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The Addition of Dibromodifluoromethane to (Trimethylsilyl)acetylene and Transformation of the Products

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Abstract: Reaction of dibromodifluoromethane (**1**) with (trimethylsilyl)acetylene (**2**) initiated by ammonium persulfate/sodium formate ($(NH_4)_2S_2O_8$ / HCO_2Na) yield the addition-reduction product (**3a**), tribromide compound (**3b**) and the non-fluorinated compound (**4**) which could be separated by careful distillation. The reaction appears to be initiated by $CO_2^{\bullet-}$. Indium mediated coupling of **3a** with aldehydes gave the corresponding *gem*-difluorohomoallyl alcohols bearing a trimethylsilyl group **8** in high yields. In the presence of indium, **3b** reacted with aldehydes to afford the coupling-reduction product *gem*-difluorohomoallyl alcohols **9**. The regiochemistry of this reaction and the retention of the configuration of double bond could be rationalized in terms of the more nucleophilic α-carbon of the *gem*-difluoroallyl intermediate.

INTRODUCTION

The synthesis of compounds containing difluoromethylene (CF_2) group has been an area of active interest, as many of these compounds have been found to be biologically active.[1] A well-tried approach involves the transformation of a ketonic carbonyl group directly using (diethylamino)sulfur trifluoride (DAST).[2,3] However, in complex molecules the installation of the appropriate carbonyl precursor to the CF_2 group may be far from straightforward. There may be additional limitations imposed by the nature of the mechanism of the DAST fluorination reaction. An alternative strategy uses fluorinated building blocks, and methods involving these are being reported for the synthesis of functionalized, difluoromethyl-substituted compounds.[4,5] Of the two strategies, the building block approach is potentially more versatile.

Readily available dibromodifluoromethane (CF_2Br_2) is frequently used as a starting material for the synthesis of difluoromethylene -containing building blocks, in which three type reactions are involved. CF_2Br_2

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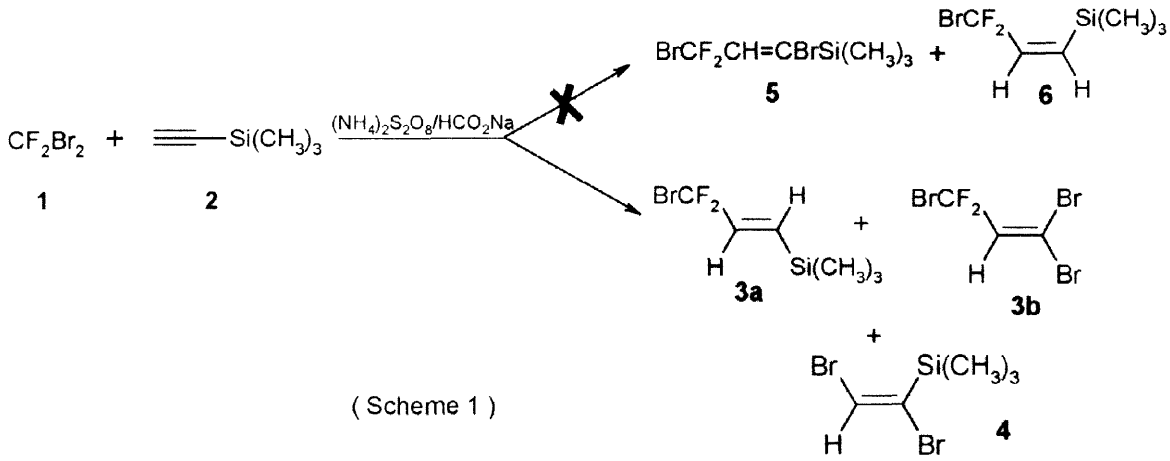
reacts with nucleophiles such as phenoxides, thiophenoxides, carbanions or enamines in an apparent nucleophilic displacement reaction ,which usually involves a radical or carbene mechanism;[6] Reaction of CF_2Br_2 with alkenes in the presence of zinc or base afforded *gem*-difluorocyclopropanes;[7] The majority of reactions proceed by the free-radical addition of CF_2Br_2 across alkenes.[8] Difluoromethylene radicals are very promising intermediates for the preparation of complex fluorinated molecules under mild conditions. They are usually more reactive than the corresponding non-fluorinated radicals in carbon-carbon bond forming reactions, because of the σ-nature of the radical and the increased strength of the bond formed.[9] Difluoromethylene radicals are generally considered as strongly electrophilic.[10] The addition of CF_2Br_2 involving difluoromethylene radical to alkenes initiated by dibenzoyl peroxide,[11] copper(I) chloride,[12] or UV light in the case of electron rich alkenes,[13] has been well studied. New initiators for this reaction have also been reported: triethylborane/oxygen at room temperature;[14] a chromium trichloride/iron bimetal redox system;[15] and a manganese mediated electrochemical initiation.[16] To the best of our knowledge , however, the free- radical addition of CF_2Br_2 to the alkynes rarely appeared. The only two examples have been hitherto the addition of CF_2Br_2 across acetylene[17]and 1-dodecyne[14] to form the 1:1 adducts. This paper is devoted to the addition of dibromodifluoromethane to (trimethylsilyl)acetylene initiated by a redox pair for the preparation of highly functionalized difluoromethylene -containing building blocks and their further transformation.

RESULTS AND DISCUSSION

We found that, when initiated by a redox pair, dibromodifluoromethane (CF_2Br_2 **1**)can add to alkynes. In the presence of an equimolar mixture of $(NH_4)_2S_2O_8$ and $HCO_2Na.2H_2O$, the addition of **1** to (trimethylsilyl)acetylene (**2**) proceeded smoothly in DMF suspension at 50°C to yield the mixture of E-isomer of addition-reduction product (**3a**), tribromide compound (**3b**) and the non-fluorinated compound **4** which could be separated by careful distillation (Scheme 1). The ratio of **3a** : **3b** : **4** is 4 : 12 : 3 as determined by ^1H NMR spectra. The structures of **3a**, **3b** and **4** were readily determined by their ^1H NMR spectra, ^{13}C-NMR spectra, MS and elemental analysis. The configuration of double bond in **3a** was assigned by the coupling constant of the two vinyl protons (**3a** $J_{H,H}$= 19.0 Hz). The 1:1 adduct product **5** and the Z-isomer of addition-reduction product **6** were not detected. The addition did not occur below 40°C. This reaction was quite solvent sensitive. In aqueous CH_3CN, no reaction occurred. The results described here represent the first example of the addition of perfluoroalkyl halides like R_fX (X=I, Br) to alkynes to give the stereo-specific addition-reduction products in one step.



(Scheme 1)

Ammonium persulfate is a one-electron oxidant that spontaneously decomposes to $SO_4^{\bullet-}$. When $(NH_4)_2S_2O_8$ and HCO_2Na are mixed together, $CO_2^{\bullet}$ is formed.[18] Experiments showed that the presence of both $(NH_4)_2S_2O_8$ and $HCO_2Na.2H_2O$ was necessary for the addition to occur. It thus seems likely that the reaction is initiated by the transfer of a single electron to CF_2Br_2 from $CO_2^{\bullet-}$ rather than from $SO_4^{\bullet-}$. The transfer of a single electron to CF_2Br_2 from $CO_2^{\bullet-}$ produced $BrCF_2\bullet$ and $Br\bullet$ in two different reaction routes. The intermediate $BrCF_2\bullet$ added to alkyne **2** to form $BrCF_2CH{=}C^{\bullet}Si(CH_3)_3$. Because trimethylsilyl group can stabilize the carboradical and is sterically bulky, [19,20] $BrCF_2CH{=}C^{\bullet}Si(CH_3)_3$ abstracted a hydrogen presumably from the solvent to stereo-specifically form **3a**. The self-coupling of $Br\bullet$ formed Br_2, then addition of Br_2 across alkyne **2** afforded **4**. The addition of $BrCF_2\bullet$ to **4**, followed by abstracting a bromine produced $BrCF_2CHBrCBr_2Si(CH_3)_3$, this compound was unstable and subsequently eliminated $(CH_3)_3SiBr$ [21] to give **3b**. A tentative mechanism for this reaction was shown in Scheme 2.

$$S_2O_8^{2-} \rightarrow 2\ SO_4^{\bullet-}$$

$$SO_4^{\bullet-} + HCO_2^- \rightarrow HSO_4^- + CO_2^{\bullet-}$$

$$CF_2Br_2 + CO_2^{\bullet-} \rightarrow BrCF_2\bullet + CO_2 + Br^- \text{ and}$$

$$CF_2Br_2 + CO_2^{\bullet-} \rightarrow BrCF_2^- + CO_2 + Br\bullet$$

$$BrCF_2\bullet + HC{\equiv}CSi(CH_3)_3 \rightarrow BrCF_2CH{=}C^{\bullet}Si(CH_3)_3 \rightarrow \underset{\textbf{3a}}{BrCF_2CH{=}CHSi(CH_3)_3}$$

$$2\ Br\bullet \rightarrow Br_2$$

$$Br_2 + HC{\equiv}CSi(CH_3)_3 \rightarrow \underset{\textbf{4}}{BrCH{=}CBrSi(CH_3)_3}$$

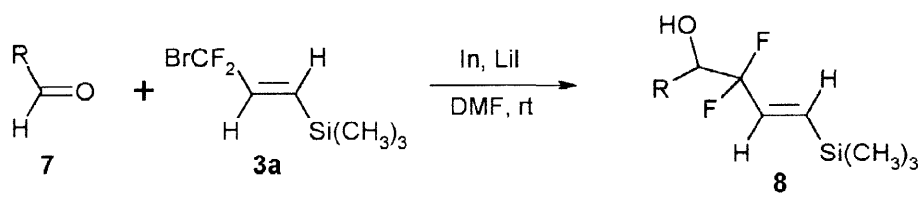
$$BrCF_2\bullet + BrCH{=}CBrSi(CH_3)_3 \rightarrow BrCF_2CHBr\ C^{\bullet}BrSi(CH_3)_3 \rightarrow BrCF_2CHBrCBr_2Si(CH_3)_3$$

$$\downarrow$$

$$BrCF_2CH{=}CBr_2 \quad \textbf{3b}$$

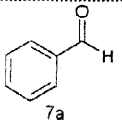
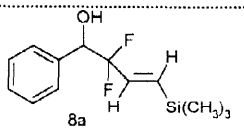
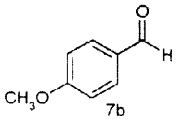
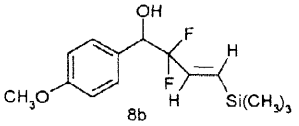
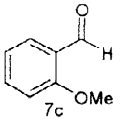
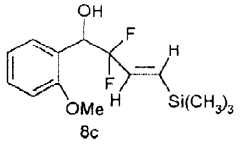
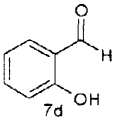
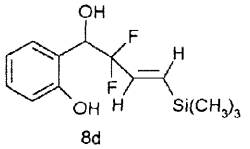
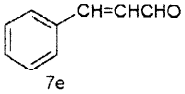
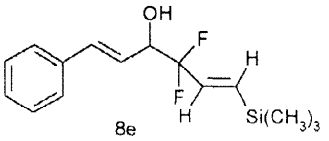
(Scheme 2)

The coupling of aldehydes to allylic and allenic indium reagents is currently an active area of research .[22] The allylic reagents can be readily generated form allylic halides and indium metal and they are relatively nontoxic. Unlike their more reactive counterparts, allylic Grignard and lithium reagents, they are compatible with protic solvents and can easily be generated in water and combinations of water and miscible organic solvents. They also show no tendency to give dimeric hydrocarbons as byproducts of their formation from bromides. The most used allylic halides in these coupling are allyl bromide,[23] α-(bromomethyl)acrylic acid [24] and its ester.[25] Coupling involving fluorinated allylic halides has rarely appeared. Only indium-mediated allylation of aldehydes with 1,1,1-trifluoro-4-bromobut-2-ene [26] and 3-bromo-3,3-difluoropropene [27] were reported. **3a** and **3b** are a valuable building block in the synthesis of compounds containing the difluoromethyl group because three functional groups are present: the C-Br bond, the C=C bond, and the trimethylsilyl group. To demonstrate the synthetic utilities of **3a** and **3b**, the indium mediated coupling of aldehydes with **3a** and **3b** was investigated. The indium mediated coupling of benzaldehyde (**7a**) with **3a** was used as model reaction to enable us to explore the reaction conditions. Initially we attempted to carry out this model reaction in water under vigorously stirring , but no reaction occurred. In THF or 1 : 1 mixture of THF and water, no reaction was observed too. When the coupling reaction was conducted in DMF at 50°C for 24 h, only 50% of **3a** was converted into the allylated product **8a**. Finally we found, in the presence of an equimolar mixture of indium and lithium iodide, the coupling of benzaldehyde (**7a**) with **3a** proceeded smoothly in DMF at room temperature for 8 h to yield **8a** in 71% isolated yield. The accelerating effect of lithium iodide may be due to the exchange of bromine-carbon bond in **3a** to a carbon- iodide bond. Based on these reaction conditions, reaction of **3a** with other aldehydes formed corresponding allylated product in high yield in all cases, and several characteristic features were observed (Scheme 3 and Table 1). (1). the reaction was α-regioselective, these results are in agreement with previous experimental results [27,28] and Tonachini theoretical description, [29] in which the negative charge is shown to reside at the α-carbon in the *gem*-difluoroallyl anion (CF_2 site). (2). The configuration of double bonds remained intact. These results are in contrast with (Z)-1-trimethylsilylpropenylbromide in the indium-mediated allylation, [30] where the coupling product was a mixture of E- and Z-vinylsilanes. (3) The reaction with the α,β-unsaturated aldehyde **7e** gave the 1,2-adduct **8e** exclusively.



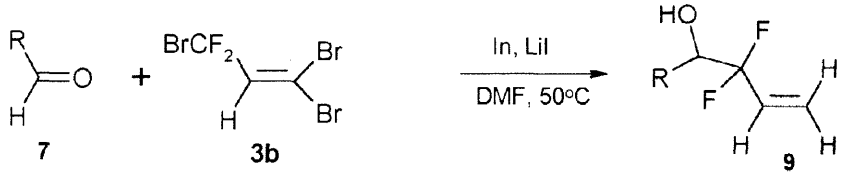
(Scheme 3)

Table 1. Allylation reaction of aldehydes with **3a** [a]

Aldehyde	Product	Yield (%) [b]
 7a	 8a	71
 7b	 8b	75
 7c	 8c	74
 7d	 8d	75
 7e	 8e	80

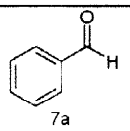
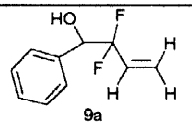
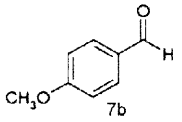
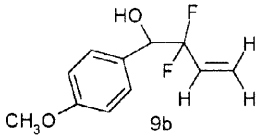
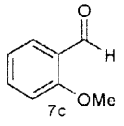
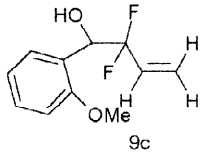
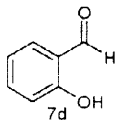
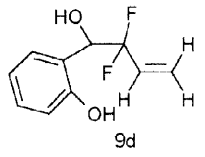
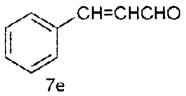
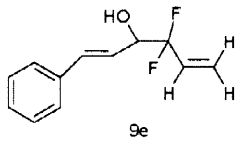
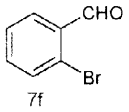
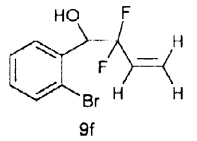
[a] All reactions were carried out on a 1.0-1.5 mmol scale, see Experimental Section. [b] Yield of purified product.

After the successful coupling reaction of **3a** with aldehydes, we then extended the reaction conditions to **3b**. However, in the presence of indium and lithium iodide, the reaction of **3b** with aldehydes in DMF did not occur at room temperature. When the reaction mixture was warmed to 50°C, the coupling reaction took place and the coupling-reduction products *gem*-difluorohomoallyl alcohols **9** were isolated in high yields (Scheme 4 and Table 2). This success suggested that the reaction temperature was important for the coupling of **3b** with aldehydes. It should be noted that under these reaction conditions the vinyl carbon-bromine bonds (**3b**) were totally reduced, whereas the aryl-bromine bond (**7f**) was tolerated.



(Scheme 4)

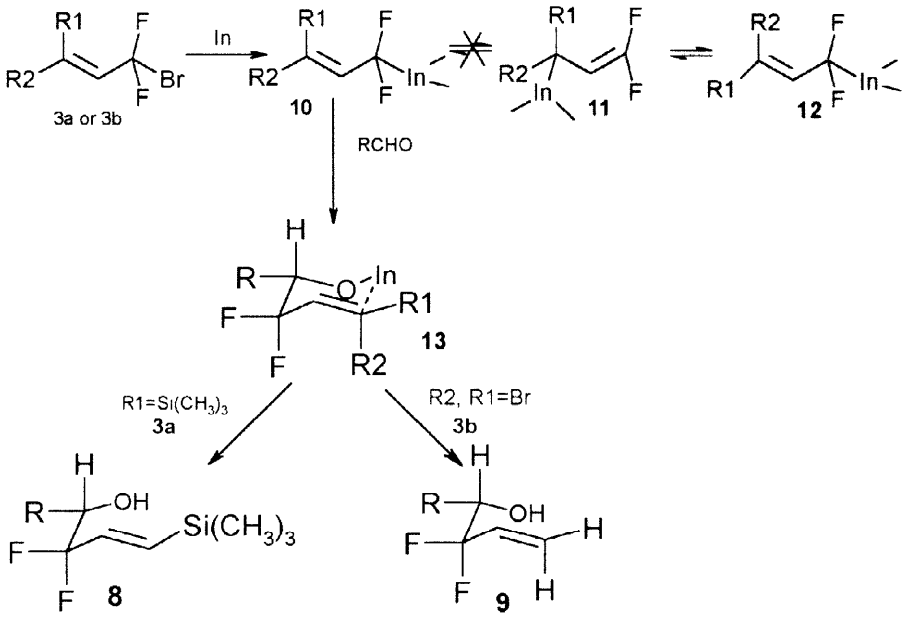
Table 2. Allylation reaction of aldehydes with **3b**[a]

Aldehyde	Product	Yield (%)[b]
 7a	 9a	72
 7b	 9b	74
 7c	 9c	71
 7d	 9d	78
 7e	 9e	77
 7f	 9f	66

[a] All reactions were carried out on a 1.0-1.5 mmol scale, see Experimental Section. [b] Yield of purified product.

To account for the above observations, we propose in broad terms the following mechanism for the indium mediated coupling of **3a** and **3b** with aldehydes (Scheme 5). First , an allyl indium species **10** was formed which did not exist in equilibrium with its regioisomer **11** , because the the pyramidal structure of the *gem*-difluorohomoallyl intermediate is more stable than the planar structure and the negative charge in the intermediate resides at the α-carbon (CF_2 site). Thus, the α-regioselectivity of these coupling reactions can be rationalized in terms of attack of the more nucleophilic α-carbon of the *gem*-difluorohomoallyl intermediate. Furthermore, there was no regioisomer **12**. Thus, the stereochemistry of the double bond in the allylic indium species **10** can not be isomerised so that the configuration of double bonds remained intact. In the coupling with aldehyde, the reaction presumably proceeded the cyclic transition state **13** . In case where the R1 and R2

were bromine (**3b**), the reduction of carbon-bromine bond initiated by indium was further carried out and coupling-reduction product **9** was obtained.



(Scheme 5)

In summary, a convenient method for the preparation of new difluoromethylene-containing building blocks (**3a** and **3b**) has been developed. Indium mediated the coupling of **3a** and **3b** with aldehydes provided a variety of *gem*-difluorohomoallyl alcohols (**8** and **9**). These reactions offered a new method for the introduction of the difluoromethylene functionality into organic compounds under mild conditions.

EXPERIMENTAL SECTION

Boiling points are uncorrected. ^{19}F NMR spectra (56.4 Hz) were recorded with Varian EM-360L instrument using CF_3CO_2H as an external standard, upfield positive. ^1H NMR and ^{13}C NMR spectra were recorded on a 300 MHz spectrometer with tetramethylsilane as the internal standard. All chemical shifts are expressed in ppm. Light petroleum ether refers to the fraction with distillation range 60-90°C.

General procedure for the addition of dibromodifluoromethane to (trimethylsilyl)acetylene

A 500ml, three-necked, round-bottomed flask was equipped with an efficient magnetic stirring bar, a thermometer and a dry ice-acetone condenser. To this flask were added (trimethylsilyl)acetylene (9.82g, 0.1 mol), DMF (100 ml), $(NH_4)_2S_2O_8$ (22.8g, 0.1 mol), $HCO_2Na.2H_2O$ (10.4g, 0.1 mol) and CF_2Br_2 (14 ml, 0.15 mol). After the mixture was stirred at 50°C for 2 h, the mixture was cooled to room temperature , and $(NH_4)_2S_2O_8$ (22.8g, 0.1 mol), $HCO_2Na.2H_2O$ (10.4g, 0.1 mol) and CF_2Br_2 (14 ml, 0.15 mol) were added. The resulting mixture was still stirred at 50°C overnight. The stirred reaction mixture was then diluted with 150 ml

of ethyl ether. The suspension was filtered through an Buchner funnel fitted with two filter papers and the solid was washed with three 50 ml portions of ethyl ether. The filtrate was washed with three 100 ml portions of water and twice with 100 ml of brine. The organic solution was dried over anhydrous magnesium sulfate. The solvent was removed by rotary evaporation using a water aspirator. The same scale reaction was repeated three times. The combined crude material was fractionally distilled through spinning band fractionating colume to afford **3a** (6.1g), **3b** (24.6g) and **4** (5.1g).

(E)-(3-Bromo-3,3-difluoro-1-propenyl)trimethylsilane (3a)

colorless liquid; bp 33-34°C / 15mmHg. ^{19}F NMR ($CDCl_3$): -30.0(d, J= 9.0 Hz); ^{1}H NMR ($CDCl_3$): 0.01 (s, 9H), 6 05(dt, J= 19.0, 9.0 Hz, 1H), 6.25 (dt, J= 19.0, 2.0 Hz, 1H); ^{13}C NMR ($CDCl_3$): -2.1, 117.3 (t, J= 300 Hz), 135.9 (t, J= 5 Hz), 138.7(t, J= 24 Hz); IR (film) 2961, 1810, 1606, 1253, 1207, 1097, 927, 866 and 844cm^{-1}; MS *m/z* (EI) 215 (M^+-CH_3, 30.6), 213 (M^+-CH_3, 29.6), 143 (24.9), 141 (24.1), 81 (58.4), 77 (63.9), 53 (100.0); HRMS calcd for C_{12} H_8 $Br^{79}F_2$ Si (M^+-CH_3) 212.9546, Found: 212.9519; HRMS calcd for C_{12} H_8 $Br^{81}F_2$ Si (M^+-CH_3) 214.9526, Found: 214.9517.

1, 1, 3-Tribromo-3,3-difluoro-1-propene (3b)

pale-yellow liquid; bp 45-46°C / 12mmHg. ^{19}F NMR (CD_3COCD_3): -33.3(d, J= 9.0 Hz); ^{1}H NMR (CD_3COCD_3): 7.50 (t, J= 9.0 Hz); ^{13}C NMR (CD_3COCD_3): 101.4 (t, J= 8 Hz), 115.7 (t, J= 299 Hz), 134.9 (t, J= 29 Hz); IR (film) 3057, 1605, 1203, 1110, 859, 835, 688, and 563 cm^{-1}; MS *m/z* (EI) 237 (M^+-Br, 57.9), 235 (M^+-Br, 100.0), 233(M^+-Br, 49.5), 75 (21.0); Anal. Calcd for $C_3HBr_3F_2$: C, 11.45; H, 0.32; Br, 76.16. Found: C, 11.48; H, 0.43; Br, 74.84.

(1,2-Dibromoethenyl)trimethylsilane (4)[31]

colorless liquid; b.p. 62°C / 12mmHg. ^{1}H NMR (CD_3COCD_3): 0.37 (s, 9H), 7.43 (s, 1H); ^{13}C NMR (CD_3COCD_3): 0.1, 116.0, 128.4; MS *m/z* (EI) 260 (M^+, 8.8), 258 (M^+, 16.5), 256(M^+, 8.3), 245 (18.5), 243 (32.9), 241 (16.5), 139 (100.0), 137 (86.8). This date was consistent with that reported in the literature.

General Procedure for the indium mediated coupling of 3a and 3b with aldehydes.

A mixture of **3a** or **3b** (**3a**, 0.34g; **3b**, 0.47g, 1.5 mmol), indium powder (0.17g, 15 mmol), lithium iodide (0.38g, 2.0 mmol) and aldehyde **5** (1.0 mmol) in anhydrous DMF (2 ml) was stirred vigorously at room temperature (for **3b**, at 50°C) for 8 h. Then, saturated aqueous ammonium chloride (10 ml) and ethyl acetate (10 ml) was introduced, and the aqueous phase was extracted with ethyl acetate (2 X 10 ml). The combined organic solutions were washed with water (3 X 10 ml) and brine (2 X 10 ml), and then dried over anhydrous magnesium sulfate. After evaporation of the solvents, the residue was subjected to flash chromatography on silica gel (elution with 10 : 1 petroleum ether/ ethyl acetate) to afford **8** or **9**.

(E)-2,2-Difluoro-1-phenyl-4-trimethylsilyl-3-buten-1-ol (8a)

colorless liquid; ^{19}F NMR ($CDCl_3$): 31.3(d, J=9.0 Hz); ^1H NMR ($CDCl_3$): 0.08 (s, 9H), 2.53 (br, 1H), 4.89 (t, J= 9.0 Hz, 1H), 5.92(dt, J= 19.0, 9.0 Hz, 1H), 6.22 (dt, J=19.0, 2.0 Hz, 1H), 7.32-7.40 (m, 5H); IR (film) 3435, 2959, 1497, 1456, 1336, 1251, 1054, 990, 867, 742, 699 and 598 cm^{-1}; MS *m/z* (EI) 257 (M^+ +1, 5.8), 179 (21.6), 147 (11.2), 127 (30.7) 105 (100.0); Anal. Calcd for $C_{13}H_{18}F_2OSi$: C, 60.94; H, 7.10; F, 14.84. Found: C, 60.98; H, 6.96; F, 14.81.

(E)-2,2-Difluoro-1-(4-methoxy-phenyl)-4-trimethylsilyl-3-buten-1-ol (8b)

colorless oil; ^{19}F NMR ($CDCl_3$): 31.3(d, J= 9.0 Hz); ^1H NMR ($CDCl_3$): 0.06 (s, 9H), 2.53 (br, 1H), 3.80 (s, 3H), 4.81 (t, J= 9.0 Hz, 1H), 5.96(dt, J= 19.0, 9.0 Hz, 1H), 6.21 (dt, J=19.0, 2.0 Hz, 1H), 6.86 (d, J=9.0 Hz, 2H), 7.32 (d, J=9.0 Hz, 2H); IR (film) 3450, 2958, 1614, 1516, 1252,1177, 1036, 866, 843 and 579 cm^{-1}; MS *m/z* (EI) 286 (M^+, 0.8), 269 (24.0), 137 (100.0), 109 (33.7), 77 (24.3); Anal. Calcd for $C_{14}H_{20}F_2O_2Si$: C, 58.71; H, 7.04; F, 13.27. Found: C, 57.80; H, 7.19; F, 13.33.

(E)-2,2-Difluoro-1-(2-methoxy-phenyl)-4-trimethylsilyl-3-buten-1-ol (8c)

colorless oil; ^{19}F NMR ($CDCl_3$): 32.6(d, J= 9.0 Hz); ^1H NMR ($CDCl_3$): 0.06 (s, 9H), 3.02 (br, 1H), 3.84 (s, 3H), 5.19 (t, J= 9.0 Hz, 1H), 6.02(dt, J= 19.0, 9.0 Hz, 1H), 6.25 (dt, J=19.0, 2.0 Hz, 1H), 6.88-6.98 (m, 2H), 7.26-7.37 (m, 2H); IR (film) 3450, 2957, 2841, 1604, 1495, 1466, 1249, 1050, 867, 756 and 695 cm^{-1}; MS *m z* (EI) 286 (M^+, 0.8), 269 (1.5), 137 (100.0), 107 (37.0), 77 (16.0); Anal. Calcd for $C_{14}H_{20}F_2O_2Si$: C, 58.71; H, 7.04; F, 13.27. Found: C, 57.40; H, 7.06; F, 13.36.

(E)-2,2-Difluoro-1-(2-hydroxy-phenyl)-4-trimethylsilyl-3-buten-1-ol (8d)

colorless oil; ^{19}F NMR ($CDCl_3$): 32.0(d, J= 9.0 Hz); ^1H NMR ($CDCl_3$): 0.06 (s, 9H), 4.09 (br, 1H), 5.02 (t, J= 9.0 Hz, 1H), 6.01(dt, J= 19.0, 9.0 Hz, 1H), 6.28 (dt, J=19.0, 2.0 Hz, 1H), 6.82-6.93 (m, 2H), 7.01-7.05 (m, 1H), 7.19-7.39 (m, 1H), 7.83 (br, 1H); IR (film) 3362, 2958, 2901, 1614, 1591, 1493, 1460, 1251, 1033, 989, 867, 755 and 609 cm^{-1}; MS *m/z* (EI) 199 (M^+-TMS, 1.3), 179 (35.8), 124 (10.7), 123 (100.0), 95 (22.2); Anal. Calcd for $C_{13}H_{18}F_2O_2Si$: C, 57.32; H, 6.66; F, 13.95. Found: C, 57.42; H, 6.32; F, 13.82.

(5 E)-4, 4 -Difluoro-1-phenyl-6-trimethylsilyl-1,5-hexadien-3-ol (8e)

colorless oil; ^{19}F NMR ($CDCl_3$): 30.6 (dd, J= 112, 9.0 Hz); ^1H NMR ($CDCl_3$): 0.10 (s, 9 H), 4.49 (t, J= 9.0 Hz, 1H), 6.14(dt, J= 19.0, 9.0 Hz, 1H), 6.20 (d, J= 16.0 Hz, 1H), 6.45 (dt, J=19.0, 2.0 Hz, 1H), 6.74 (dt, J= 19.0, 9.0 Hz, 1H), 7.27-7.57 (m, 5H); IR (film) 3341, 2957, 1668, 1498, 1451, 1250, 1129, 1050, 972, 868, 749 and 691 cm^{-1}; MS *m/z* (EI) 245 (2.4), 133 (100.0), 115 (20.6), 77 (16.9); Anal. Calcd for $C_{15}H_{20}F_2OSi$: C, 63.80; H, 7.14. Found: C, 63.71; H, 6.84.

2, 2-Difluoro-1-phenyl-3-buten-1-ol (9a) [28]

colorless liquid ; ^{19}F NMR ($CDCl_3$): 30.9 (d, J= 30.0 Hz); ^1H NMR ($CDCl_3$): 2.46 (br, 1H), 4.84 (t, J= 11.0 Hz, 1H), 5.40 (d, J= 11.0 Hz, 1H), 5.49-5.57(m, 1H), 5.74-5.84 (m, 1H), 7.23-7.46 (m, 5H); MS *m/z* (EI) 164 (M^+- HF, 1.1), 108 (14.4), 107 (100.0), 79 (75.6), 77 (45.3). This date was consistent with that reported in the literature.

2,2-Difluoro-1-(4-methoxy-phenyl)-3-buten-1-ol (9b)

colorless oil; ^{19}F NMR ($CDCl_3$): 30.2 (d, J= 30.0 Hz); ^1H NMR ($CDCl_3$): 2.63 (br, 1H), 3.80 (s, 3H), 4.84(t, J= 11.0 Hz, 1H), 5.45(d, J= 11.0 Hz, 1H), 5.55-5.62(m, 1H), 5.77-5.94 (m, 1H), 6.88 (d, J= 9.0Hz, 2H), 7.30 (d, J= 9.0Hz, 2H); IR (film) 3553, 2927, 1614, 1516, 1421, 1253, 1177, 1069, 994, 954 and 801 cm^{-1}; MS *m/z* (EI) 214 (M^+, 1.7), 138 (10.6), 137 (100.0), 77 (29.1); Anal. Calcd for $C_{11}H_{12}F_2O_2$: C, 61.68; H, 5.65; F, 17.74. Found: C, 61.37; H, 5.62; F, 17.47.

2,2-Difluoro-1-(2-methoxy-phenyl)-3-buten-1-ol (9c)

colorless oil; ^{19}F NMR ($CDCl_3$): 32.2 (s); ^1H NMR ($CDCl_3$): 3.20(br, 1H), 3.84 (s, 3H), 5.33(t, J= 11.0 Hz, 1H), 5.44(d, J= 11.0 Hz, 1H), 5.57-5.65(m, 1H), 5.86-6.04(m, 1H), 6.89-7.02 (m, 2H), 7.29-7.39 (m, 2H); IR (film) 3445, 2943, 1604, 1495, 1466, 1248, 1052, 994, 854, 757 and 701cm^{-1}; MS *m/z* (EI) 214 (M^+, 0.2), 138 (13.3), 137 (100.0), 107 (58.2), 77 (29.1); Anal. Calcd for $C_{11}H_{12}F_2O_2$: C, 61.68; H, 5.65; F, 17.74. Found: C, 61.46; H, 5.62; F, 18.04.

2,2-Difluoro-1-(2-hydroxy-phenyl)-3-buten-1-ol (9d)

colorless oil; ^{19}F NMR ($CDCl_3$): 32.2 (d, J= 20.0 Hz); ^1H NMR ($CDCl_3$): 3.92 (br, 1H), 5.04(t, J= 11.0 Hz, 1H), 5.51(d, J= 9.0 Hz, 1H), 5.65(d, J=19.0 Hz, 1H), 5.81-5.99 (m, 1H), 6.85-6.89(m, 2H), 7.06-7.13 (m, 1H), 7.20-7.28 (m, 1H), 7.72(s, 1H); IR (film) 3351, 2925, 1613, 1590, 1494, 1421, 1242, 1032, 995, 877, 757, 699 and 644 cm^{-1}; MS *m/z* (EI) 201 (M^++ 1, 2.0), 200(M^+, 6.3), 183 (10.3), 129 (11.5), 123 (100.0), 77 (45.8); Anal. Calcd for $C_{10}H_{10}F_2O_2$: C, 60.00; H, 5.04; F, 18.98. Found: C, 59.77; H, 5.09; F, 18.87.

4, 4 -Difluoro-1-phenyl-1,5-hexadien-3-ol (9e) [28]

colorless oil; ^{19}F NMR ($CDCl_3$): 31.5 (d, J= 80.0 Hz); ^1H NMR ($CDCl_3$): 2.27(br, 1H), 4.53 (t, J= 9.0 Hz, 1H), 5.57 (d, J= 9.0 Hz, 1H), 5.72-5.79 (m, 1H), 5.93-6.06 (m, 1 H), 6.09-6.24 (m, 1 H), 6.78 (d, J= 16.0 Hz, 1 H), 7.27-7.43 (m, 5H); MS *m/z* (EI) 210 (M^+, 1.1), 170 (9.2), 134 (19.6), 133 (100.0), 115 (42.2), 103 (15.0), 77 (23.4). This date was consistent with that reported in the literature.

2,2-Difluoro-1-(2-bromo-phenyl)-3-buten-1-ol (9f)

colorless oil; ^{19}F NMR (CD_3COCD_3): 32.5(s); ^1H NMR (CD_3COCD_3): 5.39(t, J= 11.0 Hz, 1H), 5.49-5.56 (m, 2H), 5.59(s, 1H), 6.03-6.19 (m, 1H), 7.22-7.28 (m, 1H), 7.33-7.41(m, 1H), 7.55-7.65 (m, 2H); IR (film) 3412, 2930, 1593, 1570, 1474, 1421, 1194, 1069, 995, 849, 753 and 680 cm^{-1}; MS *m/z* (EI) 187 (

100.0), 185 (83.3), 159 (17.6), 157 (19.5), 77 (59.1); Anal. Calcd for $C_{10}H_9BrF_2O$: C, 45.65; H, 3.45. Found: C, 45.58; H, 3.59.

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