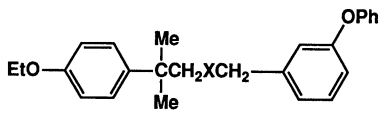
  Bull. Chem. Soc. Jpn., 65, 2401—2410 (1992)

Synthesis of Non-Ester Pyrethroids Having a 1-Fluoro-1-methylethyl Group Using 1,2-Migration of an Aryl Group[1)]

Hideki UNEME* and Yoshiyuki OKADA
Agricultural Research Laboratories, Agro Division, Takeda Chemical Industries, Ltd.,
10 Wadai, Tsukuba, Ibaraki 300-42
(Received April 8, 1992)

When 1,4-diaryl-4-methyl-1,3-pentanediol was treated with diethylaminosulfur trifluoride to introduce fluorine atoms into the central link, 1,2-aryl group migration products which have a 1-fluoro-1-methylethyl group were obtained as two diastereomers. Utilizing this migration, some non-ester pyrethroids possessing a 1-fluoro-1-methylethyl group were prepared. The reactivity of other fluorinating reagents is also discussed.

A number of fluorinated bioactive compounds are in use as therapeutic and agrochemical agents. Some of them inhibit or mimic the activity of their parent compounds and others exhibit an improved biological activity when compared with their non-fluorinated counterparts by increasing lipid permeability and metabolic stability.[2)] This fluorination tactic has also been applied to pyrethroidal chemistry and some fluorinated pyrethroids have already been commercialized.[3)] Recently, a novel type of pyrethroids, so-called non-ester pyrethroids, which apparently have no structural similarity to the original pyrethrin (Fig. 1), were developed by Mitsui Toatsu Co., Ltd.[4)] Their success prompted us to modify these compounds by introducing a fluorine atom into them. As a result, a unique aryl group migration and fluorination was found when an alcohol which has two methyl groups and an aryl group at the α-position was allowed to react with diethylaminosulfur trifluoride (DAST). In this paper, although potently active compounds were not obtained, we report the migration-fluorination reaction of several types of alcohols and compare DAST to a few other fluorinating reagents with regard to this reaction.



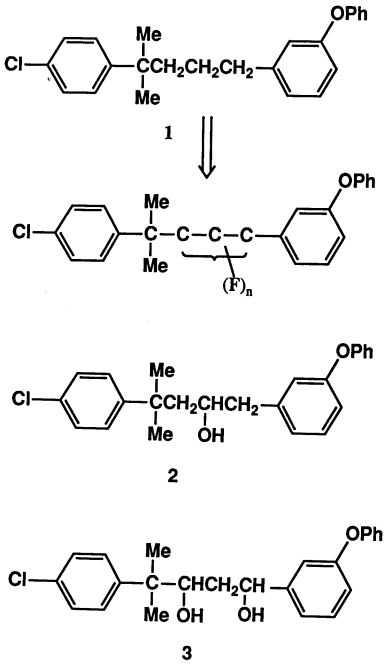
Etofenprox (X=O)
MTI-790 (X=CH_2)

Fig. 1. Non-Ester Pyrethroids.

Results and Discussion

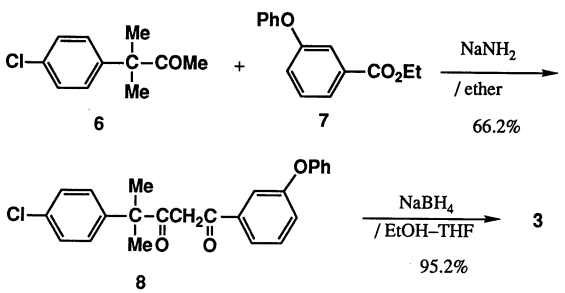
Reaction of Alcohols Possessing a 1,4-Diaryl-4-pentane Skeleton with DAST. Our first approach was to introduce (a) fluorine atom(s) into the bridged trimethylene part of the 4-chloro analog (**1**) of MTI-790.

Several methods have been developed to introduce a fluorine atom. In this case, replacement of a hydroxyl group with a fluorine atom seemed most convenient because of the ease of synthesis for the precursor alcohols and of their conversion. Compounds **2** and **3**, which have a hydroxyl group at the center and two hydroxyl groups at both ends of the trimethylene part of **1**, respectively, were selected as the precursors.

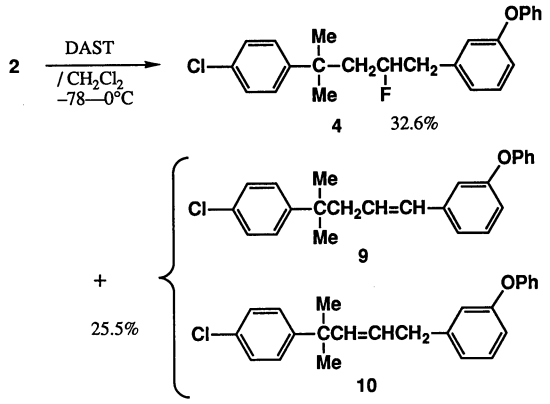


Alcohol **2** was prepared by the reported method.[5)] The synthetic route of diol **3** is shown in Scheme 1. Reaction of 3-(4-chlorophenyl)-3-methyl-2-butanone (**6**) with ethyl 3-phenoxybenzoate (**7**) in the presence of sodium amide[6)] afforded 1,3-dione **8**, which was reduced with sodium borohydride to give diol **3**.

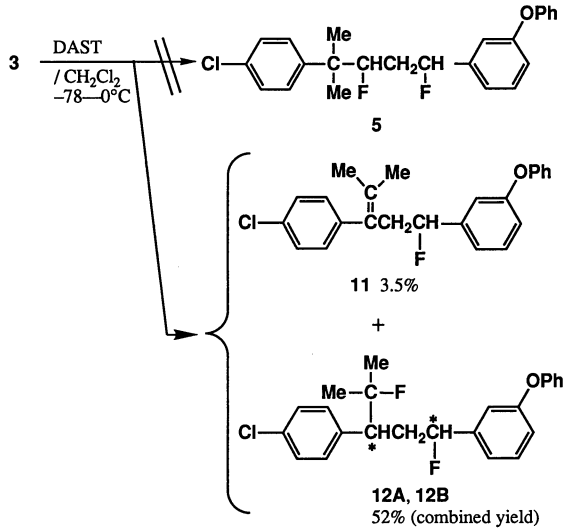
Among several reagents able to replace a hydroxyl group with fluorine, DAST was selected because of its



Scheme 1.



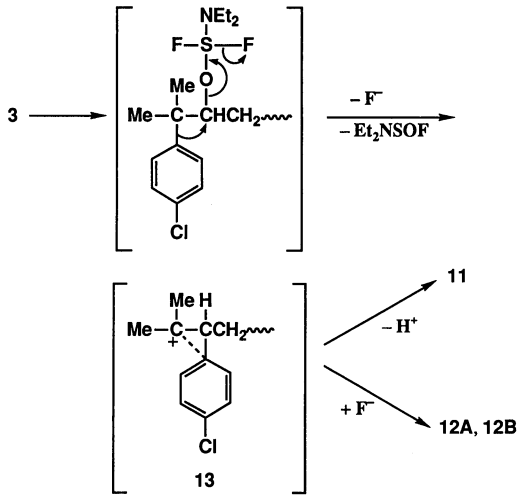
Scheme 2.



Scheme 3.

very mild reaction conditions.[7] The reactivity of other reagents will be discussed later. Thus, alcohol **2** was treated with DAST at −78—0°C in dichloromethane. The desired 4-(4-chlorophenyl)-2-fluoro-4-methyl-1-(3-phenoxyphenyl)pentane (**4**) was obtained in a 32.6% yield together with two dehydrated compounds, **9** and **10** (Scheme 2).

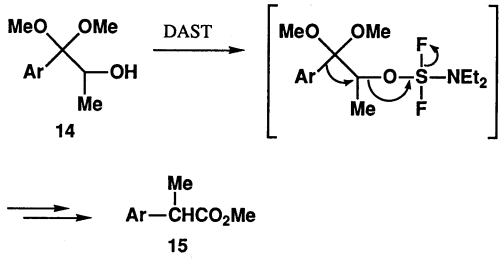
Unlike that above, the reaction of diol **3** with DAST did not afford difluoride **5**. Instead, three compounds, **11**, **12A** and **12B** (eluted in this order), were obtained after column chromatographic separation (Scheme 3). The structure of **11** was established unequivocally as 3-(4-chlorophenyl)-5-fluoro-2-methyl-5-(3-phenoxyphenyl)-2-pentene by its ^{1}H NMR spectrum [(CCl_4) δ=1.54 (3H, s), 1.73 (3H, s), 2.35—3.3 (2H, m), 5.14 (1H, ddd, J=47.4, 8.1, and 5.4 Hz), and 6.8—7.4 (13H, m)]. Elemental analyses and MS spectra of **12A** and **12B** indicated both of their molecular formulas as $C_{24}H_{23}ClF_2O$. The ^{1}H NMR peaks at δ=1.21 (3H, d, J=21.8 Hz) and 1.38 (3H, d, J=21.5 Hz) and the ^{13}C NMR peaks at δ=25.5 (J_{C-F}=24.8 Hz) and 26.3 (J_{C-F}=24.2 Hz) of **12A** suggested the existence of two methyl groups at the geminal



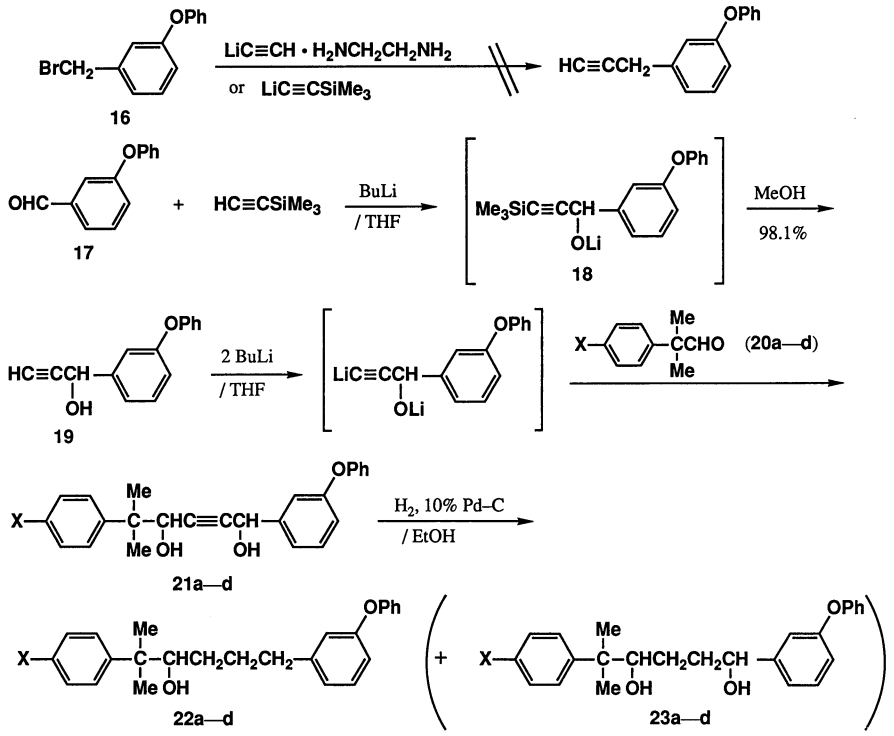
Scheme 4.

position of the fluorine atom. Considering this information and four one-proton peaks [δ=2.15 (dddd), 2.50 (tdd), 3.08 (ddd), and 4.97 (ddd)], **12A** was identified as 3-(4-chlorophenyl)-1,4-difluoro-4-methyl-1-(3-phenoxyphenyl) pentane. This structure was also well supported by other ^{13}C NMR signals. Compound **12B** was proposed to be the diastereomer of **12A** since the IR and MS spectra of **12A** and **12B** are roughly the same and their ^{13}C NMR showed the same pattern, although the ^{1}H NMR spectrum of **12B** [($CDCl_3$) δ=1.17 (3H, d, J=21.8 Hz),1.24 (3H, d, J=21.5 Hz), 2.40—2.59 (3H, m), and 5.06 (1H, dm, J=47.2 Hz)] was a little different from that of **12A**. The reaction mechanism is shown in Scheme 4. A fluorine atom was introduced at the 1-position in the usual manner. Whereas at the 3-position, migration of the 4-chlorophenyl group occurred to give cationic intermediate **13**. Attack of a fluoride ion at the cation center afforded **12A** and **12B**, while elimination of a proton from **13** lead to the formation of **11**.

It has already been reported that carbocation-type rearrangement occurs in the course of the reaction of DAST.[7,8] As an example of an alcohol, isobutyl alcohol gave isobutyl fluoride and *t*-butyl fluoride in yields of 49% and 21%, respectively.[7a] More recently, Yamauchi et al. reported that the reaction of α-hydroxypropiophenone derivatives (**14**) with DAST gave methyl 2-arylpropanoates (**15**) via a 1,2-aryl group



Scheme 5.



20—23: **a**, X=Cl; **b**, X=H; **c**, X=OMe; **d**, X=CF_3

Scheme 6.

migration (Scheme 5).[9] But in this case, a fluorine atom is not introduced into the product. As far as we know, the conversion of **3** with DAST into **12** is the first example of fluorination of an alcohol accompanied by 1,2-aryl group migration.

Reaction of Alcohols Possessing a 1,5-Diaryl-5-methylhexane Skeleton with Several Fluorination Reagents. Fluorinated compouds **12A** and **12B** exhibited almost no insecticidal activity. We attributed this to the shortened central linkage between the two aryl groups caused by the migration. Our next approach was to lengthen the central chain of **12** by one methylene unit.

To obtain the compounds mentioned above, the precursor alcohols **22** were prepared according to the route in Scheme 6. Although our first attempt to link 3-phenoxybenzyl bromide (**16**) with an acetylenic unit[10] was unsuccessful, the reaction of 3-phenoxybenzaldehyde (**17**) with lithium trimethylsilylacetylide afforded alcoholate **18**. At this stage, addition of MeOH was effective[11] for desilylation of **18** and acetylenic alcohol **19** was obtained in a quantitative yield. Condensation of **19** with 2-(4-chlorophenyl)-2-methylpropanal (**20a**) in the presence of two equivalents of butyllithium gave acetylenic diol **21a** in a yield of 74.7%. Catalytic hydrogenation of **21a** caused not only the reduction of the triple bond but of the benzylic hydroxyl group, giving alcohol **22a**. Likewise, unsubstituted, 4-methoxy, and 4-trifluoromethyl analogs (**22b**, **22c** and **22d**, respectively) were prepared (Table 1). Reduction of **21b** or **21c** afforded a mixture of mono-ol **22b** or **22c** and diol **23b** or **23c**.

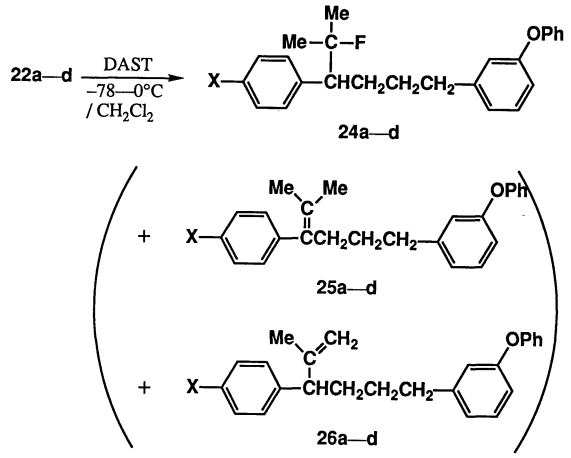
Table 1. Preparation of Acetylenic Diol **21** and Reduction Products **22** and **23**

	X	**21** (%)	**22** (%)	**23** (%)
a	Cl	74.7	49.5	Trace
b	H	60.4[a]	38.9	45.7
c	OMe	54.8	51.0	37.6
d	CF_3	47.8	76.0	Trace

a) LDA was employed as a base.

Alcohols **22a—d** were treated with DAST at −78—0°C to furnish the desired products: 4-Aryl-5-fluoro-5-methyl-1-(3-phenoxyphenyl)hexanes (**24a—d**)[12] in fair to good yields as expected (Scheme 7 and Table 2). In the case of **22d** (X=CF_3), a considerable amount of a mixture of dehydrates **25d** and **26d** were also formed. In each case, none of the compounds were detected which were expected to be obtained by fluorination without migration. It is important to note that phenyl groups substituted with an electron-withdrawing group such as 4-chloro- and 4-trifluoromethyl groups as well as an electron-donating group underwent 1,2-aryl group migration.

To examine the reactivity of other reagents reported to replace a hydroxyl group with fluorine, **22b** (X=H) was treated with hexafluoropropene–diethylamine (1:1)

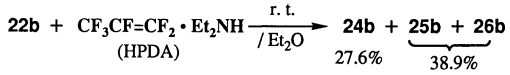


Scheme 7.

Table 2. Reaction of **22** with DAST

Run	22	X	24 (%)	25+26 (%)
1	a	Cl	48.9	<10[a,b]
2	b	H	77.2	<5[a,b]
3	c	OMe	79.0	—
4[c]	c	OMe	81.5	—
5	d	CF_3	55.1	28.3[a,d]

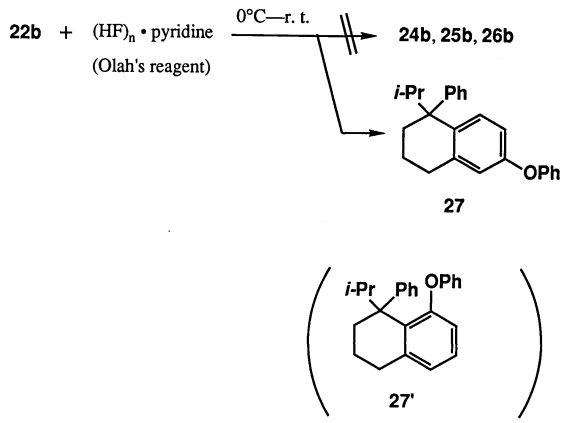
a) **25** and **26** could not be separated. b) Containing other by-product(s). c) Reaction was carried out at 0°C. d) Ca. 4:1 based on ^{1}H NMR.



Scheme 8.

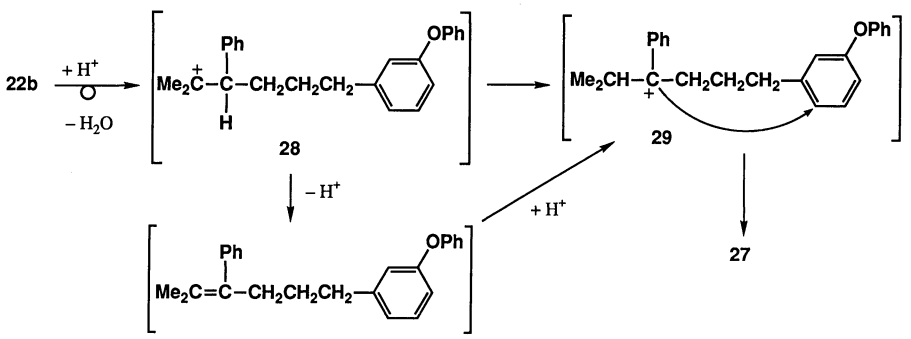
(HPDA)[13] and pyridinium poly(hydrogen fluoride) (Olah's reagent).[14] In the former case, the same product **24b** as the reaction with DAST was obtained in a 27.6% yield, but the formation of dehydrated products **25b** and **26b** was also observed in a combined yield of 38.9% (Scheme 8). This result agrees with Middleton's comment: "Dehydration appears to be less of a problem with DAST than other fluorinating reagents." [7a]

The reaction of **22b** with Olah's reagent proceeded in a completely different way; compounds **24b**, **25b**, and **26b**

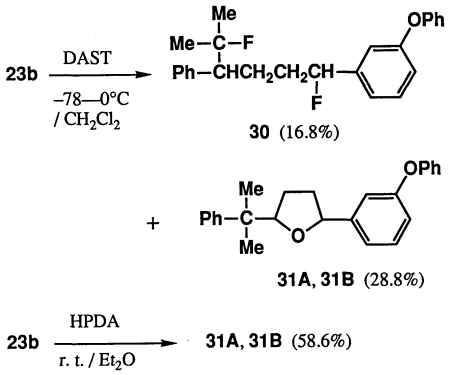


Scheme 9.

were not detected, but a compound which was free from fluorine atoms ($C_{25}H_{26}O$ based on elemental analysis and MS spectrum) was obtained as a major product (Scheme 9). ^{1}H and ^{13}C NMR indicated the existence of an isopropyl group [δ=0.84 (3H, d), 0.90 (3H, d), and ca. 2.6 (1H, m) in ^{1}H NMR and δ=18.2 (q), 19.3 (q), and 36.2 (d) in ^{13}C NMR], three methylenes [δ=19.4 (t), 30.1 (t), and 30.2 (t) in ^{13}C NMR), and a tertiary carbon [δ=48.9 (s) in ^{13}C NMR]. Thus the structure was determined to be 1-isopropyl-6-phenoxy-1-phenyl-1,2,3,4-tetrahydronaphthalene (**27**). The inhibition of free rotation of the phenyl group at the 1-position can account for sixteen peaks for aromatic carbons in the ^{13}C NMR spectrum (free rotation will afford fourteen kinds of carbon). The possibility that cyclization occurred at the ortho position of the phenoxyl group (**27'**) was rejected by the existence of a peak at δ=6.71 (1H, d, J=2.7 Hz) in the ^{1}H NMR spectrum assignable to the proton at the ortho position of the phenoxyl segment coupled *only* with one meta proton as well as by steric difficulty of formation. The proposed mechanism is shown in Scheme 10. Carbocation **28** was formed first by the migration of the phenyl group. A direct hydride shift or deprotonation followed by reprotonation afforded benzylic cation **29**. Electrophilic attack of the cationic center toward the 3-phenoxyphenyl group gave the cyclic product **27**. This result indicates that Olah's reagent did not function as a fluorinating agent unlike DAST and HPDA in this



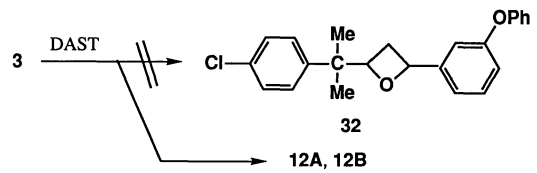
Scheme 10.



Scheme 11.

reaction system, but acted just as an acidic catalyst to produce a stable carbocation which subsequently underwent a Friedel–Crafts-type reaction.

As a next step, diol **23b** was treated with DAST and HPDA (Scheme 11). Several compounds were obtained with DAST; the three major products were identified as the desired double-fluorinated compound, **30**,[12] and two isomers of 2-(1-methyl-1-phenylethyl)-5-(3-phenoxyphenyl)tetrahydrofuran (**31A** and **31B**). In contrast to that above, the reaction of **23b** with HPDA predominantly afforded **31A** and **31B** accompanied by small amounts of unidentified by-products. To consider the easy formation of the five-membered cyclic tetrahydrofuran moiety, it is rather surprising that migrated-fluorinated product **30** was obtained in the case of DAST. This fact again reveals the excellent ability of DAST as a fluorinating reagent. Four-membered cyclic compound **32** was not obtained by the reaction of diol **3** with DAST because of the difficulty of formation of the oxetane moiety or the ring opening of the oxetanium ion once formed by the attack of a fluoride

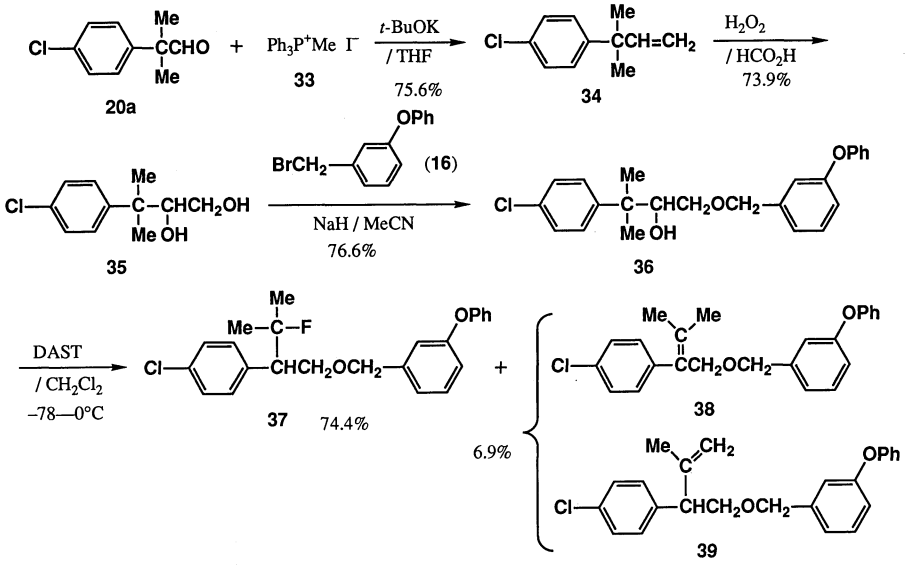


ion.

Synthesis of an Ether-Type Analog Having a 1-Fluoro-1-methylethyl Group. As already described, there are two main varieties of non-ester pyrethroids: ether type (e.g. etofenprox) and alkane type (e.g. MTI-790). As a last step, a compound which has an ether moiety as the central chain was synthesized according to Scheme 12. Aldehyde **20a** was condensed with methylene Wittig reagent **33** to give alkene **34**, which was oxidized with hydrogen peroxide in formic acid[15] to give diol **35**. The reaction of **35** with 3-phenoxybenzyl bromide (**16**) in the presence of one equivalent of sodium hydride took place predominantly at the primary hydroxyl group to form a key intermediate, hydroxy ether **36**. **36** was then treated with DAST to give the desired migrated-fluorinated product, **37**,[12] in a 74.4% yield accompanied by a small amount of dehydrated compounds **38** and **39**.

Experimental

General. Melting points were determined on a Yanagimoto micro melting point apparatus. Melting points and boiling points are uncorrected. The NMR spectra were measured on a Varian EM-390 (^{1}H; 90 MHz), Bruker AC-200P (^{1}H; 200 MHz, ^{13}C; 50 MHz, ^{19}F; 188 MHz) or JEOL JNM-GX270FT (^{1}H; 270 MHz, ^{13}C; 67.8 MHz) spectrometer using tetramethylsilane (^{1}H and ^{13}C) or fluorotrichloromethane (^{19}F) as an internal standard. IR spectra were recorded on a Shimadzu IR-435. Mass spectra were obtained with a



Scheme 12.

Shimadzu QP-1000 (70 eV) or JEOL JMS-AX505W (70 eV, for high-resolution mass measurements). Column chromatography was performed on silica gel (Kiesel gel 60, Merck Co., Ltd.). Some starting materials were prepared according to the reported procedures. Dry solvents were prepared by the usual methods. Other starting materials and solvents were commercially available and used without further purification.

Preparation of Alcohols. 4-(4-Chlorophenyl)-4-methyl-1-(3-phenoxyphenyl)-1,3-pentanedione (8): The procedure reported by Levine et al.[6] was applied. A solution of 3.37 g (0.0171 mol) of 3-(4-chlorophenyl)-3-methyl-2-butanone (**6**)[16] in dry ether (5 ml) was added dropwise to a mixture of 1.56 g (0.04 mol) of crushed sodium amide and 40 ml of dry ether over 10 min in a water bath (20 °C). After stirring for 15 min, a solution of 4.85 g (0.02 mol) of ethyl 3-phenoxybenzoate (**7**) in ether (5 ml) was added dropwise for 15 min. The reaction mixture was stirred under reflux for 4 h, poured into 100 ml of cooled 1 M hydrochloric acid (1 M=1 mol dm^{-3}) and extracted with ether twice. The extracts were dried over $MgSO_4$ and evaporated. Purification by column chromatography (CH_2Cl_2–hexane 2 : 3) gave 5.20 g (66.2%) of **8** as a viscous liquid: ^1H NMR ($CDCl_3$) δ=1.57 (6H, s), 5.93 (1H, s), 6.9—7.6 (13H, m), and 15.90 (1H, br. s). The ^1H NMR spectrum suggested it existed as an enol form.

4-(4-Chlorophenyl)-4-methyl-1-(3-phenoxyphenyl)-1,3-pentanediol (3): Sodium borohydride (0.75 g, 19.8 mmol) were added portionwise to a solution of **8** (1.32 g, 3.36 mmol) in EtOH (10 ml) and THF (5 ml) in a water bath (20 °C) over 2 min. The reaction mixture was stirred for 5.5 h at room temperature, poured into water (100 ml) and extracted with $CHCl_3$ twice. After being dried over $MgSO_4$ and evaporated, the residue was purified by column chromatography (CH_2Cl_2–MeOH 20 : 1) to give 1.27 g (95.2%) of **3** as a viscous liquid: ^1H NMR ($CDCl_3$) δ=1.1—1.4 (6H, m), 1.45—1.8 (2H, m), 2.01 (1H×2/3, d, J=3.9 Hz), 2.7—2.9 (1H×2/3+1H×1/3, m), 3.46 (1H×1/3, br. s), 3.65—4.05 (1H, m), 4.65—5.1 (1H, m), and 6.7—7.5 (13H, m); IR (neat) 3350 and 1580 cm^{-1}. Found: C, 72.42; H, 6.10%. Calcd for $C_{24}H_{25}ClO_3$: C, 72.63; H, 6.35%. The ^1H NMR spectrum showed it consisted of two diastereomers in a ratio of 1 : 2.

1-(3-Phenoxyphenyl)-2-propyn-1-ol (19): Butyllithium in hexane (1.6 M; 34.4 ml, 0.055 mol) were added dropwise to a solution of trimethylsilylacetylene (5.89 g, 0.06 mol) in dry THF (100 ml) at −78 °C under nitrogen atmosphere over 6 min. The acetone–Dry Ice bath was removed and the mixture was stirred for 30 min. Then, 9.91 g (0.05 mol) of 3-phenoxybenzaldehyde (**17**) were added dropwise at −78 °C for 15 min and the mixture was stirred at room temperature for 1.5 h. Methanol (50 ml) was added and after stirring for 2 h, the reaction mixture was poured into 200 ml of 2 M hydrochloric acid and extracted with ether twice. The extracts were washed with brine, dried over $MgSO_4$ and evaporated. The residue was column chromatographed (CH_2Cl_2–AcOEt 20 : 1) to give 11.0 g (98.1%) of **19** as a viscous liquid: ^1H NMR ($CDCl_3$) δ=2.33 (1H, d, J=6.1 Hz), 2.62 (1H, d, J=2.1 Hz), 5.42 (1H, dd, J=6.1 and 2.1 Hz), and 6.8—7.5 (9H, m).

5-(4-Chlorophenyl)-5-methyl-1-(3-phenoxyphenyl)-2-hexyne-1,4-diol (21a): Butyllithium in hexane (1.59 M; 6.92 ml, 11.0 mmol) were added dropwise to a solution of **19** (1.12 g, 5.0 mmol) in dry THF (15 ml) at −78 °C under nitrogen atmosphere over 5 min. After stirring for 30 min at this temperature, a solution of 2-(4-chlorophenyl)-2-methylpropanal (**20a**)[17] (0.91 g, 5.0 mmol) in 3 ml of THF was added dropwise for 5 min at −78 °C and stirring was continued for 2 h. The reaction was poured into 50 ml of 1 M hydrochloric acid and extracted with ether twice. The ethereal extracts were washed with brine, dried over $MgSO_4$ and evaporated. The residue was column chromatographed (CH_2Cl_2–MeOH 30 : 1) to give 1.52 g (74.7%) of **21a** as a liquid: ^1H NMR ($CDCl_3$) δ=1.33 (6H, s), 2.39 (1H, br. s), 2.97 (1H, br. s), 4.37 (1H, br. s), 5.34 (1H, br. s), and 6.8—7.5 (13H, m); IR (neat) 3300 and 1580 cm^{-1}.

According to this method, the following compounds were prepared. 5-Methyl-1-(3-phenoxyphenyl)-5-phenyl-2-hexyne-1,4-diol (**21b**) [60.4%, lithium diisopropylamide (1.56 M solution in THF–hexane, purchased from Toyo Staufer Co., Ltd.) was used as a base]: ^1H NMR ($CDCl_3$) δ=1.35—1.5 (6H, m), 1.8—2.0 (1H, m), 2.35—2.55 (1H, m), 4.4—4.55 (1H, m), 5.3—5.5 (1H, m), and 6.9—7.5 (14H, m). 5-(4-Methoxyphenyl)-5-methyl-1-(3-phenoxyphenyl)-2-hexyne-1,4-diol (**21c**) (54.8%): ^1H NMR ($CDCl_3$) δ=1.3—1.45 (6H, m), 1.92 (1H, br. d, J=ca. 6 Hz), 2.56 (1H, br. d, J=ca. 5 Hz), 3.76 (3H, s), 4.39 (1H, br. d, J=ca. 6 Hz), 5.39 (1H, br. d, J=ca. 5 Hz), and 6.75—7.45 (13H, m). 5-Methyl-1-(3-phenoxyphenyl)-5-[4-(trifluoromethyl)phenyl]-2-hexyne-1,4-diol (**21d**) (47.8%): ^1H NMR ($CDCl_3$) δ=1.39 (6H, s), 2.33 (2H, br. s), 4.4—4.5 (1H, m), and 6.9—7.65 (13H, m).

Reduction of 21a: A solution of **21a** (1.52 g, 3.74 mmol) in 50 ml of EtOH was hydrogenated in the presence of 0.2 g of 10% palladium–carbon at room temperature under atmospheric pressure. Absorption of hydrogen (290 ml) ceased within 45 min. The catalyst was filtered off and the filtrate was concentrated. Purification by column chromatography ($CHCl_3$) gave 0.73 g (49.5%) of 2-(4-chlorophenyl)-2-methyl-6-(3-phenoxyphenyl)-3-hexanol (**22a**): ^1H NMR ($CDCl_3$) δ=0.9—2.1 (11H, m), 2.54 (2H, t, J=7.7 Hz), 3.45—3.7 (1H, m), and 6.7—7.45 (13H, m); IR (neat): 3420 and 1580 cm^{-1}. Found: C, 76.16; H, 7.13%. Calcd for $C_{25}H_{27}ClO_2$: C, 76.03; H, 6.89%.

Reduction of 21b: According to the above-mentioned procedure, **21b** was reduced to give 2-methyl-6-(3-phenoxyphenyl)-2-phenyl-3-hexanol (**22b**) (38.9%) and 5-methyl-1-(3-phenoxyphenyl)-5-phenyl-1,4-hexanediol (**23b**) (45.5%).

22b: ^1H NMR ($CDCl_3$) δ=1.0—2.1 (11H, m), 2.55 (2H, t, J=7.5 Hz), 3.5—3.73 (1H, m), and 6.7—7.45 (14H, m).

23b: ^1H NMR ($CDCl_3$) δ=1.1—2.2 (11H, m), 2.6—3.3 (1H, m), 3.55—3.75 (1H, m), 4.45—4.8 (1H, m), and 6.8—7.5 (14H, m); ($CDCl_3$–D_2O) δ=1.1—1.9 (10H, m) 3.55—3.75 (1H, m), 4.45—4.8 (1H, m), and 6.8—7.5 (14H, m).

Reduction of 21c: Similarly, **21c** was reduced to give 2-(4-methoxyphenyl)-2-methyl-6-(3-phenoxyphenyl)-3-hexanol (**22c**) (51.0%) and 5-(4-methoxyphenyl)-5-methyl-1-(3-phenoxyphenyl)-1,4-hexanediol (**23c**) (37.6%).

22c: ^1H NMR ($CDCl_3$) δ=0.9—2.1 (11H, m), 2.56 (2H, t, J=7.5 Hz), 3.44—3.67 (1H, m), 3.78 (3H, s), and 6.7—7.45 (13H, m).

23c: ^1H NMR ($CDCl_3$–D_2O) δ=1.1—2.0 (10H, m), 3.5—3.7 (1H, m), 3.77 (3H, s), 4.5—4.75 (1H, m), and 6.7—7.45 (13H, m).

Reduction of 21d: The reduction of **21d** gave 2-methyl-6-(3-phenoxyphenyl)-2-[4-(trifluoromethyl)phenyl]-3-hexanol (**22d**) (76.0%): ^1H NMR ($CDCl_3$) δ=1.0—2.1 (11H, m), 2.56 (2H, t, J=7.5 Hz), 3.5—3.75 (1H, m), and 6.7—7.7 (13H, m).

3-(4-Chlorophenyl)-3-methyl-1-butene (34): Potassium *t*-butoxide (6.17 g, 0.055 mol) were added portionwise to an ice-

cooled mixture of 22.23 g (0.055 mol) of methyltriphenylphosphonium iodide (**33**) and 150 ml of dry THF over 10 min. The bath was removed and the mixture was stirred for 40 min. A solution of 9.13 g (0.05 mol) of **20a** in THF was added dropwise over 20 min at room temperature and after stirring for 2 h, the reaction mixture was poured into 200 ml of cold water. The mixture was extracted with $CHCl_3$ twice and the extracts were dried over $MgSO_4$ and evaporated. Hexane (200 ml) was added to the residue, insoluble triphenylphosphine oxide was removed by filtration, and the mother liquid was concentrated. Distillation under reduced pressure gave 6.83 g (75.6%) of **34**: Bp 122—123°C/30 mmHg (1 mmHg=133.322 Pa); ^{1}H NMR ($CDCl_3$) δ=1.35 (6H, s), 4.9—5.15 (2H, m), 5.98 (1H, dd, J=17.9 and 10.1 Hz), and 7.25 (4H, s).

3-(4-Chlorophenyl)-3-methyl-1,2-butanediol (35): The oxidation method reported by Swern et al.[15] was employed. Aqueous hydrogen peroxide (30%; 2.27 g, 0.02 mol) were added in one portion to a mixture of **34** (2.71 g, 0.015 mol) and formic acid (20 ml) at room temperature. The reaction mixture was stirred in a water bath (40°C) for 24 h and concentrated under reduced pressure. Thirty grams of 10% ethanolic potassium hydroxide were added and the mixture was heated under reflux for 1 h. After evaporation of ethanol, 50 ml of water were added, and the mixture was neutralized with conc. hydrochloric acid and extracted with $CHCl_3$ twice. The extracts were washed with brine, dried over $MgSO_4$ and evaporated. The residue was column chromatographed (CH_2Cl_2–MeOH 20 : 1) to give 2.38 g (73.9%) of **35**: Mp 94—95°C (recrystallized from cyclohexane–diisopropyl ether); ^{1}H NMR ($CDCl_3$–D_2O) δ= 1.19 (6H, s), 2.86 (1H, dd, J=7.3 and 6.0 Hz), 3.97 (1H, dd, J=11.0 and 6.0 Hz), 4.14 (1H, dd, J=11.0 and 7.3 Hz), and 7.1—7.4 (4H, m). Found: C, 61.54; H, 6.86%. Calcd for $C_{11}H_{15}ClO_2$: C, 61.54; H, 7.04%.

3-(4-Chlorophenyl)-3-methyl-1-(3-phenoxybenzyloxy)-2-butanol (36): Sodium hydride in mineral oil (60%; 0.22 g, 5.5 mmol) was added portionwise to a solution of **35** (1.13 g, 5.26 mmol) in dry MeCN (10 ml) at room temperature, and the mixture was stirred for 20 min. A solution of 3-phenoxybenzyl bromide (**16**) (1.45 g, 5.5 mmol) in 2 ml of MeCN was added dropwise to the mixture over 2 min at room temperature and stirring was continued for 18 h at this temperature. The reaction mixture was then poured into 40 ml of 0.5 M hydrochloric acid and extracted with $CHCl_3$. The extract was washed with brine, dried over $MgSO_4$ and evaporated. The residue was column chromatographed ($CHCl_3$) to give 1.60 g (76.6%) of **36** as a liquid: ^{1}H NMR ($CDCl_3$) δ=1.1—1.2 (6H, m), 2.85—3.05 (2H, m), 3.73—4.07 (2H, m), 4.48 (2H, s), and 6.85—7.5 (13H, m). Found: C, 72.74; H, 6.41%. Calcd for $C_{24}H_{25}ClO_3$: C, 72.63; H, 6.35%.

Reaction of Alcohols with DAST and Other Fluorinating Reagents. Reaction of 4-(4-Chlorophenyl)-4-methyl-1-(3-phenoxyphenyl)-2-pentanol (2) with DAST: A solution of **2**[5] (0.82 g, 2.15 mmol) in 3 ml of dry CH_2Cl_2 was added dropwise to a solution of 0.55 g (3.41 mmol) of DAST in 3 ml of dry CH_2Cl_2 at −78°C over 10 min. Dry Ice was removed from the bath and the mixture was allowed to warm in the bath with stirring. After stirring for 1.5 h, reaction temperature reached 0°C; the mixture was then poured into 20 ml of water. The organic phase was separated and the water phase was extracted with CH_2Cl_2 twice. The combined organic phases were dried over $MgSO_4$ and concentrated. The residue was column chromatographed with a mixture of hexane–CH_2Cl_2 (3 : 1) as eluent. From the first fraction, 0.20 g (25.5%) of a mixture of 4-(4-chlorophenyl)-4-methtyl-1-(3-phenoxyphenyl)-1-pentene (**9**) and 4-(4-chlorophenyl)-4-methyl-1-(3-phenoxyphenyl)-2-pentene (**10**) was obtained: ^{1}H NMR ($CDCl_3$) δ=1.2—1.5 (6H, m), 2.4—2.7 (2H×1/4, m, methylene for **9**), 3.35 (2H×3/4, d, J=5.1 Hz, methylene for **10**), 5.3—6.4 (2H, m), and 6.7—7.5 (13H, m). As judged by the absorptions of methylene protons, **9** was a mixture of (*E*)- and (*Z*)-isomers (ca. 3 : 2 or 2 : 3) and **10** appeared to be a single isomer, probably the (*E*)-isomer considering the steric hindrance of (*Z*)-**10**. Their structures were confirmed by preparing a mixture of **9** and **10** in an independent procedure.[16] Further elution gave 0.27 g (32.6%) of 4-(4-chlorophenyl)-2-fluoro-4-methyl-1-(3-phenoxyphenyl)pentene (**4**): ^{1}H NMR ($CDCl_3$) δ=1.29 (3H, s), 1.38 (3H, s), 1.70—2.08 (2H, m), 2.54—2.95 (2H, m), 4.47 (1H, dm, J=46.6 Hz), and 6.74—7.37 (13H, m); ^{13}C NMR($CDCl_3$) δ=27.6 ($^3J_{C-F}$=2.5 Hz), 30.9, 36.9, 42.5 ($^2J_{C-F}$=22.2 Hz), 48.4 ($^2J_{C-F}$=19.7 Hz), 92.1 ($^1J_{C-F}$=170.7 Hz), 117.0, 118.9, 119.8, 123.3, 124.3, 127.3, 128.2, 129.65, 129.74, 131.5, 138.9 ($^3J_{C-F}$= 5.7 Hz), 147.1, 157.1, and 157.3; ^{19}F NMR ($CDCl_3$) δ=−174.3 (m); n_D^{25} 1.5734; MS m/z (%) 382 (M^+, 60), 153 (100). Found: C, 75.57; H, 6.34%. Calcd for $C_{24}H_{24}ClFO$: C, 75.28; H, 6.32%.

Reaction of Diol 3 with DAST: Similarly, 0.91 g (2.28 mmol) of **3** were treated with 0.81 g (5.03 mmol) of DAST. Separation using column chromatography (hexane–CH_2Cl_2 3 : 1) gave three compounds: 3-(4-chlorophenyl)-5-fluoro-2-methyl-5-(3-phenoxyphenyl)-2-pentene (**11**) (0.03 g, 3.5%): ^{1}H NMR (CCl_4) δ=1.54 (3H, s), 1.73 (3H, s), 2.35—3.3 (2H, m), 5.14 (1H, ddd, J=47.4, 8.1, and 5.4 Hz), and 6.8—7.4 (13H, m), and a diastereomeric mixture (ca. 1 : 1 based on ^{1}H NMR) of 3-(4-chlorophenyl)-1,4-difluoro-4-methyl-1-(3-phenoxyphenyl)-pentane (**12A** and **12B**) (0.48 g, 52.5%). Diastereomers **12A** (eluted faster) and **12B** could be separated by more precise column chromatography.

12A: ^{1}H NMR (270 MHz, $CDCl_3$) δ=1.21 (3H, d, J= 21.8 Hz, CH_3), 1.38 (3H, d, J=21.5 Hz, CH_3), 2.15 (1H, dddd, J=39.1, 14.5, 12.4, and 2.1 Hz, H–C–H), 2.50 (1H, tdd, J=14.5, 10.9, and 3.1 Hz, H–C–H), 3.08 (1H, ddd, J=21.7, 12.4, and 3.1 Hz, $Me_2C(F)$–CH), 4.97 (1H, ddd, J=48.3, 10.9, and 2.1 Hz, F–C–H), 6.87—7.01 (5H, m), 7.10 (1H, td, J=7.4 and 1.2 Hz), and 7.19—7.37 (7H, m); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ=25.5 (q, $^2J_{C-F}$=24.8 Hz, CH_3), 26.3 (q, $^2J_{C-F}$=24.2 Hz, CH_3), 38.1 (t, $^2J_{C-F}$=23.4 Hz, $^3J_{C-F}$=4.1 Hz, CH_2), 50.7 (d, $^2J_{C-F}$=21.8 Hz, $^3J_{C-F}$=1.4 Hz, $Me_2C(F)$–C), 91.6 (d, $^1J_{C-F}$=173.0 Hz, F–C–H), 96.5 (s, $^1J_{C-F}$=172.4 Hz, Me_2CF), 115.7 (d, $^3J_{C-F}$=7.2 Hz), 118.4 (d, $^4J_{C-F}$=1.7 Hz), 118.9 (d), 119.9 (d, $^3J_{C-F}$=7.2Hz), 123.4 (d), 128.7 (d), 129.79 (d), 129.82 (d), 130.8 (d, $^4J_{C-F}$=2.2 Hz), 133.0 (s), 138.3 (s, $^3J_{C-F}$=2.8 Hz), 142.5 (s, $^2J_{C-F}$=19.8 Hz), 156.9 (s), and 157.4 (s); ^{19}F NMR ($CDCl_3$) δ=−181.3 (m) and −146.2 (m); MS m/z (%) 400 (M^+, 36), 201 (100); n_D^{25} 1.5668. Found: C, 72.04; H, 5.71%. Calcd for $C_{14}H_{23}ClF_2O$: C, 71.91; H, 5.78%.

12B: ^{1}H NMR (270 MHz, $CDCl_3$) δ=1.17 (3H, d, J= 21.8 Hz), 1.24 (3H, d, J=21.5 Hz), 2.40—2.59 (3H, m), 5.06 (1H, dm, J=47.2 Hz), 6.82 (1H, d, J=1.0 Hz), 6.90—7.17 (7H, m), and 7.22—7.39 (5H, m); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ=24.4 (q, $^2J_{C-F}$=24.8 Hz), 26.2 (q, $^2J_{C-F}$=24.8 Hz), 36.6 (t, $^2J_{C-F}$=25.9 Hz, $^3J_{C-F}$=3.9 Hz), 50.7 (d, $^2J_{C-F}$=22.3 Hz, $^3J_{C-F}$= 8.0 Hz), 93.4 (d, $^1J_{C-F}$=170.2 Hz), 96.5 (s, $^1J_{C-F}$=173.0 Hz), 116.4 (d, $^3J_{C-F}$=6.1 Hz), 119.0 (d, $^4J_{C-F}$=1.7 Hz), 119.2 (d), 120.9 (d, $^3J_{C-F}$=6.1 Hz), 123.6 (d), 128.6 (d), 129.8 (d), 130.0 (d), 130.5 (d, $^4J_{C-F}$=1.1Hz), 133.0 (s), 138.1 (s, $^3J_{C-F}$=5.0 Hz), 140.9

(s, $^2J_{C-F}$=19.8 Hz), 156.8 (s), and 157.7 (s); MS *m/z* (%) 400 (M^+, 44), 201 (100); n_D^{25} 1.5680. Found: C, 72.42; H, 5.78%. Calcd for $C_{24}H_{23}ClF_2O$: C, 71.91; H, 5.78%.

Reaction of Alcohols 22a—d with DAST: Similarly, 1—2 mmol of **22a—d** were treated with 1.5 equiv of DAST to afford fluorides **24a—d**. The results are shown in Table 2. In the case of **22d**, a mixture of 2-methyl-6-(3-phenoxyphenyl)-3-[4-(trifluoromethyl)phenyl]-2-hexene (**25d**) and 2-methyl-6-(3-phenoxyphenyl)-3-[4-(trifluoromethyl)phenyl]-1-hexene (**26d**) (ca. 4:1) eluted first on column chromatographic separation.

4-(4-Chlorophenyl)-5-fluoro-5-methyl-1-(3-phenoxyphenyl)hexane (24a): ^{1}H NMR ($CDCl_3$) δ=1.22 (3H, d, *J*=21.9 Hz), 1.27 (3H, *J*=21.6 Hz), 1.30—1.44 (2H, m), 1.64—2.01 (2H, m), 2.40—2.68 (2H, m), 2.68 (1H, ddd, *J*=17.8, 11.6, and 3.4 Hz), 6.72—6.84 (3H, m), 6.93—7.02 (2H, m), and 7.05—7.37 (8H, m); ^{13}C NMR ($CDCl_3$) δ=24.9 ($^2J_{C-F}$=24.8 Hz), 26.1 ($^2J_{C-F}$=24.5Hz), 28.7 ($^3J_{C-F}$=4.2 Hz), 29.3, 35.6, 54.9 ($^2J_{C-F}$=21.8 Hz), 96.9 ($^1J_{C-F}$=169.8 Hz), 116.3, 118.7, 118.9, 123.1, 123.4, 128.3, 129.5, 129.7, 130.6, 132.5, 139.1 ($^3J_{C-F}$=4.2 Hz), 144.2, 157.1, and 157.4; ^{19}F NMR ($CDCl_3$) δ=−142.3 (m); MS *m/z* (%) 396 (M^+, 72), 183 (100); n_D^{25} 1.5685. Found: C, 75.46; H, 6.42%. Calcd for $C_{25}H_{26}ClFO$: C, 75.65; H, 6.60%.

5-Flouro-5-methyl-1-(3-phenoxyphenyl)-4-phenylhexane (24b): ^{1}H NMR ($CDCl_3$) δ=1,24 (3H, d, *J*=22.0 Hz), 1.27 (3H, d, *J*=21.7 Hz), 1.38 (2H, quintet, *J*=7.7 Hz), 1.69—2.03 (2H, m), 2.40—2.64 (2H, m), 2.72 (1H, ddd, *J*=17.2, 11.4, and 3.7 Hz), 6.74—6.85 (3H, m), and 6.92—7.30 (11H, m); ^{13}C NMR ($CDCl_3$) δ=24.6 ($^2J_{C-F}$=24.7 Hz), 26.5 ($^2J_{C-F}$=24.4 Hz), 28.7 ($^3J_{C-F}$=4.1 Hz), 29.4, 35.7, 55.5 ($^2J_{C-F}$=21.8 Hz), 97.2 ($^1J_{C-F}$=169.5 Hz), 116.2, 118.7, 119.0, 123.0, 123.4, 126.7, 128.1, 129.3, 129.4, 129.7, 140.6 ($^3J_{C-F}$=5.3 Hz), 144.5, 157.1, and 157.4; ^{19}F NMR ($CDCl_3$) δ=−141.1 (m); MS *m/z* (%) 362 (M^+, 55), 91 (100); n_D^{25} 1.5630. Found: C, 83.00; H, 7.49%. Calcd for $C_{25}H_{27}FO$: C, 82.84; H, 7.51%.

5-Flouro-4-(4-methoxyphenyl)-5-methyl-1-(3-phenoxyphenyl)hexane (24c): ^{1}H NMR ($CDCl_3$) δ=1.23 (3H, d, *J*=22.0 Hz), 1.25 (3H, d, *J*=21.7 Hz), 1.39 (2H, quintet, *J*=7.8 Hz), 1.68—1.81 (1H, m), 1.85—1.97 (1H, m), 2.43—2.64 (2H, m), 2.67 (1H, ddd, *J*=16.8, 12.0, and 3.6 Hz), 3.77 (3H, s), 6.74—6.85 (5H, m), 6.94—7.00 (2H, m), 7.03—7.10 (3H, m), 7.13—7.22 (1H, m), and 7.26—7.34 (2H, m); ^{13}C NMR ($CDCl_3$) δ=24.4 ($^2J_{C-F}$=24.8 Hz), 26.4 ($^2J_{C-F}$=24.6 Hz), 28.7 ($^3J_{C-F}$=4.1 Hz), 29.4, 35.7, 54.6 ($^2J_{C-F}$=22.0 Hz), 55.1, 97.4 ($^1J_{C-F}$=170.3 Hz), 113.5, 116.2, 118.7, 119.0, 123.0, 123.4, 129.4, 129.7, 130.2, 132.6 ($^3J_{C-F}$=5.5 Hz), 144.5, 157.0, 157.4, and 158.4; ^{19}F NMR ($CDCl_3$) δ=−141.0 (m); MS *m/z* (%) 392 (M^+, 20), 161 (100); n_D^{25} 1.5623. Found: C, 79.42; H, 7.61%. Calcd for $C_{26}H_{29}FO$: C, 79.56; H, 7.45%.

5-Fluoro-5-methyl-1-(3-phenoxyphenyl)-4-[4-(trifluoromethyl)phenyl]hexane (24d): ^{1}H NMR ($CDCl_3$) δ=1.22 (3H, d, *J*=21.4 Hz), 1.29 (3H, d, *J*=20.7 Hz), 1.31—1.42 (2H, m), 1.74—2.01 (2H, m), 2.44—2.64 (2H, m), 2.77 (1H, ddd, *J*=18.3, 11.7, and 3.4 Hz), 6.73—6.75 (1H, m), 6.78—6.84 (2H, m), 6.94—7.00 (2H, m), 7.05—7.11 (1H, m), 7.19 (1H, t, *J*=7.8 Hz), 7.26—7.35 (4H, m), and 7.53 (2H, d, *J*=8.0 Hz); ^{13}C NMR ($CDCl_3$) δ=25.2 ($^2J_{C-F}$=24.9 Hz), 26.0 ($^2J_{C-F}$=24.6 Hz), 28.7 ($^3J_{C-F}$=4.4 Hz), 29.3, 35.6, 55.4 ($^2J_{C-F}$=21.9 Hz), 96.7 ($^1J_{C-F}$=171.9 Hz), 116.4, 118.8, 118.9, 123.1, 123.3, 124.3 ($^1J_{C-F}$=271.8 Hz, CF_3), 125.1 ($^3J_{C-F}$=3.8 Hz), 129.1 ($^2J_{C-F}$=32.6 Hz), 129.5, 129.7 ($^4J_{C-F}$=1.6 Hz), 129.7, 144.1, 144.9 ($^3J_{C-F}$=4.0 Hz), 157.2, and 157.4; ^{19}F NMR ($CDCl_3$) δ=−142.5 (m) and −62.9 (s); MS *m/z* (%) 430 (M^+, 100); n_D^{25} 1.5295. Found: C, 72.22; H, 6.35%. Calcd for $C_{26}H_{26}F_4O$: C, 72.54; H, 6.09.

25d: ^{1}H NMR ($CDCl_3$) δ=1.3—1.75 (5H, m), 1.77 (3H, m), 2.25—2.7 (4H, m), and 6.75—7.65 (13H, m); MS (mixture of **25d** and **26d**) *m/z* (%) 410 (M^+, 23), 184 (100). The structure of **26d** and its proportion had to be postulated based on the existence of small peaks at δ=1.27 (t, *J*=7.2 Hz, methyne) and 4.83—4.93 (m, exo methylene) in ^{1}H NMR, MS, and elemental analysis of the mixture since separation of **25d** and **26d** was difficult using column chromatography or HPLC. Comparison of the mixture's ^{1}H NMR spectrum with that of **25b** and **26b** (see below) also supported this assignment.

Reaction of 22b with Hexafluoropropene-diethylamine (1/1) (HPDA): According to the literature method,[13] a mixture of **22b** (0.54 g, 1,5 mmol) and HPDA (0.45 g, 2.0 mmol) in 4 ml of dry ether was stirred for 21 h at room temperature. Since the reaction was not completed, 0.22 g of HPDA (1.0 mmol) was added to the mixture and stirring was continued for another 24 h. After being concentrated, the mixture was column chromatographed (hexane–CH_2Cl_2 3:1) to give 0.20 g (38.9%) of a mixture of 2-methyl-6-(3-phenoxyphenyl)-3-phenyl-2-hexene (**25b**) and 2-methyl-6-(3-phenoxyphenyl)-3-phenyl-1-hexene (**26b**) in a ratio of ca. 1:5, and 0.15 g (27.6%) of **24b**. The structures of **25b** and **26b** were identified on the basis of ^{1}H NMR and its comparison with that of a mixture of **25d** and **26d** obtained by the reaction of **22d** with DAST. ^{1}H NMR of **26b** ($CDCl_3$) δ=1.4—2.0 (7H, m), 2.57 (2H, t, *J*=7.2 Hz), 3.20 (1H, t, *J*=7.0 Hz), 4.75—4.95 (2H, m), and 6.7—7.4 (14H, m).

Reaction of 22b with Pyridinium Poly(hydrogen fluoride): The procedure reported by Olah[14] was employed. A solution of **22b** (0.54 g, 1.5 mmol) in 2 ml of dry THF was added dropwise to 10 ml of pyridinium poly (hydrogen fluoride) in an ice-cooled Teflon flask over 15 min. The temperature of the reaction mixture was gradually raised to 20 °C in the bath over a period of 2 h. The mixture was poured into 100 ml of ice-water and extracted with ether twice. The extracts were washed with aqueous sodium hydrogencarbonate, dried over $MgSO_4$ and evaporated. Purification by column chromatography (CH_2Cl_2–hexane 1:4) gave 0.41 g (79.8%) of 1-isopropyl-6-phenoxy-1-phenyl-1,2,3,4-tetrahydronaphthalene (**27**): ^{1}H NMR (270 MHz, $CDCl_3$) δ=0.84 (3H, d, *J*=6.9 Hz), 0.90 (3H, d, *J*=6.9 Hz), 1.55—1.78 (2H, m), 1.80—1.95 (1H, m), 2.14—2.27 (1H, m), 2.43—2.70 (3H, m), 6.71 (1H, d, *J*=2.7 Hz), 6.80 (1H, dd, *J*=8.9 and 2.7 Hz), 6.88—7.09 (4H, m), 7.10—7.27 (6H, m), and 7.31 (1H, d, *J*=8.9 Hz); ^{13}C NMR (67.8 MHz, $CDCl_3$) δ=18.2 (q), 19.3 (q), 19.4 (t), 30.1 (t), 30.2 (t), 36.8 (d), 48.9 (s), 115.7 (d), 118.7 (d, 2C), 118.8 (d), 122.8 (d), 125.1 (d), 127.6 (d), 127.7 (d), 127.8 (d), 128.0 (d), 129.5 (d, 2C), 130.1 (d), 136.6 (s), 140.2 (s), 148.1 (s), 154.6 (s), and 157.3 (s); MS *m/z* (%) 342 (M^+, 1), 299 (100); n_D^{25} 1.6067. Found: C, 87.85; H, 7.80%. Calcd for $C_{25}H_{26}O$: C, 87.68; H, 7.65%.

Reaction of 23b with DAST: In a manner similar to that described for the reaction of **2** with DAST, 1.53 g (4.06 mmol) of **23b** were allowed to react with 2.20 g (13.6 mmol) of DAST. Following column chromatographic separation (CH_2Cl_2–hexane 2:3 to 1:1), 0.10 g of a mixture of a few unidentified by-products, 0.26 g (16.8%) of a diastereomixture (ca. 2:3) of 1,5-difluoro-5-methyl-1-(3-phenoxyphenyl)-4-phenylhexane (**30**), 0.12 g (8.2%) of one isomer of 2-(1-methyl-1-phenylethyl)-5-(3-phenoxyphenyl)tetrahydrofuran (**31A**), and 0.30 g (20.6%) of another isomer, **31B**, were obtained in that order. No positive proof for the cis-trans determination of **31A** and **31B** could be

obtained.

30: ^{1}H NMR (270 MHz, $CDCl_3$) δ=1.23 (3H×3/5, d, J=21.8 Hz), 1.25 (3H×2/5, J=22.1 Hz), 1.27 (3H×2/5, d, J=21.4 Hz), 1.28 (3H×3/5, d, J=21.8 Hz), 1.42—2.22 (4H, m), 2.60—2.81 (1H, m), 5.29 (1H×3/5, ddd, J=47.8, 7.4, and 4.6 Hz), 5.37 (1H×2/5, ddd, J=47.9, 7.7, and 4.5 Hz), 6.86—7.00 (5H, m), and 7.04—7.35 (9H, m); ^{19}F NMR ($CDCl_3$) δ=−178.3 (m), −174.7 (m), −141.7 (m), and −141.2 (m); MS m/z (%) 380 (M^+, 100); n_D^{25} 1.5584. Found: C, 79.24; H, 6.86%. Calcd for $C_{25}H_{26}F_2O$: C, 78.92; H, 6.89%. The ^{13}C NMR spectrum was too complex to analyze.

31A: Viscous liquid; ^{1}H NMR ($CDCl_3$) δ=1.38 (6H, s), 1.4—1.83 (3H, m), 2.02—2.19 (1H, m), 4.08 (1H, t, J=7.3 Hz), 4.74 (1H, dd, J=8.2 and 6.7 Hz), 6.82—6.91 (1H, m), and 6.99—7.47 (13H, m); ^{13}C NMR ($CDCl_3$) δ=23.8, 26.0, 27.1, 34.5, 41.1, 80.5, 87.1, 116.3, 117.5, 118.9, 120.8, 123.2, 125.9, 126.9, 127.8, 129.5, 129.7, 145.1, 146.7, 157.2, and 157.3; MS m/z (%) 358 (M^+, 2), 119 (100). Found: C, 84.04; H, 7.36%. Calcd for $C_{25}H_{26}O_2$: C, 83.76; H, 7.31%.

31B: Viscous liquid; ^{1}H NMR ($CDCl_3$) δ=1.37 (3H, s), 1.41 (3H, s), 1.47—1.83 (3H, m), 1.93—2.14 (1H, m), 4.21—4.31 (1H, m), 4.74 (1H, t, J=6.8 Hz), 6.80—6.90 (1H, m), 6.98—7.40 (11H, m), and 7.43—7.50 (2H, m); ^{13}C NMR ($CDCl_3$) δ=24.3, 25.9, 28.1, 35.5, 41.6, 80.8, 87.9, 116.2, 117.3, 118.8, 120.4, 123.1, 125.9, 127.0, 127.8, 129.6, 129.7, 146.4, 146.5, 157.2, and 157.3; MS m/z (%) 358 (M^+, 3), 119 (100). Found: C, 83.75; H, 7.26%. Calcd for $C_{25}H_{26}O_2$: C, 83.76; H, 7.31%.

Reaction of 23b with HPDA: Similarly to the case of the reaction of **22b** with HPDA, a solution of 0.330 g (0.876 mmol) of **23b** and 0.587 g (2.63 mmol) of HPDA in 3 ml of dry ether was stirred for 16 h at room temperature. The mixture was poured into 5 ml of water and extracted with CH_2Cl_2 twice. The organic layers were dried over $MgSO_4$ and evaporated. Column chromatographic separation (CH_2Cl_2–hexane 2 : 3) of the residue gave 0.050 g of several unidentified compounds and 0.184 g (58.6%) of a mixture of **31A** and **31B** (ca. 2 : 3).

Reaction of 36 with DAST: In a manner similar to the reaction of **2** with DAST , 1.00 g (2.52 mmol) of **36** was allowed to react with 0.61 g (3.78 mmol) of DAST to give 0.066 g (6.9%) of a mixture of 3-(4-chlorophenyl)-2-methyl-4-(3-phenoxybenzyloxy)-2-butene (**38**) and 3-(4-chlorophenyl)-2-methyl-4-(3-phenoxybenzyloxy)-1-butene (**39**) (ca. 2 : 1) as characterized by ^{1}H NMR, and 0.747 g (74.4%) of 2-(4-chlorophenyl)-3-fluoro-3-methyl-1-(3-phenoxybenzyloxy)butane (**37**).

A Mixture of 38 and 39: ^{1}H NMR ($CDCl_3$) δ=1.56 (3H×1/3, s, CH_3 for **39**), 1.63 (3H×2/3, s, CH_3 for **38**), 1.85 (3H×2/3, s, CH_3 for **38**), 3.49—3.85 (3H×1/3, m, $CHCH_2$ for **39**), 4.20 (2H×2/3, s, $=CCH_2O$ for **38**), 4.43 (2H×2/3, s, OCH_2Ar for **38**), 4.47 (2H×1/3, s, OCH_2Ar for **39**), 4.82—4.95 (2H×1/3, m, $CH_2=$ for **39**), and 6.85—7.45 (13H, m).

37: ^{1}H NMR ($CDCl_3$) δ=1.21 (3H, d, J=21.9 Hz), 1.35 (3H, d, J=21.7 Hz), 3.02 (1H, ddd, J=20.7, 8.1, and 5.0 Hz), 3.77 (1H, dd, J=9.5 and 8.1 Hz), 3.97 (1H, dd, J=9.5 and 5.0 Hz), 4.38 (1H, d, J=12.4 Hz), 4.45 (1H, d, J=12.4 Hz), and 6.84—7.37 (13H, m); ^{13}C NMR ($CDCl_3$) δ=25.8 ($^2J_{C-F}$=24.4 Hz), 26.4 ($^2J_{C-F}$=24.4 Hz), 54.5 ($^2J_{C-F}$=20.9 Hz), 70.0 ($^3J_{C-F}$=5.9 Hz), 72.6, 96.1 ($^1J_{C-F}$=170.4 Hz), 117.6, 117.9, 118.9, 122.1, 123.3, 128.2, 129.6, 129.7, 130.6, 132.6, 138.1 ($^3J_{C-F}$=2.8 Hz), 140.2, 157.1, and 157.4; ^{19}F NMR ($CDCl_3$) δ=−142.9 (m); MS m/z (%) 398 (M^+, 42), 183 (100); n_D^{25} 1.5732. Found: m/z 398.1454. Calcd for $C_{24}H_{24}ClFO_2$: M, 398.1449.

We would like to thank Ms. Fumiko Kasahara, Chemistry Research Laboratories, Research and Development Division, Takeda Chemical Industries Ltd. for measurement and discussion of the ^{1}H NMR (270 MHz) and ^{13}C NMR (67.8 MHz) spectra, and Mr. Tetsuya Yanai for measurement of the MS spectra.

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