slowly introducing aqueus NaOH. The GC analysis of the run at -78 °C gave a **3a**:**4a** ratio of 72:28; the run at 20 °C gave a **3a**:**4a** ratio of 59:41 (see table).

In both runs, about 35% of 2-ethoxy-1-decanol was a significant side product, as well as 5-10% of 1- and 2-decanol. The latter side products were identified by co-injection of the authentic decanols, as well as by collection and matching of IR and ^1H and ^{13}C NMR spectra. The 2-ethoxy-1-decanol was identified by GC-MS spectrometry and by ^1H and ^{13}C NMR spectroscopy.

Reactions of Titanium Reagents with 2a. Under an Ar a 10-mmol sample of 1,2-epoxydecane (1.56 g) in 20 mL of anhydrous heptane was added with magnetic stirring to a heptane solution of 11 mmol of $TiCl_4$ or $TiBr_4$ or to a heptane solution of 5.5 mmol of $TiBr_4$ and 5.5 mol of $Ti(NEt_2)_4$ that had been previously cooled to the stated temperature. After the indicated reaction time the reaction mixture was cooled at 0 °C and slowly hydrolyzed. The separated organic layer was dried and evaporated in the usual manner (method 1, vida supra) and the residue then analyzed by GC, IR, and NMR methods.

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Nickel-Catalyzed Reaction of Iododifluoroacetates with Alkenes and Zinc: A Novel and Practical Route to α,α-Difluoro-Functionalized Esters and $\alpha,\alpha,\omega,\omega$-Tetrafluoro Diesters

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Iododifluoroacetates **1a-c** react with alkenes and zinc in the presence of nickel dichloride hexahydrate in THF at room temperature or 60 °C to give the corresponding α,α-difluoro esters in good yields. The reaction is also applicable to alkenes containing a variety of functional groups such as trimethylsilyl, hydroxy, ketone, and ester moieties. The reaction of **1** works well with dienes; the products formed depend on the length of chain of the dienes. 1,8-Nonadiene and 1,5-hexadiene afford the $\alpha,\alpha,\omega,\omega$-tetrafluoro diesters, while 1,6-heptadiene gave a mixture of ethyl 2,2-difluoro-8-nonenoate (**19**) and the cyclopentyl-substituted α,α-difluoro ester **20**. When diallyl ether was used as a substrate, only the tetrahydrofuran derivative **21** was formed. The nickel-catalyzed reaction can be suppressed by *p*-dinitrobenzene and hydroquinone. A single electron transfer initiated radical mechanism is proposed.

Introduction

Organofluorine compounds have been widely utilized in the areas of agrochemicals and pharmaceuticals or as probes for investigating biochemical processes, since the introduction of fluorine into organic molecules leads to significant changes in biological activities.[1] The change can be mainly ascribed to the strong carbon fluorine bond and the increased lipid solubility. Also, fluorine and hydrogen are comparable in size so that the fluorine-containing molecule would be indistinguishable from its fluorine-free analogue. In addition, fluoroorganic compounds often exhibit different chemical properties due to the high electronegativity of fluorine. Indeed, recent reports have demonstrated that the difluoromethyl moiety is an isopolar and isosteric replacement for oxygen,[2] and a number of molecules containing the difluoromethylene functionality exhibit powerful antitumor and anticancer properties as well as function as enzyme inhibitors.[1]

The importance of α,α-difluoromethylene-functionalized compounds in the synthesis of biologically active molecules prompted us to develop general methodologies for the preparation of difluoromethylene-functionalized compounds. The most widely utilized method for the introduction of such type of functionality has been the Reformatsky reaction using halodifluoroacetates,[3] halodifluoromethyl ketones,[4] difluoroallyl halides,[5] and difluoropropargyl bromides.[6] The Lewis acid-catalyzed reaction of difluoroketene silyl acetates with carbonyl substrates has also been used for the synthesis of compounds bearing the carboalkoxydifluoromethyl group.[7] However, these methods could not be utilized for the direct

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preparation of α,α-difluoro esters.[8]

Although fluorination of α-keto esters with sulfur tetrafluoride has been used to synthesize α,α-difluoro esters,[9] this reaction has limited application due to the volatility and high toxicity of sulfur tetrafluoride. In addition, the fluorination reaction has poor chemical selectivity; some functionalities could not be tolerated under the reaction conditions. Recently, *N*-fluorosulfonyl imides have been utilized for α-fluorination of enolates.[10] Although this methodology provides reasonable yields of the α,α-difluoro ester under mild conditions, it necessitates the prior preparation of the *N*-(fluorosulfonyl)imides.

Kobayashi has developed a somewhat better methodology for the preparation of α,α-difluoro esters using carbomethoxydifluoromethylcopper prepared from methyl iododifluoroacetate and copper in aprotic coordinating solvents.[11] The copper reagent reacted with aryl, alkenyl, and allyl halides to give good yields of the coupled products, but the reaction with butyl iodide required elevated temperatures in HMPA, and only a modest yield of α,α-difluorohexanoate was obtained.

The atom transfer reaction of methyl iododifluoroacetate with alkenes has been reported by Kiseleva,[12] Burton,[13] and Taguchi.[14] However, the radical cyclization of allyl iododifluoroacetate using organotin reagents gave none of the desired product and only iododifluoroacetate was recovered.[15] We now report a novel and direct method for the preparation of α,α-difluoro-functionalized esters.

Results and Discussion

Recently, we reported a new approach to α,α-difluoro esters by an addition–reduction two-step sequence.[16a]

$$R^1CH{=}CHR^2 + ICF_2CO_2R \xrightarrow[50\text{–}60\ ^\circ C]{Cu} R^1CHICHR^2CF_2CO_2R \quad (65\text{–}92\%)$$

Copper could initiate the addition of iododifluoroacetates to alkenes to give the corresponding adduct, which could be reduced with Zn in the presence of nickel chloride hexahydrate in moist THF to produce α,α-difluoro esters.

$$R^1CHICHR^2CF_2CO_2R + Zn \xrightarrow[THF,\ rt]{NiCl_2{\cdot}6H_2O} R^1CH_2CHR^2CF_2CO_2R$$

A single electron transfer mechanism for the addition reaction was proposed. Although the mechanism of the reduction reaction has not been investigated in detail, Ni^0 is considered the active intermediate. We anticipated that nickel could not only catalyze the reduction of the adduct to give α,α-difluoro esters but also initiate the addition of 1 to alkenes, so that the SET-initiated addition and reduction reactions could be conducted in one pot. In a preliminary communication, we briefly described the nickel-catalyzed reaction of 1 with alkenes.[16b] This methodology avoids the utilization of expensive and difficult to obtain fluorinating reagents or multistep procedures and provides a simple and useful approach for the preparation of α,α-difluoro-functionalized esters. We now report our detailed results.

Table I. Ni-Catalyzed Reaction of 1 with Alkenes

$$RCH{=}CH_2 + ICF_2CO_2R' \xrightarrow[Zn/THF]{NiCl_2{\cdot}6H_2O} RCH_2CH_2CF_2CO_2R'$$

no.	R	R′	yield (%)
2	C_2H_5	C_2H_5	78
3	n-C_3H_7	$CH(CH_3)_2$	83
4	n-C_4H_9	C_2H_5	72
5	n-C_4H_9	$CH(CH_3)_2$	71
6	n-C_5H_{11}	C_2H_5	68
7	n-C_5H_{11}	$CH(CH_3)_2$	74
8	n-C_6H_{13}	$CH(CH_3)_2$	80
9	n-$C_{12}H_{25}$	C_2H_5	64
10	Me_3Si	$CH(CH_3)_2$	65
11	$HO(CH_2)_8$	$CH(CH_3)_2$	76
12	$AcOCH_2CH_2CH_2$	$CH(CH_3)_2$	63
13	$CH_3C(O)CH_2CH_2$	CH_3	76
14	$CH_3C(O)CH_2CH_2$	C_2H_5	67
15	$EtOC(O)CH(CH_3)CH_2$	C_2H_5	73
16	$EtOC(O)CH(CH_3)CH_2$	$CH(CH_3)_2$	60

Reaction of 1 with Alkenes. When a mixture of zinc and a catalytic amount of nickel dichloride hexahydrate in THF was stirred at room temperature for 10 min, a black heterogeneous solution was formed. After the alkene and iododifluoroacetate 1 were added to the heterogeneous solution, the resultant mixture was stirred at room temperature or 60 °C for several hours to give the corresponding α,α-difluoro ester in high yields. For example, upon reaction of **1b** with 1-hexene and zinc in the presence of 5 mol % of $NiCl_2{\cdot}6H_2O$ at room temperature overnight, ^{19}F NMR analysis indicated that only ethyl 2,2-difluorooctanoate (4) was formed and no ethyl difluoroacetate was detected. Both short- and long-chain alkenes gave good yields of α,α-difluoro esters. In the case of reaction with 1-tetradecene at room temperature, **1b** afforded ethyl α,α-difluorohexadecanoate in 64% isolated yield. With shorter chain alkenes, the reaction was conducted in a sealed tube in order to avoid low concentration of alkenes in solution and to minimize the formation of difluoroacetate. For example, reaction of 1-butene with **1b** in a sealed tube at room temperature gave ethyl α,α-difluorohexanoate in 78% yield. All results are summarized in Table I.

$$RCH{=}CH_2 + ICF_2CO_2R' \xrightarrow[Zn/THF]{NiCl_2{\cdot}6H_2O} RCH_2CH_2CF_2CO_2R' \quad (60\text{–}83\%)$$

1a: R′ = CH_3
1b: R′ = C_2H_5
1c: R′ = $CH(CH_3)_2$

As illustrated in Table I, a variety of functionalized alkenes were also used as substrates and the functionalities in the alkenes did not interfere with the nickel-catalyzed reaction. This method is particularly useful for the preparation of α,α-difluoro-functionalized esters which are difficult to obtain by alternative methodologies. For example, treatment of **1a** with 5-hexen-2-one and zinc in the presence of nickel chloride hexahydrate in moist THF gave the corresponding α,α-difluoro ester in 76% yield. Like-

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wise, other functionalized groups such as trimethylsilyl, ester, and hydroxy in the alkenes can be tolerated under the reaction conditions.

Reaction of 1 with Dienes. The nickel-catalyzed reaction could also be successfully applied to dienes. The products formed depended on the chain length of the dienes. In the case of the reaction of 1,8-nonadiene with 2 equiv of **1b** at room temperature, the corresponding 2,2,12,12-tetrafluorotridecane-1,13-dioate **18** was isolated in 73% yield. Similarly, when 1,5-hexadiene was used as a substrate, **1b** gave 2,2,9,9-tetrafluorodecane-1,10-dioate **17** in 55% yield.

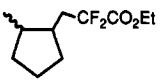
$$CH_2{=}CH(CH_2)_nCH{=}CH_2 + 2ICF_2COEt \xrightarrow[Zn]{NiCl_2\cdot 6H_2O} \xrightarrow[\text{rt to 65 °C}]{} EtO_2CCF_2(CH_2)_{n+4}CF_2CO_2Et$$

17: $n = 2$; 55%
18: $n = 5$; 73%

When **1b** reacted with 2 equiv of 1,6-heptadiene and zinc in the presence of nickel chloride in moist THF (1 M concentration), a mixture of **19** and **20** was obtained in 77% yield. The structures and their ratio could be readily determined by ^{19}F and ^1H NMR as well as GC–MS. In the ^{19}F NMR spectrum, **19** and **20** were respectively observed at −106.4 (t, $^3J_{F,H}$ = 17.1 Hz) and −104.9 (tm, $^3J_{F,H}$ = 17.1 Hz) ppm in a 1:1.3 ratio. The ^1H NMR spectrum exhibited a typical terminal vinyl hydrogen at 5.85–5.71 ppm for **19**, and two methyl groups for *cis*- and *trans*-**20** with a 7:1 ratio. GC–MS analysis indicated three compounds with the same M^+ peak (220). Three types of CF_2 groups were also observed in the ^{13}C NMR spectrum, which were assigned to **19** and the two isomers of **20**. We were unable to separate **19** and **20** by simple distillation.

$$CH_2{=}CH(CH_2)_3CH{=}CH_2 + ICF_2CO_2Et \xrightarrow[Zn]{NiCl_2\cdot 6H_2O} CH_2{=}CH(CH_2)_5CF_2CO_2Et +$$

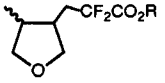
19



20

However, reaction of diallyl ether with **1b** and zinc in the presence of $NiCl_2\cdot 6H_2O$ at room temperature for 2 h gave only a mixture of the cis and trans tetrahydrofuran derivatives **21b** in 73% yield, which were characterized by ^1H and ^{19}F NMR spectroscopy. No ethyl 2,2-difluoro-6-oxa-8-nonenoate was detected. In the ^1H NMR spectrum, the two methyl groups of **21b** exhibited two sets of doublets in a 1:4 ratio at 1.06 ($^3J_{H,H}$ = 6.1 Hz) and 0.96 ($^3J_{H,H}$ = 6.9 Hz) ppm, respectively. Similarly, the ^{19}F NMR spectrum of **21b** exhibited two sets of a typical AB doublet of doublet of doublets for the diastereotopic CF_2 group. Similarly, when **1a** was used as a substrate, **21a** was formed in 53% yield.

$$CH_2{=}CHCH_2OCH_2CH{=}CH_2 + ICF_2CO_2R \xrightarrow[Zn]{NiCl_2\cdot 6H_2O}$$



21

21 a, R = Me: 53%
21 b, R = Et: 74%

Scope and Limitation of the Reaction. Although the nickel-catalyzed reactions work well with a variety of terminal functionalized alkenes and dienes, treatment of **1** with internal or cyclic alkenes under similar conditions gave no desired α,α-difluoro ester; only difluoroacetate was formed in quantitative yield. For example, when **1b** was treated with cyclohexene or 3-octene at room temperature overnight, ^{19}F NMR analysis indicated only the formation of ethyl difluoroacetate. Fortunately, the preparation of cyclic or branched alkyl-substituted α,α-difluoro esters could be readily accomplished by the addition–reduction two-step sequence reported previously.[16] Electron-deficient alkenes also gave no desired α,α-difluoro ester. Upon reaction of acrylonitrile with **1b** and zinc in the presence of nickel dichloride hexahydrate in THF at room temperature, ^{19}F NMR analysis of the reaction mixture indicated only ethyl difluoroacetate and no ethyl 4-cyano-2,2-difluorobutanoate. When a terminal unsaturated carboxylic acid was used as a substrate, no addition product was observed and only ethyl difluoroacetate was detected.

Substitution of ethyl bromodifluoroacetate for **1b** gave only difluoroacetate in the reaction with 1-hexene. No ethyl 2,2-difluorooctanoate (**4**) was detected, even when the reaction was carried out at 60 °C.

Mechanism. Urushibara first reported that addition of $NiCl_2$ to a suspension of Zn dust in water gave a nickel catalyst.[17] Recent investigation on the surface characterization of this catalyst system revealed that Ni^{2+} had been reduced on the metallic zinc surface, generating zinc particles that are coated with metallic nickel.[18] This bimetallic system is very active and is able to reduce water to molecular hydrogen under neutral conditions.[19] α,β-Unsaturated carbonyl compounds and carbonyl substrates could also be reduced by $NiCl_2$/Zn in this aqueous medium.[20]

Perfluoroalkyl iodides are powerful electron acceptors which readily participate in single electron transfer (SET) reactions with zero or lower valent metals,[22] including Raney-Ni.[23] Previous reports have demonstrated that **1** is also a good electron acceptor and copper can readily initiate addition of **1** to alkenes. Accordingly, we propose that the Ni-catalyzed reaction of **1** with alkene may also involve a single electron transfer process to form the adduct, followed by reduction to give the α,α-difluoro esters.

Inhibition of the reaction by both an electron scavenger and a radical inhibitor is consistent with the proposed mechanism. For example, when **1b** was reacted with 1-heptene, 20 mol % of $NiCl_2\cdot 6H_2O$ and 2 equiv of zinc in the presence of 50 mol % of *p*-dinitrobenzene (SET scavenger)[22] in moist THF at room temperature for 10 h, no reaction was observed by ^{19}F NMR analysis. Even if the reaction mixture was stirred for 20 h, only **1b** was detected. The radical inhibitor could partially inhibit the reaction. For example, upon treatment of **1b**, 1-heptene, zinc, and 20 mol % of $NiCl_2\cdot 6H_2O$ in the presence of 50 mol % of hydroquinone at room temperature for 20 h, ^{19}F NMR analysis indicated that 13% of **1b** still remained and 70% of ethyl difluoroacetate was formed with 17% of ethyl 2,2-difluoro-4-iodononanoate.[16] The significant increase

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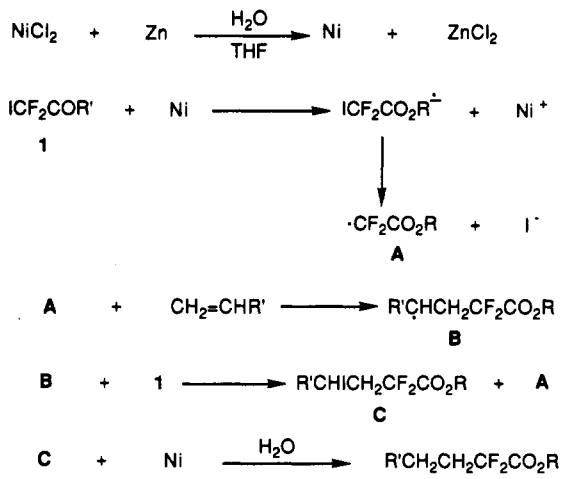
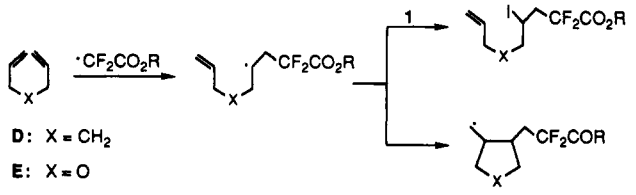


in the difluoroacetate can be ascribed to the low efficiency of the chain propagation steps. Thus, **A** accepted a second electron, resulting in overall conversion of 1 into difluoroacetate instead of the formation of the desired α,α-difluoro ester.

Cyclization in the exo-mode from the 5-hexenyl radical is an excellent probe for elucidating a radical mechanism.[23] When 1,6-heptadiene was used as a substrate, the formation of cyclized addition products further provides strong evidence supporting a radical intermediate. With diallyl ether, 1 gave the cyclized products exclusively, due to enhancement of the cyclization rate with the oxygen-containing radical. Since the length of the carbon–oxygen bond is less than that of a carbon–carbon bond and the bond angle C–O–C is less than that of C–C–C, the distance between C1 and C5 in radical **E** is less than it is in radical **D**.[24] Therefore, radical **E** undergoes ring closure in an exo-mode much more rapidly than the radical **D**, which can either abstract iodine from 1 or cyclize. Similar rate enhancement has been previously observed in the reduction of allyl ethers vs 5-hexenyl halide analogue with tributyltin hydride[25] or (η^5-cyclopentadienyl)tricarbonylhydridovanadate.[26]



It could be argued that **B** could directly abstract hydrogen to form the α,α-difluoro ester rather than go through the iodoadduct. Though this possibility can not be ruled out entirely, it probably does not occur. First, when the adduct, prepared by the copper-catalyzed reaction of 1 with an alkene, was treated with zinc and water in the presence of nickel chloride, the corresponding α,α-difluoro ester was formed exclusively.[16] Secondly, when the reaction of 1 with an alkene and zinc in the presence of nickel chloride in moist THF was monitored by ^{19}F NMR, the adduct was detected (typical **AB** pattern signal) along with 1 and the product. With time, the adduct signals decreased with a concomitant increase in the product signals.

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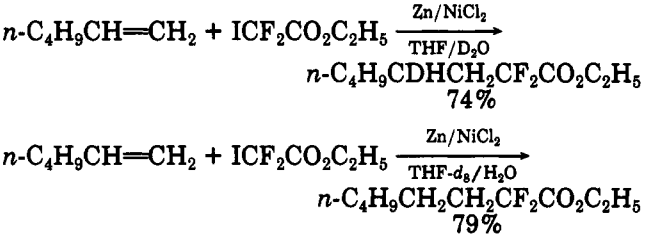
In order to determine the source of the hydrogen in the nickel-catalyzed reaction, we carried out the following experiment: reaction of **1b** with 1-hexene and zinc in the presence of anhydrous $NiCl_2$ and D_2O in dry THF at room temperature for 2 h, GC–MS analysis of the reaction mixture indicated the formation of 75% deuterium-incorporation product. After isolation, the deuterium-incorporated product, ethyl 2,2-difluoro-4-deuteriooctanoate, was further characterized by ^1H and ^{13}C NMR. In the ^1H NMR spectrum, the CH_2 adjacent to the CF_2 exhibited a triplets of doublets at 2.04 (td, $^3J_{H,F}$ = 16.8 Hz, $^3J_{H,H}$ = 7.7 Hz) ppm, while CH_2CF_2 in ethyl 2,2-difluorooctanoate exhibited a multiplet at 2.10–1.98 ppm. The carbon–deuterium coupling ($^1J_{C,D}$ = 19.5 Hz) was also observed by ^{13}C NMR spectroscopy, the $CDHCH_2CF_2$ exhibiting a triplet of triplets at 21.29 ppm. However, when a similar reaction was carried out in water and THF-d_8, the α,α-difluoro ester was isolated without deuterium incorporation. These results confirm that the source of hydrogen in the reduction step is water rather than THF and further support the intermediacy of the iodo adduct in this reaction.



In conclusion, the nickel-catalyzed reaction of 1 with a variety of alkenes and zinc in moist THF gave the corresponding α,α-difluoro esters in good yields. A single electron transfer mechanism is proposed. The ready availability of the catalyst and the precursors, the simplicity of the experimental procedure, and the mild reaction conditions make this direct preparation of α,α-difluoro-functionalized esters an attractive and practical entry to partially fluorinated building blocks for the synthesis of difluoromethylene-substituted biologically active compounds.

Experimental Section

General. All reactions were performed in an oven-dried apparatus that consisted of a two- or three-necked flask equipped with a Teflon-coated magnetic stirring bar and a reflux condenser connected to a nitrogen source and mineral oil bubbler. All boiling points were determined during fractional distillation using a partial immersion thermometer and are uncorrected. ^{19}F NMR, ^1H NMR and ^{13}C NMR spectra were recorded on JEOL FX 90Q and Bruker AC-300 spectrometers. All chemical shifts are reported in parts per million downfield (positive) of the standard. ^{19}F NMR spectra are referenced against internal $CFCl_3$; ^1H NMR and ^{13}C NMR spectra against internal tetramethylsilane. FT-IR spectra were recorded as CCl_4 solutions using a solution cell with 0.1-cm path length. GC–MS spectra were performed at 70 eV in the electron-impact mode. GC analyses were performed on a 5% OV-101 column with a thermal conductivity detector. ROTAFLO tube is a heavy-walled glass ampule topped with a Corning Rotaflo Teflon valve.

Materials. Iododifluoroacetates **1a–c** were prepared by the literature procedure.[16] Nickel dichloride hexahydrate, Zn powder, all alkenes, and THF were obtained from the Aldrich Chemical Co. and used without purification, except Zn (325 mesh) which was washed with acid, water, and acetone.

Representative General Procedure for the Preparation of α,α-Difluoro-Functionalized Esters: Preparation of Isopropyl 2,2-Difluorodecanoate (8). A flask was charged with 0.20 g (0.84 mmol) of $NiCl_2 \cdot 6H_2O$ and 0.65 g (10 mmol) of zinc, 10 mL of THF, and 1 drop of water. The resultant mixture was

stirred at rt for 10 min, then 1.12 g (10 mmol) of 1-octene and 1.32 g (5 mmol) of **1c** were added via syringe. The reaction mixture was stirred at rt overnight and then poured into a beaker with 30 mL of ether and 30 mL of saturated NH_4Cl solution. The solids were removed by filtration and washed with ether (2 × 20 mL). The organic layer was separated, washed with water, and dried over $MgSO_4$. After evaporation of the ether, 1.2 g of crude product was obtained, which was distilled at reduced pressure to give 1.0 g (80%) of **8**, 97% GC purity, bp 96–98 °C (1.4 mmHg): ^{19}F NMR ($CDCl_3$) −106.5 (t, $^3J_{F,H}$ = 17.1 Hz); ^1H NMR ($CDCl_3$) 5.14 (hept, $^3J_{H,H}$ = 6.2 Hz, 1 H), 2.10–1.96 (m, 2 H), 1.45–1.38 (m, 2 H), 1.32–1.01 (m, 16 H), 0.88 (t, $^3J_{H,H}$ = 7.1 Hz, 3 H); ^{13}C NMR ($CDCl_3$) 164.05 (t, $^2J_{F,C}$ = 33.0 Hz), 116.47 (t, $^1J_{F,C}$ = 250.0 Hz), 70.90, 34.59 (t, $^2J_{F,C}$ = 23.2 Hz), 31.88, 29.30, 29.17, 28.79, 22.72, 21.63, 21.55, 14.10; FT-IR (CCl_4) 2984 (s), 1769 (s), 1377 (s), 1182 (s), 1082 (s); GC–MS 207 (0.62), 119 (1.33), 69 (8.46), 57 (43.75), 43 (100), 41 (36.40).

Ethyl 2,2-Difluorohexanoate (2). A 50-mL ROTAFLO tube fitted with a stir bar was charged with 4.1 g (63 mmol) of Zn, 0.46 (1.9 mmol) of $NiCl_2·6H_2O$, and 10 mL of THF and then cooled with liquid nitrogen. After 3.8 g (30 mmol) of **1b** was added, the tube was evacuated, 5 g (89 mmol) of 1-butene was condensed into the tube via a vacuum line, and the tube was sealed. The reaction mixture was stirred at rt overnight. Workup gave a residue, which was distilled to give 4.2 g (78%) of **2**: bp 83–85 °C (15 mmHg); ^{19}F NMR ($CDCl_3$) −106.4 (t, $^3J_{F,H}$ = 17.1 Hz); ^1H NMR ($CDCl_3$) 4.32 (q, $^3J_{H,H}$ = 7.1 Hz, 2 H), 2.16–1.97 (m, 2 H), 1.48–1.33 (m, 4 H), 1.35 (t, $^3J_{H,H}$ = 7.1 Hz, 3 H), 0.93 (t, $^3J_{H,H}$ = 7.0 Hz, 3 H); ^{13}C NMR ($CDCl_3$) 164.55 (t, $^2J_{F,C}$ = 33.7 Hz), 116.58 (t, $^1J_{F,C}$ = 249.0 Hz), 62.76, 34.37 (t, $^2J_{F,C}$ = 23.2 Hz), 23.68, 22.34, 14.01, 13.75; FT-IR (CCl_4) 2965 (s), 1772 (s), 1762 (s), 1309 (m), 1222 (s), 1058 (s); GC–MS 151 (1.0), 124 (20.1), 116 (25.0), 87 (67.1), 67 (41.7), 55 (8.3), 45 (16.7).

Isopropyl 2,2-Difluoroheptanoate (3). **3** (0.55 g, 83%) was similarly prepared by reaction at rt for 6 h, 97.4% GC purity: ^{19}F NMR ($CDCl_3$) −106.5 (t, $^3J_{F,H}$ = 17.0 Hz); ^1H NMR ($CDCl_3$) 5.14 (hept, $^3J_{H,H}$ = 6.3 Hz, 1 H), 2.05 (m, 2 H), 1.50–1.34 (m, 6 H), 1.32 (d, $^3J_{H,H}$ = 6.3 Hz, 6 H), 0.90 (t, $^3J_{H,H}$ = 5.6 Hz, 3 H); ^{13}C NMR ($CDCl_3$) 164.05 (t, $^2J_{F,C}$ = 33.0 Hz), 116.47 (t, $^1J_{F,C}$ = 249.8 Hz), 70.92, 34.52 (t, $^2J_{F,C}$ = 23.3 Hz), 31.27, 22.34, 21.54, 21.28 (t, $^3J_{F,C}$ = 4.3 Hz), 13.82; FT-IR (CCl_4) 2959 (s), 2932 (s), 1767 (s), 1756 (s), 1376 (s), 1301 (s), 1185 (s), 1107 (s), 1081 (s); GC–MS 209 (M^+ + 1, 0.02), 81 (5.1), 77 (3.1), 56 (2.7), 45 (12.6), 43 (100), 41 (29.1).

Ethyl 2,2-Difluorooctanoate (4). **4** (1.5 g, 72%) was similarly prepared by reaction at rt overnight, bp 44 °C (0.25 mmHg), 96% GC purity: ^{19}F NMR ($CDCl_3$) −106.3 (t, $^3J_{F,H}$ = 17.0 Hz); ^1H NMR ($CDCl_3$) 4.31 (q, $^3J_{H,H}$ = 7.1 Hz, 2 H), 2.10–1.96 (m, 2 H), 1.49–1.41 (m, 2 H), 1.34 (t, $^3J_{H,H}$ = 7.1 Hz, 3 H), 1.38–1.31 (m, 6 H), 0.89 (t, $^3J_{H,H}$ = 7.0 Hz, 3 H); ^{13}C NMR ($CDCl_3$) 164.58 (t, $^2J_{F,C}$ = 33.22 Hz), 116.67 (t, $^1J_{F,C}$ = 251.2 Hz), 62.77, 34.75 (t, $^2J_{F,C}$ = 23.3 Hz), 31.68, 28.98, 22.87, 22.64, 21.69 (t, $^3J_{C,F}$ = 4.7 Hz), 14.03; FT-IR (CCl_4) 2933 (s), 1773 (s), 1305 (m), 1190 (s), 1072 (s); GC–MS 179 (M^+ − Et, 12.1), 144 (29.8), 124 (24.8), 101 (23.9), 73 (29.8), 69 (31.9), 43 (100), 41 (45.2).

Isopropyl 2,2-Difluorooctanoate (5). **5** (0.47 g, 71%) was similarly prepared by reaction at 60 °C for 4 h, bp 67–68 °C (1.4 mmHg), 100% GC purity: ^{19}F NMR ($CDCl_3$) −106.7 (t, $^3J_{H,F}$ = 17.1 Hz); ^1H NMR ($CDCl_3$) 5.14 (hept, $^3J_{H,H}$ = 6.2 Hz, 1 H), 2.03 (m, 2 H), 1.32 (d, $^3J_{H,H}$ = 6.2 Hz, 6 H), 1.51–1.30 (m, 8 H), 0.89 (t, $^3J_{H,H}$ = 6.9 Hz, 3 H); ^{13}C NMR ($CDCl_3$) 164.04 (t, $^2J_{F,C}$ = 32.9 Hz), 116.49 (t, $^1J_{F,C}$ = 250.3 Hz), 70.86, 34.61 (t, $^2J_{F,C}$ = 23.2 Hz), 31.51, 28.84, 22.48, 21.55, 21.50, 13.97; FT-IR (CCl_4) 2963 (s), 1769 (s), 1303 (m), 1212 (s), 1193 (s), 1075 (s); GC-MS 207 (M^+ − Me, 0.32), 135 (4.20), 95 (7.87), 69 (6.63), 43 (100).

Ethyl 2,2-Difluorononanoate (6). **6** (0.30 g, 68%) was similarly prepared by reaction at 60 °C for 4 h, bp 77–79 °C (1.6 mmHg), 96% GC purity: ^{19}F NMR ($CDCl_3$) −106.4 (t, $^3J_{F,H}$ = 17.1 Hz); ^1H NMR ($CDCl_3$) 4.32 (q, $^3J_{H,H}$ = 7.1 Hz, 2 H), 2.08 (m, 2 H), 1.35 (t, $^3J_{H,H}$ = 7.1 Hz, 3 H), 1.58–1.28 (m, 8 H), 0.89 (t, $^3J_{H,H}$ = 6.9 Hz, 3 H); ^{13}C NMR ($CDCl_3$) 164.57 (t, $^2J_{F,C}$ = 35.0 Hz), 116.53 (t, $^1J_{F,C}$ = 249.2 Hz), 62.74, 34.63 (t, $^2J_{F,C}$ = 23.1 Hz), 31.70, 29.16, 29.01, 22.68, 21.56, 14.06, 14.00; FT-IR (CCl_4) 2983 (m), 1773 (s), 1206 (s), 1188 (s), 1080 (s), 1023 (s); GC–MS 193 (M^+ − Et, 2.77), 115 (12.66), 77 (15.51), 57 (43.67), 43 (100).

Isopropyl 2,2-Difluorononanoate (7). **7** (0.70 g, 74%) was similarly prepared by reaction at rt for 4 h, 97% GC purity: ^{19}F NMR ($CDCl_3$) −106.4 (t, $^3J_{F,H}$ = 17.1 Hz); ^1H NMR ($CDCl_3$) 5.14 (hept, $^3J_{H,H}$ = 6.3 Hz, 1 H), 2.03 (m, 2 H), 1.45–1.29 (m, 16 H), 0.89 (t, $^3J_{H,H}$ = 7.0 Hz, 3 H); ^{13}C NMR ($CDCl_3$) 164.06 (t, $^2J_{C,F}$ = 33.0 Hz), 116.58 (t, $^1J_{C,F}$ = 250.1 Hz), 70.90, 34.71 (t, $^2J_{C,F}$ = 23.3 Hz), 31.81, 29.25, 29.13, 22.77, 21.72 (t, $^3J_{C,F}$ = 4.7 Hz), 21.55, 14.10; FT-IR (CCl_4) 2985 (s), 1768 (s), 1755 (s), 1377 (m), 1184 (s), 1080 (s); GC–MS 222 (M^+, 0.2), 195 (5.8), 131 (5.3), 107 (8.9), 87 (10.9), 57 (22.5), 45 (22.6), 43 (100), 41 (58.0).

Ethyl 2,2-Difluorohexadecanoate (9). After the reaction mixture was stirred rt overnight, workup gave a residue, which was purified on silica gel (hexane) to give 0.60 g (64%) of **9**: ^{19}F NMR ($CDCl_3$) −106.4 (t, $^3J_{F,H}$ = 17.1 Hz); ^1H NMR ($CDCl_3$) 4.31 (q, $^3J_{H,H}$ = 7.1 Hz, 2 H), 2.12–1.96 (m, 2 H), 1.37–1.26 (m, 26 H), 0.88 (t, $^3J_{H,H}$ = 6.7 Hz, 3 H); ^{13}C NMR ($CDCl_3$) 164.43 (t, $^2J_{F,C}$ = 22.5 Hz), 116.43 (t, $^1J_{F,C}$ = 250.0 Hz), 62.63, 34.59 (t, $^2J_{F,C}$ = 23.0 Hz), 32.01, 29.74, 29.64, 29.53, 29.46, 29.44, 29.31, 29.16, 27.48, 22.76, 21.52 (t, $^3J_{F,C}$ = 4.2 Hz), 14.12, 13.99; FT-IR (CCl_4) 2955 (s), 1772 (s), 1304 (m), 1193 (s), 1097 (s); GC–MS 320 (2.47), 193 (41.88), 179 (46.04), 85 (13.33), 57 (58.33), 43 (100).

Isopropyl 2,2-Difluoro-4-(trimethylsilyl)butanoate (10). **10** (0.42 g, 65%) was similarly prepared by reaction at rt, bp 60 °C (1.5 mmHg), 95% GC purity: ^{19}F NMR ($CDCl_3$) −107.9 (t, $^3J_{F,H}$ = 17.1 Hz); ^1H NMR ($CDCl_3$) 5.15 (hept, 3$J_{H,H}$ = 6.3 Hz, 1 H), 2.00 (m, 2 H), 1.32 (d, $^3J_{H,H}$ = 6.3 Hz, 6 H), 0.59 (m, 2 H), 0.02 (s, 9 H); ^{13}C NMR ($CDCl_3$) 164.02 (t, $^2J_{F,C}$ = 33.34 Hz), 116.96 (t, $^1J_{F,C}$ = 250 Hz), 70.77, 29.44 (t, $^2J_{F,C}$ = 24.5 Hz), 21.56, 7.78 (t, $^3J_{F,C}$ = 2.6 Hz), −2.08; FT-IR (CCl_4) 2985 (m), 1769 (s), 1302, 1207, 1024; GC–MS 196 (0.2), 181 (6.2), 104 (22.1), 77 (37.4), 73 (100), 59 (33.5), 43 (78.8).

Isopropyl 2,2-Difluoro-12-hydroxydodecanoate (11). **11** (1.1 g, 76%) was similarly prepared by reaction at rt overnight, bp 122–125 °C (0.4 mmHg): ^{19}F NMR ($CDCl_3$) −106.6 (t, $^3J_{F,H}$ = 17.1 Hz); ^1H NMR ($CDCl_3$) 5.14 (hept, $^3J_{H,H}$ = 6.3 Hz, 1 H), 3.61 (t, $^3J_{H,H}$ = 6.6 Hz, 2 H), 2.17–1.96 (m, 3 H), 1.59–1.49 (m, 2 H), 1.45–1.40 (m, 2 H), 1.32 (d, $^3J_{H,H}$ = 6.3 Hz, 6 H), 1.33–1.29 (m, 12 H); ^{13}C NMR ($CDCl_3$) 164.01 (t, $^2J_{F,C}$ = 33.3 Hz), 116.40 (t, $^1J_{F,C}$ = 249.9 Hz), 70.95, 62.90, 34.51 (t, $^2J_{C,F}$ = 23.2 Hz), 32.79, 29.55, 29.45, 29.36, 29.26, 29.10, 25.81, 21.54; FT-IR (CCl_4) 3639 (m), 2933 (s), 1768 (s), 1755 (s), 1377 (s), 1191 (s), 1105 (s); GC–MS 223 (1.33), 83 (5.64), 70 (5.35), 69 (11.71), 55 (20.89), 43 (100.0).

Isopropyl 2,2-Difluoro-7-acetoxyheptanoate (12). **12** (0.50 g, 63%) was similarly prepared by the reaction at rt overnight, bp 95–97 °C (0.2 mmHg): ^{19}F NMR ($CDCl_3$) −106.7 (t, $^3J_{F,H}$ = 16.9 Hz); ^1H NMR ($CDCl_3$) 5.15 (hept, $^3J_{H,H}$ = 6.2 Hz, 1 H), 4.06 (t, $^3J_{H,H}$ = 6.5 Hz, 2 H), 2.11–1.98 (m, 2 H), 2.04 (s, 3 H), 1.65 (pent, $^3J_{H,H}$ = 6.8 Hz, 2 H), 1.56–1.38 (m, 4 H), 1.33 (d, $^3J_{H,H}$ = 6.2 Hz, 6 H); ^{13}C NMR ($CDCl_3$) 171.05, 163.88 (t, $^2J_{F,C}$ = 33.0 Hz), 116.25 (t, $^1J_{F,C}$ = 250 Hz), 70.98, 64.15, 34.39 (t, $^2J_{F,C}$ = 23.3 Hz), 28.39, 25.62, 21.55, 21.28 (t, $^3J_{F,C}$ = 4.0 Hz), 20.91; FT-IR (CCl_4) 2961 (s), 1761 (s), 1749 (s), 1376 (s), 1281 (s), 1191 (s), 1105 (s), 1037 (s); GC–MS 207 (M^+ − AcO, 1.41), 164 (7.84), 77 (8.56), 61 (18.27), 43 (100), 41 (17.12).

Methyl 2,2-Difluoro-7-oxooctanoate (13). **13** (0.48 g, 76%) was similarly prepared by reaction at 60 °C for 5 h, bp 65–66 °C (0.1 mmHg), 95% GC purity: ^{19}F NMR ($CDCl_3$) −106.4 (t, $^3J_{F,H}$ = 17.4 Hz); ^1H NMR ($CDCl_3$) 3.86 (s, 3 H), 2.46 (t, $^3J_{H,H}$ = 7.2 Hz, 2 H), 2.13 (s, 3 H), 2.09–2.00 (m, 2 H), 1.63 (pent, $^3J_{H,H}$ = 7.2 Hz, 2 H), 1.47 (m, 2 H); ^{13}C NMR ($CDCl_3$) 207.93, 164.71 (t, $^2J_{F,C}$ = 33.0 Hz), 116.20 (t, $^1J_{F,C}$ = 249.5 Hz), 53.25, 43.07, 34.39 (t, $^2J_{F,C}$ = 23.2 Hz), 29.89, 23.08, 21.10 (t, $^3J_{F,C}$ = 4.1 Hz); FT-IR (CCl_4) 2957 (s), 1769 (s), 1724 (s), 1203 (s), 1113 (s), 1099 (s); GC–MS 208 (M^+, 0.39), 113 (4.73), 85 (7.89), 81 (12.80), 59 (18.20), 58 (68.93), 43 (100).

Ethyl 2,2-Difluoro-7-oxooctanoate (14). **14** (0.45 g, 67%) was similarly prepared by reaction at 60 °C for 5 h, bp 68–70 °C (0.05 mmHg), 97% GC purity: ^{19}F NMR ($CDCl_3$) −106.4 (t, $^3J_{F,H}$ = 17.1 Hz); ^1H NMR ($CDCl_3$) 4.32 (q, $^3J_{H,H}$ = 7.1 Hz, 2 H), 2.47 (t, $^3J_{H,H}$ = 7.1 Hz, 2 H), 2.14 (s, 3 H), 2.19–2.00 (m, 2 H), 1.63 (pent, $^3J_{H,H}$ = 7.5 Hz, 2 H), 1.47 (m, 2 H), 1.35 (t, $^3J_{H,H}$ = 7.1 Hz, 3 H); ^{13}C NMR ($CDCl_3$) 208.06, 164.22 (t, $^2J_{F,C}$ = 33.1 Hz), 116.22 (t, $^1J_{F,C}$ = 249.5 Hz), 62.83, 43.06, 34.36 (t, $^2J_{F,C}$ = 23.3 Hz), 29.88, 23.11, 21.12 (t, $^3J_{F,C}$ = 4.2 Hz), 13.97; FT-IR (CCl_4) 2984 (m), 1771 (s), 1722 (s), 1185 (s), 1099 (s); GC–MS 222 (M^+, 0.5), 137 (3.9), 71 (14.6), 58 (61.7), 43 (100).

Ethyl 2,2-Difluoro-6-methyl-6-carbethoxyhexanoate (15). **15** (0.58 g, 73%) was similarly prepared by reaction at rt overnight,

bp 72–74 °C (0.1 mmHg): ^{19}F NMR ($CDCl_3$) −106.2 (t, $^3J_{H,F}$ = 17.1 Hz); ^{1}H NMR ($CDCl_3$) 4.32 (q, $^3J_{H,H}$ = 7.1 Hz, 2 H), 4.12 (q, $^3J_{H,H}$ = 7.1 Hz, 2 H), 2.43 (m, 1 H), 2.15–1.98 (m, 2 H), 1.70–1.52 (m, 1 H), 1.50–1.47 (m, 3 H), 1.33 (t, $^3J_{H,H}$ = 7.1 Hz, 3 H), 1.24 (t, $^3J_{H,H}$ = 7.3 Hz, 3 H), 1.14 (d, $^3J_{H,H}$ = 7.0 Hz, 3 H); ^{13}C NMR ($CDCl_3$) 176.16, 164.29 (t, $^2J_{C,F}$ = 33.0 Hz), 116.56 (t, $^1J_{C,F}$ = 249.1 Hz), 62.90, 60.37, 39.41, 34.59 (t, $^2J_{C,F}$ = 23.3 Hz), 33.35, 19.63 (t, $^3J_{C,F}$ = 4.7 Hz), 17.14, 14.32, 14.01; FT-IR (CCl_4) 2984 (m), 1768 (s), 1756 (s), 1735 (s), 1377 (m), 1298 (m), 1180 (s), 1103 (s); GC–MS 267 (M^+ + 1, 0.2), 165 (10.2), 115 (16.6), 102 (100), 74 (25.9), 55 (28.9), 41 (23.44).

Isopropyl 2,2-Difluoro-6-methyl-6-carbethoxyhexanoate (16). **16** (0.50 g, 60%) was similarly prepared by reaction at rt overnight, bp 76–78 °C (0.07 mmHg): ^{19}F NMR ($CDCl_3$) −106.6 (t, $^3J_{F,H}$ = 17.1 Hz); ^{1}H NMR ($CDCl_3$) 5.14 (hept, $^3J_{H,H}$ = 6.2 Hz, 1 H), 4.13 (q, $^3J_{H,H}$ = 7.1 Hz, 2 H), 2.44 (m, 1 H), 2.07 (m, 2 H), 1.50 (m, 1 H), 1.48 (m, 3 H), 1.32 (d, $^3J_{H,H}$ = 6.2 Hz, 6 H), 1.25 (t, $^3J_{H,H}$ = 7.2 Hz, 3 H), 1.15 (d, $^3J_{H,H}$ = 7.0 Hz, 3 H); ^{13}C NMR ($CDCl_3$) 176.16, 163.82 (t, $^2J_{F,C}$ = 33.0 Hz), 116.18 (t, $^1J_{F,C}$ = 250.4 Hz), 70.98, 60.29, 39.32, 34.44 (t, $^2J_{F,C}$ = 23.3 Hz), 33.17, 21.53, 19.43 (t, $^3J_{F,C}$ = 4.2 Hz), 17.03, 14.25; FT-IR (CCl_4) 2982 (m), 1772 (s), 1761 (s), 1735 (s), 1249 (m), 1180 (s), 1098 (m); GC–MS 235 (M^+ − EtO, 13.3), 193 (22.8), 165 (58.8), 145 (15.3), 115 (58.8), 102 (100.0), 87 (25.6), 43 (91.2), 41 (37.6).

Diethyl 2,2,9,9-Tetrafluorodecane-1,10-dioate (17). **17** (1.8 g, 55%) was similarly prepared by reaction at rt for 5 h, bp 125–126 °C (0.2 mmHg): ^{19}F NMR ($CDCl_3$) −106.4 (t, $^3J_{F,H}$ = 17.1 Hz); ^{1}H NMR ($CDCl_3$) 4.32 (q, $^3J_{H,H}$ = 7.1 Hz, 4 H), 2.12–1.98 (m, 4 H), 1.48 (m, 4 H), 1.54–1.31 (m, 10 H); ^{13}C NMR ($CDCl_3$) 164.41 (t, $^2J_{F,C}$ = 32.3 Hz), 116.33 (t, $^1J_{F,C}$ = 249.7 Hz), 62.81, 34.40 (t, $^2J_{F,C}$ = 23.2 Hz), 28.72, 21.30 (t, $^3J_{F,C}$ = 4.1 Hz), 13.98; FT-IR (CCl_4) 2941 (m), 1770 (s), 1766 (s), 1216 (s), 1192 (s), 1089 (s); GC–MS 240 (M^+ − 2OEt, 22.8), 238 (72.4), 113 (30.2), 111 (100), 75 (81.8), 50 (55.5).

Diethyl 2,2,12,12-Tetrafluorotridecane-1,13-dioate (18). **18** (0.78 g, 73%) was similarly prepared by reaction at 65 °C for 4 h. ^{19}F NMR ($CDCl_3$) −104.8 (t, $^3J_{F,H}$ = 17.1 Hz); ^{1}H NMR ($CDCl_3$) 4.32 (q, $^3J_{H,H}$ = 7.1 Hz, 4 H), 2.02 (m, 4 H), 1.99–1.31 (m, 20 H); ^{13}C NMR ($CDCl_3$) 164.50 (t, $^2J_{C,F}$ = 33.0 Hz), 116.54 (t, $^1J_{C,F}$ = 249.8 Hz), 62.78, 34.58 (t, $^2J_{C,F}$ = 23.1 Hz), 29.23, 29.10, 28.39, 21.57 (t, $^3J_{C,F}$ = 4.5 Hz), 13.97; FT-IR (CCl_4) 2984 (s), 1773 (s), 1767 (s), 1304 (s), 1196 (s), 1093 (s), 1059 (s); GC–MS 373 (M^+ + 1, 0.2), 234 (33.8), 193 (30.4), 179 (28.4), 101 (28.4), 81 (30.6), 55 (100), 43 (55.1), 41 (79.7).

Reaction of 1b with 1,6-Heptadiene. After a mixture of 0.65 g (10 mmol) of zinc, 0.1 g (0.42 mmol) of $NiCl_2$·$6H_2O$, and 1 drop of water in 5 mL of THF was stirred at rt for 10 min, 1.0 g (10 mmol) of 1,6-heptadiene and 1.25 g (5 mmol) of **1b** were added and the resultant mixture was stirred for 2 h. Usual workup gave 1.2 g of residue, which was distilled to give 0.85 g (77%) of a mixture of **19** and **20** in a 1:1.3 ratio, bp 81–83 °C (2 mmHg): ^{19}F NMR ($CDCl_3$) **19**: −104.9 (tm, $^3J_{F,H}$ = 17.1 Hz); **20**: −106.4 (t, $^3J_{F,H}$ = 17.5 Hz); ^{1}H NMR ($CDCl_3$) 5.85–5.71 (m, 0.4 H), 5.01–4.91 (m, 0.8 H), 4.31 (t, $^3J_{H,H}$ = 7.1 Hz, 2 H), 2.26–1.34 (m, 11 H), 0.98 (d, $^3J_{H,H}$ = 5.5 Hz, 0.2 H), 0.80 (d, $^3J_{H,H}$ = 6.3 Hz, 1.4 H); ^{13}C NMR ($CDCl_3$) 164.77 (t, $^2J_{C,F}$ = 33.0 Hz, C=O), 164.48 (t, $^2J_{C,F}$ = 33.0 Hz, C=O); 138.70 (C=C), 116.96 (t, $^1J_{C,F}$ = 250.3 Hz, CF_2), for *trans*-**20**: 116.75 (t, $^1J_{C,F}$ = 249.4 Hz, CF_2), for *cis*-**20**: 115.54 (t, $^1J_{C,F}$ = 294.4 Hz, CF_2), 114.63 (C=C), 62.75 (O-C); FT-IR (CCl_4) 2960 (m), 1772 (s), 1762 (s), 1641 (w), 1308 (m), 1185 (s), 1058 (m); GC-MS **19**: 220 (M^+, 2.3), 151 (7.1), 127 (10.3), 100 (20.2), 77 (21.9), 69 (21.2), 56 (31.1), 55 (90.8), 41 (100); **20**: 220 (M^+, 0.6), 182 (14.7), 156 (13.2), 137 (15.3), 97 (39.8), 83 (41.7), 82 (25.1), 67 (23.3), 56 (60.7), 55 (100), 41 (64.5).

Reaction of 1b with Diallyl Ether. After a mixture of 0.65 g (10 mmol) of Zn, 0.1 g (0.37 mmol) of $NiCl_2$·$6H_2O$, and 1 drop of water in 5 mL of THF was stirred at rt for 10 min, 1.0 g (10 mmol) of diallyl ether and 1.25 g (5 mmol) of **1b** were added and the resultant mixture was stirred at rt for 2 h. Usual workup gave a residue which distilled at reduced pressure to give 0.81 g (74%) of **21b** as a mixture of cis and trans isomers in a 4:1 ratio, bp 85–86 °C (2 mmHg): ^{1}H NMR ($CDCl_3$) 4.33 (q, $^3J_{H,H}$ = 7.1 Hz, 2 H), 3.89–3.88 (m, 2 H), 2.51–3.41 (m, 2 H), 2.51–1.93 (m, 4 H), 1.36 (t, $^3J_{H,H}$ = 7.1 Hz, 3 H), 1.06 (d, $^3J_{H,H}$ = 6.1 Hz, 0.6 H), 0.96 (d, $^3J_{H,H}$ = 7.0 Hz, 2.4 H); ^{19}F NMR ($CDCl_3$) (a) −104.2 (ddd, $^2J_{F,F}$ = 260.3 Hz, $^3J_{H,F}$ = 22.0, 12.0 Hz), −106.4 (dm, $^2J_{F,F}$ = 260.3 Hz), (b) −104.6 (ddd, $^2J_{F,F}$ = 259.4 Hz, $^3J_{F,H}$ = 21.1, 12.8 Hz), −106.4 (ddd, $^2J_{F,F}$ = 254 Hz, $^3J_{H,F}$ = 21.8 Hz, $^3J_{H,F}$ = 6.5 Hz); ^{13}C NMR ($CDCl_3$) 164.22 (t, $^2J_{C,F}$ = 32.7 Hz), 116.40 (t, $^1J_{C,F}$ = 250.2 Hz), 116.12 (t, $^1J_{C,F}$ = 250.3 Hz), 75.00, 74.38, 73.62, 71.32, 63.06, 40.97, 40.24, 36.91 (t, $^2J_{C,F}$ = 23.3 Hz), 36.16, 36.08, 32.75 (t, $^2J_{C,F}$ = 23.3 Hz), 15.74, 13.96, 13.44; FT-IR (CCl_4) 2969 (s), 2967 (s), 1770 (s), 1765 (s), 1763 (s), 1308 (s), 1192 (s), 1070 (s), 1056 (s); GC–MS (a) 222 (M^+, 0.80), 143 (3.2), 99 (11.1), 84 (100.0), 79 (10.8), 77 (12.6), 69 (43.0), 55 (22.9), 43 (15.0), 41 (24.3), (b) 222 (M^+, 1.7), 143 (4.2), 99 (13.0), 84 (100.0), 79 (14.9), 77 (15.3), 69 (55.5), 55 (25.0), 43 (14.5), 41 (27.7).

Reaction of 1a with Diallyl Ether. **21a** (0.33 g, 53%) as a mixture of cis and trans isomers in a 3.4:1 ratio was similarly prepared by reaction at 60 °C for 4 h, 96% GC purity: ^{19}F NMR ($CDCl_3$) 105.2–106.0 (m); ^{1}H NMR ($CDCl_3$) 4.10–3.82 (m, 2 H), 3.88 (s, 3 H), 3.52–3.46 (m, 2 H), 2.50–2.19 (m, 2 H), 2.13–1.93 (m, 2 H), 1.05 (d, $^3J_{H,H}$ = 6.5 Hz, *trans*-CH_3), 0.96 (d, $^3J_{H,H}$ = 7.0 Hz, *cis*-CH_3); FT-IR (CCl_4) 2963 (s), 2959 (s), 1775 (s), 1769 (s), 1767 (s), 1310 (s), 1199 (s), 1092 (s), 1058 (s); GC–MS 208 (M^+, 2.1), 143 (5.1), 113 (8.1), 110 (16.6), 103 (11.47), 99 (14.2), 84 (92.1), 79 (23.2), 69 (78.4), 59 (58.3), 55 (46.8), 41 (87.1).

Reaction of 1b with 1-Octene in the Presence of Inhibitor. A mixture of 0.13 g (2.0 mmol) of zinc, 0.05 g (0.21 mmol) of $NiCl_2$·$6H_2O$, and 1 drop of water in 4 mL of THF was stirred at rt for 15 min. Then 0.084 g (0.5 mmol) of dinitrobenzene and 0.2 g (2 mmol) of 1-heptene were added with stirring. After 0.25 g (1 mmol) of **1b** was added, the resultant mixture was stirred at rt for 20 h. ^{19}F NMR analysis indicated only **1b**.

Similarly, the reaction was carried out in the presence of hydroquinone for 20 min. ^{19}F NMR analysis of the reaction mixture indicated **1b**, HCF_2CO_2Et, and $C_5H_{11}CHICH_2CF_2CO_2Et$[16] in a 1:1.3:5.3 ratio.

Reaction of 1b with 1-Hexene, Zinc, and D_2O in the Presence of $NiCl_2$ in THF. A 50-mL flask was charged with 0.65 g (10 mmol) of Zn, 0.05 g (0.39 mmol) of anhydrous $NiCl_2$, and 8 mL of anhydrous THF. After addition of 0.2 mL of D_2O, the mixture was stirred at rt for 10 min. Then 0.84 g (10 mmol) of 1-hexene and 1.3 g (5 mmol) of **1b** were added and the resultant reaction mixture was stirred at rt for 2 h. Usual workup gave 0.77 g (74%, 97% GC purity) of ethyl 2,2-difluorooctanoate, which was 75% deuterium incorporated determined by GC–MS analysis: ^{1}H NMR ($CDCl_3$) 4.32 (q, $^3J_{H,H}$ = 7.1 Hz, 2 H), 2.04 (td, $^3J_{H,F}$ = 16.8 Hz, $^3J_{H,H}$ = 7.7 Hz, 2 H), 1.49–1.42 (m, 1 H), 1.41–1.24 (m, 9 H), 0.89 (t, $^3J_{H,H}$ = 6.9 Hz, 3 H); ^{19}F NMR ($CDCl_3$) −106.4 (t, $^3J_{F,H}$ = 16.8 Hz); ^{13}C NMR ($CDCl_3$) 164.59 (t, $^2J_{C,F}$ = 33.6 Hz), 116.64 (t, $^1J_{C,F}$ = 249.8 Hz), 62.80, 34.64 (t, $^2J_{C,F}$ = 23.2 Hz), 31.61, 28.85, 22.61, 21.29 (tt, $^1J_{C,D}$ = 19.5 Hz, $^3J_{C,F}$ = 4.6 Hz), 14.28, 14.05; FT-IR 2961 (s), 2860 (m), 1772 (s), 1762 (s), 1305 (s), 1193 (s), 1073 (s); GC–MS for detuerium-incorporation product 194 (M^+ − Me, 1.2), 180 (M^+ − Et, 20.9), 145 (40.3), 96 (40.6), 70 (40.0), 44 (76.5), 43 (100.0), 41 (43.8).

Reaction of 1b with 1-Hexene, Zinc, and H_2O in the Presence of $NiCl_2$ in THF-d_8. Similarly, to a mixture of 0.4 g (6.15 mmol) of Zn, 0.05 g (0.39 mmol) of $NiCl_2$, and 0.2 mL of H_2O in 3 mL of THF-d_8 were added 0.5 g (6 mmol) of 1-hexene and 0.75 g (3 mmol), and the resultant mixture was stirred at rt for 2 h. Usual workup gave 0.5 g (80%) of **4**. GC–MS analysis indicated no deuterium incorporation in the product.

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Supplementary Material Available: A ^{13}C or ^{1}H NMR spectrum of each compound described in the Experimental Section (20 pages). This material is contained in many libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.