, 46.5%) with a trace of 4-butyl-2,3-dimethyl-2-(trifluoromethyl)tetrahydrofuran (**18**). Compounds **17** and **18** were separated by SiO_2 column chromatography. Compound **17** was obtained as a colorless oil (46.5%), and its ^{1}H-NMR spectrum shows three terminal methyl signals at 0.90, 1.09 and 1.28 ppm. Two olefinic protons appear at 5.42 and 5.61 ppm. The large coupling constant between them suggests that the olefinic part is the *E*-form. The ^{19}F-NMR spectrum shows only one peak. In this reaction, no other regio- or stereoisomers of **17** were isolated. Compound **18** was isolated in 1.5% yield. We could not determine the stereochemistry of **18** completely, but other isomers were not isolated. These results suggest that this reaction is highly regio- and stereoselective. The result with *β*-methylstyrene should not be attributed only to the absence of a terminal vinyl group; the phenyl group seems to deactivate the double bond. These results are summarized in Chart 3.

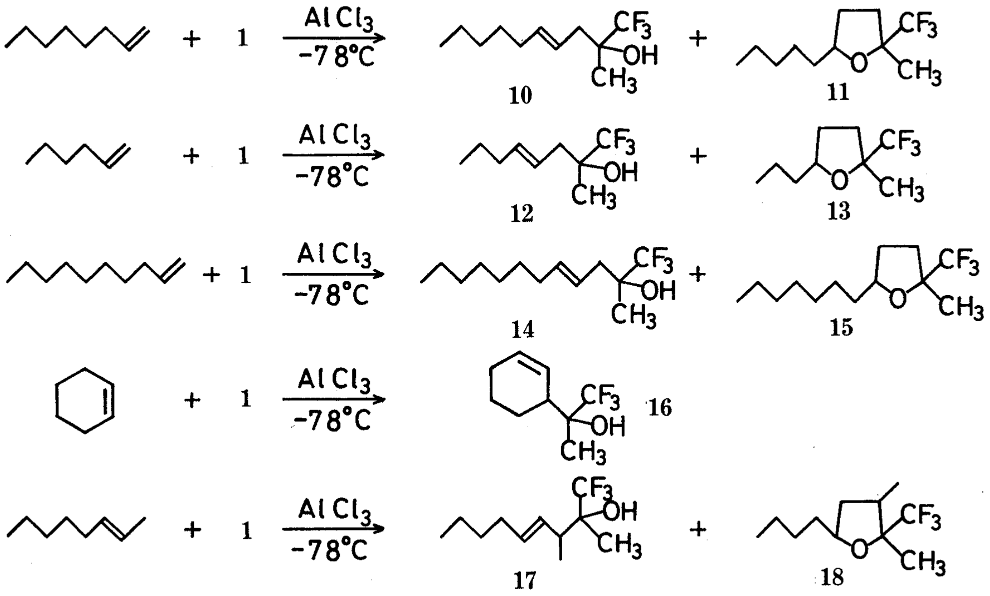

Chart 3

Finally, we examined the reaction of **1** with compounds where an allyl group was connected with a benzene ring through a hetero atom. We expected that the presumed product might be hydrolyzed to 3-hydroxy-3-(trifluoromethyl)butanal, which could be used for the synthesis of fluorine analogues of natural products. However, the reaction of allyl phenyl ether with **1** in the presence of aluminum chloride gave a complex mixture of products, from which only small amounts of 2,2-bis(4-allyloxyphenyl)-1,1,1-trifluoropropane (**19**), a Friedel–Crafts reaction product, and its isomer (**20**) were isolated. The reaction of allyl phenyl sulfide resulted in the recovery of starting materials with formation of a small amount of 1,2-bis(phenylthio)propane (**21**) (Chart 4).

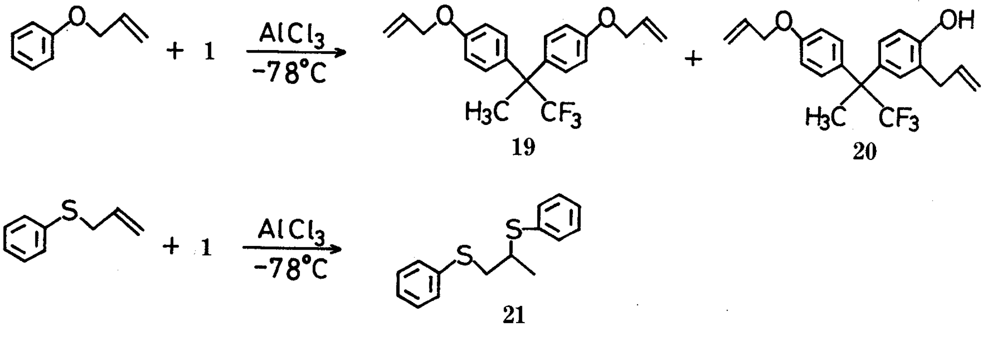

Chart 4

In conclusion, **1** was found to react with olefinic compounds as a good enophile in the presence of aluminum chloride. This reaction should be useful for this synthesis of trifluoromethylated homoallylic alcohol derivatives.

Experimental

Reaction of 1,1,1-Trifluoroacetone (1) with Allylbenzene——Aluminum chloride (1.0 g) was added to a reaction flask under a stream of argon, then CH_2Cl_2 (10 ml) and **1** (1.4 g) was added through a cannula under stirring. After the aluminum chloride had dissolved (a few minutes), the mixture was cooled to $-78\,°C$ and allylbenzene (1.3 g) was added at this temperature. The whole was stirred at this temperature for 1 h, then poured into ice-water and extracted with Et_2O. The extract was dried over $MgSO_4$ and the solvent was evaporated off under vacuum. Analysis of the ^{19}F-NMR spectrum of the residue (2.74 g, 97.5%) showed that it contained three components (**4**, **5** and **6**; ratio 65 : 21 : 14). These components were isolated by medium-pressure column chromatography (SiO_2; CH_2Cl_2–hexane, 1 : 2).

5-Phenyl-2-(trifluoromethyl)pent-4-en-2-ol (**4**): Colorless oil, bp 110 °C (4 mmHg). MS *m/e*: 230 (M^+); high-resolution MS Calcd for $C_{12}H_{13}F_3O$: 230.092. Found 230.092. ^1H-NMR ($CDCl_3$) (ppm from tetramethylsilane): 1.40 (3H, s), 2.16 (1H, s), 2.50 (1H, dd, $J=16.2$, 8.6 Hz), 2.64 (1H, dd, $J=16.2$, 7.4 Hz), 6.23 (1H, ddd, $J=15.7$, 8.6, 7.4 Hz), 6.51 (1H, d, $J=15.7$ Hz), 7.18—7.50 (5H, m). ^{19}F-NMR ($CDCl_3$) (ppm from $C_6H_5C\underline{F}_3$) 19.53 (s).

2-Methyl-5-phenyl-2-(trifluoromethyl)tetrahydrofuran (**5**): Colorless oil, bp 120 °C (17 mmHg). MS *m/e*: 230 (M^+); high-resolution MS Calcd for $C_{12}H_{13}F_3O$: 230.092. Found 230.091. [($2R^*$,$5R^*$)-form]; ^1H-NMR ($CDCl_3$) δ: 1.49 (3H, d, $J=1.0$ Hz), 1.67—2.59 (4H, m), 5.04 (1H, dd, $J=8.0$, 5.1 Hz), 7.07—7.64 (5H, m). ^{19}F-NMR ($CDCl_3$) δ: 18.30 (s). [($2R^*$,$5S^*$)-form]; ^1H-NMR ($CDCl_3$) δ: 1.52 (3H, d, $J=1.0$ Hz), 1.70—2.62 (4H, m), 4.89—5.21 (1H, m), 7.45—7.60 (5H, m). ^{19}F-NMR ($CDCl_3$) δ: 18.45 (s).

4-Chloro-5-phenyl-2-(trifluoromethyl)pentan-1-ol (**6**): Colorless oil. MS *m/e*: 266 (M^+); high-resolution MS Calcd for $C_{12}H_{14}ClF_3O$: 266.069. Found 269.069. ^1H-NMR ($CDCl_3$) δ: 1.45 (3H, d, $J=0.7$ Hz), 2.11 (1H, dd, $J=15.6$, 8.5 Hz), 2.27 (1H, dd, $J=15.6$, 3.4 Hz), 2.56 (1H, s), 3.07 (2H, d, $J=7.0$ Hz), 4.46 (1H, dtd, $J=8.5$, 7.0, 3.4 Hz), 7.20—7.43 (5H, m). ^{19}F-NMR ($CDCl_3$) δ: 19.91 (s).

Reaction of 1 with α-Methylstyrene in the Presence of Aluminum Chloride——α-Methylstylene (1.18 g) was added to a solution of aluminum chloride (1.03 g) and **1** (1.78 g) in CH_2Cl_2 (60 ml) at $-78\,°C$ under stirring, and stirring was continued for 1 h under argon. The mixture was treated as above. The tarry residue was separated by column chromatography (SiO_2; AcOEt–hexane, 1 : 10) to give **7a** and **7b** (224 mg in total, 6.6%).

4-Phenyl-2,6-bis(trifluoromethyl)-3-heptene-2,6-diol (**7a**): Colorless crystals (216 mg). MS *m/e*: 342 (M^+); high-resolution MS Calcd for $C_{15}H_{16}F_6O_2$: 342.105. Found 342.106. ^1H-NMR ($CDCl_3$) δ: 0.94 (3H, s), 1.55 (3H, s), 2.77 (1H, d, $J=13.5$ Hz), 3.78 (1H, d, $J=13.5$ Hz), 5.77 (1H, s), 5.95 (1H, s), 6.22 (1H, s), 7.02—7.82 (5H, m). ^{19}F-NMR ($CDCl_3$) δ: 20.33 (3F, s), 21.05 (3F, s).

4-Phenyl-2,6-bis(trifluoromethyl)-3-heptene-2,6-diol (**7b**): Colorless crystals (11.1 mg). MS *m/e*: 342 (M^+); high-resolution MS Calcd for $C_{15}H_{16}F_6O_2$: 342.105. Found 342.106. ^1H-NMR ($CDCl_3$) δ: 0.92 (3H, s), 1.64 (3H, s), 2.83 (1H, d, $J=13.9$ Hz), 3.81 (1H, d, $J=13.9$ Hz), 5.73 (2H, s), 6.33 (1H, s), 7.05—7.81 (5H, m). ^{19}F-NMR ($CDCl_3$) δ: 18.88 (3F, s), 20.97 (3F, s).

Reaction of 1 with α-Methylstyrene in the Presence of Diethylaluminum Chloride——A solution of Et_2AlCl (1 mol/l, 5 ml) was added to a solution of **1** (0.56 g) in CH_2Cl_2 (20 ml) at 0 °C and the solution was stirred for a few minutes at room temperature. α-Methylstyrene (0.59 g) was added to this solution at 0 °C. The mixture was stirred for 1 h at this temperature and worked up as above. Two products (**8** and **9**) were purified on an SiO_2 column in CH_2Cl_2-solution.

4-Phenyl-2-(trifluoromethyl)-4-penten-2-ol (**8**): Colorless oil (0.59 g, 51.4%). MS *m/e*: 230 (M^+); high-resolution MS Calcd for $C_{12}H_{13}F_3O$: 230.092. Found 230.091. ^1H-NMR ($CDCl_3$) δ: 1.22 (3H, s), 1.95 (1H, s), 2.76 (1H, d, $J=14.0$ Hz), 3.09 (1H, d, $J=14.0$ Hz), 5.02—5.27 (1H, m), 5.47—5.58 (1H, m), 7.13—7.53 (5H, m). ^{19}F-NMR ($CDCl_3$) δ: 20.10 (s).

4-Phenyl-2-(trifluoromethyl)-3-penten-2-ol (**9**): Colorless oil (14 mg, 1.2%). MS *m/e*: 230 (M^+); high-resolution MS Calcd for $C_{12}H_{13}F_3O$: 230.092. Found 230.092. ^1H-NMR ($CDCl_3$) δ: 1.61 (3H, br s), 2.21 (1H, s), 2.34 (3H, br s), 5.86 (1H, s), 7.19—7.46 (5H, m). ^{19}F-NMR ($CDCl_3$) δ: 20.85 (s).

Reaction of 1 with 1-Octene in the Presence of Aluminum Chloride——Aluminum chloride (1.2 g) was dried in a reaction flask and CH_2Cl_2 (10 ml) was added under argon. To this mixture, **1** (3.0 g) was added through a cannula. After aluminum chloride had dissolved completely under stirring, the mixture was cooled to $-78\,°C$ and 1-octene (2.86 g) was added under stirring. Stirring was continued at this temperature for 1 h, then the mixture was worked up as above. The extract was found to contain **10** and **11** in the ratio of 99 : 1 as estimated by gas-liquid chromatography (GLC). After evaporation of the solvent, the residue was separated by column chromatography (SiO_2; CH_2Cl_2–hexane, 1 : 5).

2-(Trifluoromethyl)-4-decen-2-ol (**10**): Colorless oil (4.52 g, 79.2% after isolation). bp 99—101 °C (50 mmHg). MS *m/e*: 224 (M^+); high-resolution MS Calcd for $C_{11}H_{19}F_3O$: 224.139. Found 224.139. ^1H-NMR ($CDCl_3$) δ: 0.90 (3H, t, $J=7.0$ Hz), 1.23—1.42 (6H, m), 1.33 (3H, s), 2.06 (2H, dt, $J=7.2$, 7.2 Hz), 2.07 (1H, s), 2.28 (1H, dd, $J=14.3$, 8.2 Hz), 2.47 (1H, dd, $J=14.3$, 6.7 Hz), 5.44 (1H, ddd, $J=15.1$, 8.2, 6.7 Hz), 5.62 (1H, d t, $J=15.1$, 7.2 Hz). ^{19}F-NMR ($CDCl_3$) δ: 19.38 (s). The presence of a small amount of an isomer (probably *cis*-, about 10% of the isolated oil) was detected by ^{19}F-NMR.

5-Pentyl-2-methyl-2-(trifluoromethyl)tetrahydrofuran (**11**): Colorless oil (0.63 g, 11.0%). MS *m/e*: 224 (M^+); high-resolution MS Calcd for $C_{11}H_{19}F_3O$: 224.139. Found 223.138. ^{1}H-NMR ($CDCl_3$) δ: 0.88 (3H, t, $J=6.9$ Hz), 1.20—1.50 (7H, m), 1.37 (3H, q, $J=1.0$ Hz), 1.60—1.70 (2H, m), 1.73—1.84 (1H, m), 1.97—2.06 (1H, m), 2.30 (1H, ddd, $J=12.8$, 8.2, 3.2 Hz), 4.01—4.10 (1H, m). ^{19}F-NMR ($CDCl_3$) δ: 18.8 (s). The isolated yield of **11** was much higher than that estimated by GLC of the extract of the reaction mixture. This suggests that some of **10** was converted to **11** during the separation.

Reaction of 1 with 1-Hexene in the Presence of Aluminum Chloride——By the same procedure as above, aluminum chloride (1.05 g), CH_2Cl_2 (20 ml), **1** (1.30 g) and 1-hexene (0.85 g) were mixed at -78 °C. The mixture was stirred for 1 h at this temperature, then worked up as above. The products were separated by column chromatography (SiO_2; CH_2Cl_2–pentane, 1 : 4) to give **12** and **13**.

2-(Trifluoromethyl)-4-octen-2-ol (**12**): Colorless oil (1.12 g, 57.0%), bp 95 °C (65 mmHg) (bulb-to-bulb distillation). MS *m/e*: 196 (M^+); high-resolution MS Calcd for $C_9H_{15}F_3O$: 196.108. Found 196.108; ^{1}H-NMR ($CDCl_3$) δ: 0.90 (3H, t, $J=7.0$ Hz), 1.19—1.65 (2H, m), 1.32 (3H, br s), 1.87—2.67 (4H, m), 2.17 (1H, s), 5.20—5.89 (2H, m). ^{19}F-NMR ($CDCl_3$) δ: 19.40 (s).

2-Methyl-5-propyl-2-(trifluoromethyl)tetrahydrofuran (**13**): Colorless oil (75.2 mg, 3.8%). bp 100—110 °C (bulb-to-bulb distillation). MS *m/e*: 196 (M^+); high-resolution MS Calcd for $C_9H_{15}F_3O$: 196.108. Found 196.110. ^{1}H-NMR ($CDCl_3$) δ: 0.93 (3H, t, $J=6.0$ Hz), 1.06—2.58 (8H, m), 1.36 (3H, br s), 3.89—4.28 (1H, m). ^{19}F-NMR ($CDCl_3$) δ: 18.82 (s). Careful examination of the ^{19}F-NMR spectrum of **12** and **13** did not indicate the presence of any isomers.

Reaction of 1 with 1-Decene in the Presence of Aluminum Chloride——By the same procedure as in the case of 1-octene, aluminum chloride (1.23 g), CH_2Cl_2 (20 ml), **1** (3 g), and 1-decene (1.40 g) were mixed at -78 °C and stirred for 1 h at this temperature. After work-up as above, the crude oil was separated on an SiO_2-column in CH_2Cl_2–hexane (1 : 4) to give 2-(trifluoromethyl)-4-dodecen-2-ol (**14**) and 5-heptyl-2-methyl-2-(trifluoromethyl)tetrahydrofuran (**15**).

14: Colorless oil (1.77 g, 70.3%), bp 80—110 °C (3.5 mmHg) (bulb-to-bulb distillation). MS *m/e*: 252 (M^+); high-resolution MS Calcd for $C_{13}H_{23}F_3O$: 252.170. Found 252.170. ^{1}H-NMR ($CDCl_3$) δ: 0.67—2.65 (17H, m), 1.32 (3H, s), 2.14 (1H, s), 5.20—5.90 (2H, m). ^{19}F-NMR ($CDCl_3$) δ: 19.40 (s).

15: Colorless oil (140.9 mg, 5.6%), MS *m/e*: 252 (M^+); high-resolution MS Calcd for $C_{13}H_{23}F_3O$: 252.170. Found 252.170. ^{1}H-NMR ($CDCl_3$) δ: 0.48—2.55 (19H, m), 1.37 (3H, s), 3.83—4.31 (1H, m). ^{19}F-NMR ($CDCl_3$) δ: 18.82 (s).

Reaction of 1 with Cyclohexene——By the same procedure as above, aluminum chloride (1.12 g), CH_2Cl_2 (20 ml), **1** (1.12 g), and cyclohexene (0.82 g) were mixed at -78 °C and stirred for 1 h at this temperature. After work-up as above, the crude products were passed through an SiO_2 column in hexane–AcOEt (50 : 1) to give 2-(2-cyclohexen-1-yl)-1,1,1-trifluoro-2-propanol (**16**).

16: Colorless oil (1.03 g, 53.3%). MS *m/e*: 194 (M^+); high-resolution MS Calcd for $C_9H_{13}F_3O$: 194.092. Found 194.092. ^{1}H-NMR ($CDCl_3$) δ: 0.89—2.23 (6H, m), 1.27 (3H, br s), 2.03 (1H, s), 2.43—2.77 (1H, m), 5.78—6.22 (2H, m). ^{19}F-NMR ($CDCl_3$) δ: 16.25 (s).

Reaction of 1 with 2-Octene——By the same procedure as above, aluminum chloride (660 mg), CH_2Cl_2 (15 ml), **1** (660 mg), and 2-octene (560 mg) were mixed and stirred at -78 °C for 3 h. The mixture was poured into a mixture of ice and conc. HCl, and the whole mixture was extracted with Et_2O. The extract was dried over $MgSO_4$ and concentrated under vacuum. The residue was separated by column chromatography (SiO_2; CH_2Cl_2–hexane 1 : 5) to give 3-methyl-2-(trifluoromethyl)-4-nonen-2-ol (**17**) and 5-butyl-2,3-dimethyl-2-(trifluoromethyl)tetrahydrofuran (**18**).

17: Colorless oil (521 mg, 46.5%). MS *m/e*: 224; high-resolution MS Calcd for $C_{11}H_{19}F_3O$: 224.139. Found 224.139. ^{1}H-NMR ($CDCl_3$) δ: 0.90 (3H, t, $J=7.1$ Hz), 1.09 (3H, dq, $J=7.0$, 1.1 Hz), 1.28 (3H, q, $J=1.0$ Hz), 1.25—1.40 (4H, m), 2.05 (2H, td, $J=7.0$, 7.0 Hz), 2.14 (1H, s), 2.57 (1H, dq, $J=7.0$, 7.0 Hz), 5.42 (1H, dd, $J=15.3$, 7.0 Hz), 5.61 (1H, dt, $J=15.3$, 7.0 Hz). ^{19}F-NMR ($CDCl_3$) δ: 15.96 (s).

18: Colorless oil (1.8 mg, 1.2%). MS *m/e*: 224. ^{1}H-NMR ($CDCl_3$) δ: 0.89 (3H, t, $J=7.0$ Hz), 1.05 (3H, d, $J=7.1$ Hz), 1.21 (3H, q, $J=1.2$ Hz), 1.12—1.36 (8H, m), 2.53 (1H, qdd, $J=7.1$, 7.1, 7.1 Hz), 3.86—4.29 (1H, m). ^{19}F-NMR ($CDCl_3$) δ: 18.24 (s).

Reaction of 1 with Allyl Phenyl Ether——By the same procedure as in the case of 1-octene, aluminum chloride (1.28 g), CH_2Cl_2 (20 ml), **1** (1.62 g) and allyl phenyl ether (1.93 g) were mixed and stirred at -78 °C for 2 h. The mixture was worked up as usual. Separation of the products by column chromatography gave only small amounts of 2,2-bis(4-allyloxyphenyl)-1,1,1-trifluoropropane (**19**) and 2-(3-allyl-4-hydroxyphenyl)-2-(4-allyloxyphenyl)-1,1,1-trifluoropropane (**20**).

19: Colorless oil. MS *m/e*: 362 (M^+). ^{1}H-NMR ($CDCl_3$) δ: 1.86 (3H, s), 4.44—4.66 (4H, m), 5.17—5.58 (4H, m), 5.84—6.35 (2H, m), 6.82 (4H, d, $J=8.7$ Hz), 7.18 (4H, d, $J=8.7$ Hz). ^{19}F-NMR ($CDCl_3$) δ: 6.62 (s).

20: Colorless oil. MS *m/e*: 362 (M^+). ^{1}H-NMR ($CDCl_3$) δ: 1.85 (3H, s), 3.36 (2H, d, $J=6.3$ Hz), 4.45—4.66 (2H, m), 4.95—5.57 (4H, m), 5.06 (1H, s), 5.75—6.38 (2H, m), 6.61—7.40 (7H, m). ^{19}F-NMR ($CDCl_3$) δ: 6.62.

Reaction of 1 with Allyl Phenyl Sulfide——By the same procedure as above, aluminum chloride (1.12 g), CH_2Cl_2 (20 ml), **1** (4.5 g) and allyl phenyl sulfide (1.5 g) were mixed and stirred at $-78\,^{\circ}C$ for 1 h. After usual work-up, the extract was passed through an SiO_2 column in CH_2Cl_2–hexane (1 : 10) to give allyl phenyl sulfide (the starting material, 0.814 g, 54%) and 1,2-bis(phenylthio)propane (**21**).

21: Colorless oil (183 mg, 12.2%). MS *m/e*: 260 (M^+). ^{1}H-NMR ($CDCl_3$) δ: 1.42 (3H, d, $J=6.6$ Hz), 2.76 (1H, dd, $J=13.8$, 10.4 Hz), 3.27 (1H, ddq, $J=10.4$, 3.4, 6.6 Hz), 3.29 (1H, dd, $J=13.8$, 3.4 Hz), 7.08—7.62 (10H, m).

Acknowledgement This work was supported in part by a Grant from Central Research Laboratory of Osaka Institute of Technology.

References and Notes

1) Part XLVIII: T. Taguchi, T. Morikawa, T. Takigawa, A. Yoshizawa, Y. Tawara, and Y. Kobayashi, *Nippon Kagaku Kaishi*, **1985**, 2177.
2) A part of this work was presented in the 104th Annual Meeting of Pharmaceutical Society of Japan, Sendai, March, 1984.
3) Urry *et al.* reported the reaction of hexafluoroacetone without referring it as an ene reaction. W. H. Urry, J. H. Y. Niu, and L. G. Lungsted, *J. Org. Chem.*, **33**, 2302 (1968).
4) Y. Kobayashi, T. Nagai, and I. Kumadaki, *Chem. Pharm. Bull.*, **32**, 5031 (1984).
5) B. B. Snider, *Acc. Chem. Res.*, **13**, 426 (1980), and references cited therein.