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Room temperature preparation of α-chloro-β,β-difluoroethenylzinc reagent ($CF_2{=}CClZnCl$) by the metallation of HCFC-133a (CF_3CH_2Cl) and a high yield one-pot synthesis of α-chloro-β,β-difluorostyrenes

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Abstract

α-Chloro-β,β-difluorovinylzinc reagent [$CF_2{=}CClZnCl$] was generated in 91% yield by the metallation of a THF solution of commercially available HCFC-133a (CF_3CH_2Cl) and zinc chloride at 15–20 °C using LDA as base. The corresponding reaction with Halothane^{TM} ($CF_3CHClBr$) produced a poor yield of $CF_2{=}CClZnCl$. The palladium catalyzed coupling reaction of the $CF_2{=}CClZnCl$ with aryl iodides under mild reaction conditions produced α-chloro-β,β-difluorostyrenes in 64–90% isolated yields. The stability of the intermediate $CF_2{=}CClLi$ and the nature of the zinc reagents are discussed.

Keywords: HCFC-133a; Chlorodifluorovinylzinc; Pd(0) coupling; Chlorodifluorovinyllithium; α-Chloro-β,β-difluorostyrene; Metallation; Transmetallation; Halothane^{TM}

1. Introduction

The α-halo-β,β-difluorostyrenes are building blocks in organofluorine chemistry not only due to the reactivity of the gem-difluoromethylene unit towards nucleophilic reagents but also by the possible functionalization at the halogen site. There are not many convenient methods available for the general synthesis of α-halo-β,β-difluorostyrenes. The few methods reported for the synthesis of α-chloro-β,β-difluorostyrenes were not general or involved multi step procedure with low overall yields. Cohen developed a multistep procedure, where zinc mediated dehalogenation of an appropriate precursor produced α-chloro-β,β-difluorostyrene in low overall yield [1]. In another method, lithium chloride mediated decarboxylation of methylchlorodifluoroacetate in HMPA followed by the trapping of the carbene with chlorodifluoroacetophenone produced an accidental formation of α-chloro-β,β-difluorostyrene along with the desired alcohol [2]. A more traditional route for α-halo-β,β-difluorostyrene was by a two-step process: addition of halogen to $RCH{=}CF_2$ [3,4] followed by dehydrohalogenation using a selective base [5]. Though this method is not general, the use of bases like Li_2CO_3 or KO^tBu improved the yield of the α-halo-β,β-difluorostyrene significantly. Treatment of benzotrichlorides in presence of chlorodifluoromethane at 575 °C has been reported to produce α-chloro-β,β-difluorostyrene in poor yield along with (α,β,β-trichloro-β,β-difluoroethyl)benzene as a by product [6].

Recent advancement in the synthesis of α,β,β-trifluorostyrenes via trifluorovinylzinc synthon, broadened the scope for the synthesis α-halo-β,β-difluorostyrene through the corresponding zinc reagent [7–10]. One such method was recently reported from this laboratory where α-bromo-

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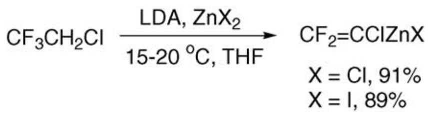
β,β-difluorostyrenes were synthesized by the Pd(0) catalyzed coupling of $CF_2{=}CBrZnBr$ with aryl iodides [11]. Normant and co-workers generated various fluorovinylzinc reagents including α-chloro-β-fluorovinylzinc reagent by the metallation of halo or hydro fluoroalkenes via the corresponding vinyllithium species [12–16]. But fluorinated vinyllithiums are thermally unstable and need to be generated at very low temperature in order to have reasonable yield of the zinc reagent [17–19].

Kumudaki and co-workers reported the generation of the α-chloro-β,β-difluorovinylzinc reagent under relatively higher temperature (−60 °C) by the metallation of $CF_2{=}CHCl$ [20,21] and 1-bromo-1-chloro-2,2,2-trifluoroethane (Halothane^{TM}) [22]. But the interpretation of this zinc reagent as a new zinc reagent compared to the zinc reagent generated by the Normant procedure was questionable, and the spectral data described were different from each other. The assigned *bis cioid/transoid* interpretation of the zinc reagent is highly unlikely and we have proposed the observed spectra could be of the starting material ($CF_2{=}CHCl$) [23].

Recently, Coe and co-workers identified fluorocarbon HFC-134a and HCFC-133a as excellent precursors for the generation of trifluorovinyllithium and α-chloro-β,β-difluorovinyllithium at low temperature [24,25]. Based on this method, we have recently developed an excellent room temperature preparation of the trifluorovinylzinc reagent by the metallation of HFC-134a, and this reagent was utilized for Pd(0) catalyzed coupling reactions with aryl iodides to obtain α,β,β-trifluorostyrenes under mild reaction conditions [26, 27]. We have then applied similar strategy for the synthesis of α-halo-β,β-difluorovinylzinc reagents [$CF_2{=}CXZnX$, where X = Cl, Br, I] and the corresponding α-halo-β,β-difluorostyreness by the metallation of the corresponding commercially available precursors [23,28,29]. This methodology serves as the first general methodology for the synthesis of α-halo-β,β-difluorovinylzinc reagents and corresponding α-halo-β,β-difluorostyrenes. In our previous communication we have described the synthesis of α-chloro-β,β-difluorovinylzinc reagent by the metallation of HCFC-133a [23]. In that report, we have unequivocally assigned the ^{19}F NMR chemical shifts for the α-chloro-β,β-difluorovinylzinc reagent and confirmed that the spectral data for this zinc reagent was similar to that generated by the Normant method. Herein we describe the full account of this study concerning the development of a general synthetic method for α-chloro-β,β-difluorostyrenes via α-chloro-β,β-difluorovinylzinc reagent.



Scheme 1. Synthesis of α-chloro-β,β-difluorovinylzinc reagent by the metallation of CF_3CH_2Cl.

2. Results and discussion

2.1. Metallation of 1-chloro-2,2,2-trifluoroethane (HCFC-133a)

Following the reaction conditions standardized for the metallation of 1,1,1,2-tetrafluoroethane (HFC-134a), reaction of 1-chloro-2,2,2-trifluoroethane (HCFC-133a) with LDA in presence of $ZnCl_2$ at 15 °C, produced a 91% yield of the α-chloro-β,β-difluorovinylzinc reagent (^{19}F NMR vs. $PhCF_3$) (Scheme 1). When $ZnCl_2$ was replaced with ZnI_2 in this metallation reaction the resultant $CF_2{=}CClZnI$ was formed in 89% yield (Scheme 1).

Treatment of this zinc reagent with acetic acid or iodine produced the corresponding hydrolysis product ($CF_2{=}CFH$) or iodinolysis product ($CF_2{=}CClI$) in quantitative yields, thus confirming the formation of the zinc reagent. The ^{19}F NMR analysis of the zinc reagent mixture showed peaks for the *mono* and *bis* zinc reagents complexed to both THF and diisopropylamine. The major doublets at −78.9 and −92.7 with $J_{FF} = 59$ Hz were assigned to the *mono* zinc reagent complexed to THF and/or diisopropylamine. Addition of stiochiometric amount of TMEDA to the medium produced one set of peaks resulting from the preferential complexation of the *mono* and *bis* zinc reagent (*mono*/*bis* 70:30) complexed to TMEDA over diisopropylamine or THF. The major doublets appeared at −76.7 and −91.0 with a coupling constant of 56 Hz corresponding to the *mono* zinc reagent complexed to TMEDA and shoulder doublets at −76.3 (behind the major doublet) and −92.1 (front of major doublet) with a coupling constant of 58 Hz corresponding to the *bis* zinc reagent complexed to TMEDA. The ^{19}F NMR chemical shifts of the TMEDA complexes of *mono* and *bis* zinc reagents are summarized in Fig. 1.

In order to demonstrate unequivocally that the above chemical shifts assignments for the *mono* and *bis* zinc reagents were correct, we have performed a series of ^{19}F NMR experiments (Scheme 2). At first we have attempted to generate only the *bis* zinc reagent by using half equivalent of zinc chloride rather than the usual one equivalent. This experiment produced exclusively the *bis* zinc reagent and the

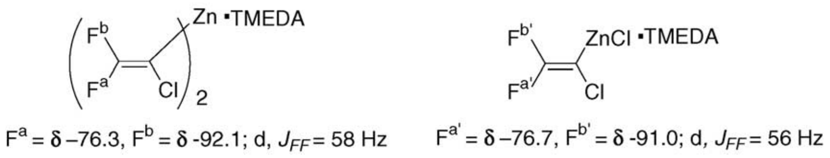
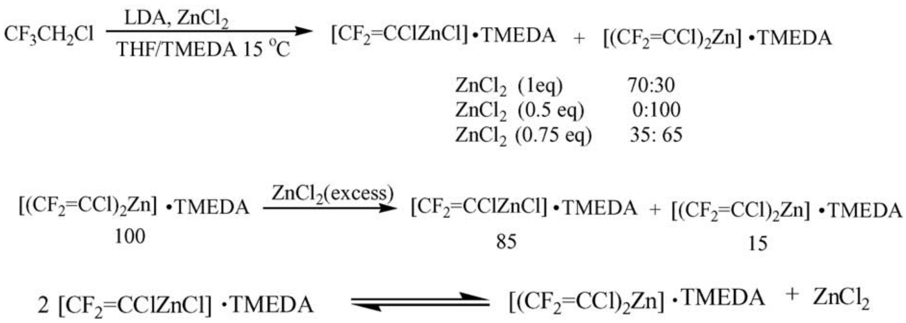


Fig. 1. The ^{19}F NMR chemical shifts of TMEDA complexes of *mono* and *bis* zinc reagents.



Scheme 2. Schlenk Equilibrium between the *mono* and *bis* zinc reagents via $ZnCl_2$.

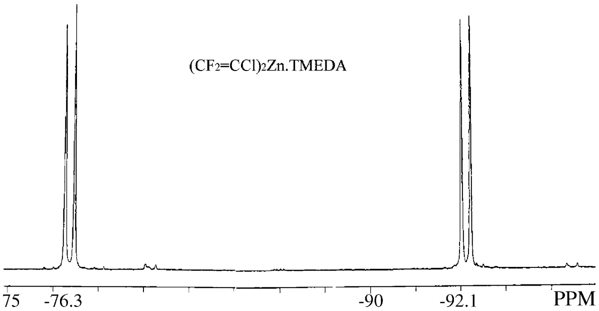


Fig. 2. The ^{19}F NMR of the *bis*-α-chloro-β,β-difluorovinylzinc reagent in THF-TMEDA.

chemical shifts and splitting pattern of this zinc reagent matched exactly for the minor component of the usual reaction, thus proving that the major zinc reagent in the usual reaction is the *mono* reagent (Fig. 2). We then added another one equiv. of $ZnCl_2$ to this reaction mixture to shift the equilibrium (Scheme 2) to the *mono* side and obtained an 85:15 mixture of the *mono* and *bis* zinc reagents proving that our assignments of the *mono* and *bis* zinc reagents were correct (Fig. 3). In another experiment we increased the concentration of $ZnCl_2$ from 0.5 to 0.75 equivalents, and this reaction produced a 35:65 mixture of the *mono* and *bis* zinc reagents and the ratio changed to 85:15 when excess (1 equiv.) $ZnCl_2$ was added to this reaction mixture. These experiments confirm the presence of a Schlenk equilibrium between the *mono* and *bis* zinc reagents through zinc chloride (Scheme 2).

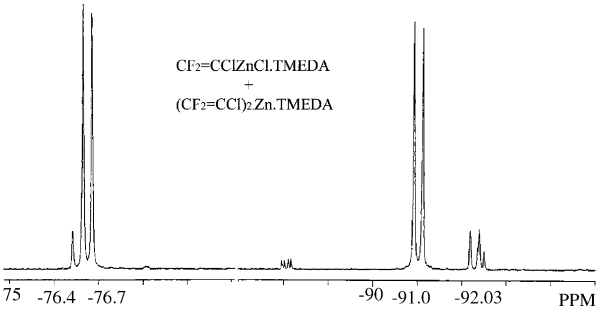


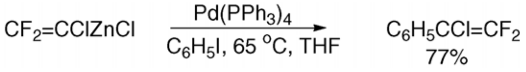
Fig. 3. The ^{19}F NMR of the *mono* and *bis*-α-chloro-β,β-difluorovinylzinc reagent mixture in THF-TMEDA (*mono*/*bis*: 85:15) obtained by the addition of $ZnCl_2$ to the *bis*-α-chloro-β,β-difluorovinylzinc reagent.

The increase in the yield of the chlorodifluorovinylzinc reagent (91% by the metallation of HCFC-133a) compared to that of trifluorovinylzinc reagent (73% by the metallation of HFC-134a) [26,27] under similar reaction conditions is most likely due to the increased stability of the intermediate chlorodifluorovinyllithium compared to trifluorovinyllithium. In order to gain a better understanding of the stability of the chlorodifluorovinyllithium we have performed a series of experiments where the $[CF_2{=}CClLi]$ was generated at −80 °C using LDA in THF-TMEDA medium and the resulting solution was warmed to −10 °C (at −15 to −10 °C the solution turned completely dark) and quenched with zinc chloride to produce a 69% yield of the zinc reagent. The reaction under similar conditions without TMEDA produced a 60% yield of the zinc reagent. Though the solution of $CF_2{=}CClLi$ turned dark during the warming process, most of the $[CF_2{=}CClLi]$ was still intact at −10 °C in both the experiments as detected by the significant formation of the zinc reagent upon transmetallation. But similar thermal stability experiments for trifluorovinyllithium ($CF_2{=}CFLi$ was generated with or without TMEDA at −80 °C and warmed to 0 °C) produced only less than 5% yield of the zinc reagent [27]. These observations clearly show that $CF_2{=}CFLi$ decomposed almost completely at a much lower temperature (−25 °C in TMEDA/THF and −45 °C in presence of $^iPr_2NH$/THF [27]) and these experiments confirmed the increased stability of $[CF_2{=}CClLi]$ compared to $[CF_2{=}CFLi]$ at higher temperature.

2.2. *Derivatization of α-chloro-β,β-difluorovinylzinc reagent to α-chloro-β,β-difluorostyrenes*

A coupling reaction, performed with this zinc reagent and iodobenzene using tetrakis(triphenylphosphine)palladium catalyst at 65 °C, produced the α-chloro-β,β-difluorostyrene in 94% NMR yield. The isolated yield of the styrene was 77% (Scheme 3).

After the successful synthesis of the parent α-chloro-β,β-difluorostyrene, this methodology was utilized for the synthesis of a series of substituted α-chloro-β,β-difluorostyrene styrenes. Thus the zinc reagent was coupled with variety of substituted aryl iodides (1:0.85) using $Pd(PPh_3)_4$ catalyst (1.5 mol%) at room temperature or 65 °C to obtain



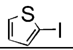
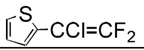
$$CF_2{=}CClZnCl \xrightarrow[C_6H_5I,\ 65\ ^{\circ}C,\ THF]{Pd(PPh_3)_4} \underset{77\%}{C_6H_5CCl{=}CF_2}$$

Scheme 3. Synthesis of α-chloro-β,β-difluorostyrene.

the substituted α-chloro-β,β-difluorostyrenes in 65–90% isolated yield. Generally the reaction was feasible at 65 °C for 3 h or at room temperature for a prolonged time. The results of these coupling experiments to produce the corresponding substituted styrenes are summarized in Table 1. odides with electron donating and withdrawing groups in the benzene ring coupled smoothly under the general coupling reaction conditions to produce the corresponding α-chloro-β,β-difluorostyrenes in good yields. 1-Fluoro-4-iodobenzene was transformed to the corresponding styrene in 81% isolated yield when it was stirred with the zinc reagent and Pd(0) at rt for 14 h (entry 2). 4-Iodotoluene coupled with the zinc reagent smoothly when treated with the palladium catalyst at rt for 12 h to produce 4-methyl-α-chloro-β,β-difluorostyrene in 83% yield (entry 3). The ester group tolerated the reaction conditions resulting in the corresponding 4-carbethoxy-α-chloro-β,β-difluorostyrene in 70% isolated yield (entry 4). The coupling reaction of 4-iodoacetophenone with zinc reagent did not result in a good conversion (40% by ^{19}F NMR) to the styrene (entry 5). The major product in this reaction was the reduced product $CF_2{=}CHCl$, presumably resulting form protonation of the zinc reagent with the enol. This was confirmed by carrying out a blank experiment where the zinc reagent generated in THF was heated with acetophenone in presence of palladium catalyst, producing a major amount of the reduced product. 3-Iodonitrobenzene also coupled with zinc reagent at rt for 15 h to produce the corresponding styrene in 77% isolated yield (entry 6). 3-Iodoanisole reacted with the zinc reagent at 60 °C for 4 h to produce the styrene in 79% isolated yield (entry 7). *m*-Iodobenzotrifluoride coupled smoothly under the normal coupling reaction conditions to produce the trifluoromethyl-substituted styrene in 67% isolated yield (entry 8). The coupling reaction of *o*-iodobenzotrifluoride with chlorodifluorovinylzinc reagent required prolonged heating (48 h at 65 °C) to effect complete conversion, and the isolated yield of corresponding styrene was 69% (entry 9). Reaction with 2-iodoisopropylbenzene produced the corresponding styrene in 75% isolated yield when heated with the zinc reagent at 65 °C for 12 h (entry 10). Reaction of 2-iodo-3-nitrotoluene with the zinc reagent proceeded smoothly under heating conditions to produce the 2-methyl-6-nitro-α-chloro-β,β-difluorostyrene in 90% isolated yield (entry 11). These results indicate (entry 10, 11) that the coupling reaction was smooth even when the aryl iodide is substituted at the *ortho* positions with bulky isopropyl, trifluoromethyl or nitro groups. 4-Iodo-2-nitroanisole coupled with the zinc reagent at 65 °C for 3 h to produce the corresponding styrene in 80% isolated yield (entry 12). 1-Chloro-4-iodobenzene coupled with the zinc reagent and palladium under normal coupling reaction conditions to produce the corresponding chloro substituted styrene in 76% isolated yield (entry 13). Coupling reaction of bromobenzene with zinc reagent was also attempted, but a sluggish reaction was the result even at heating conditions for a prolonged reaction time. When 1-bromo-4-iodobenzene was used for the coupling reaction the corresponding

Table 1
Synthesis of α-chloro-β,β-difluorostyrenes

$$CF_3CH_2Cl_{1.1\ \text{equiv.}} + ZnCl_{2\,1.0\ \text{equiv.}} + LDA_{2.0\ \text{equiv.}} \xrightarrow[2.\ \ ArI, Pd(PPh_3)_4, rt: 65\ ^{\circ}C]{1.\ \ 15\text{–}20\ ^{\circ}C/THF} ArCCl{=}CF_2$$

No.	Iodide (ArI)	Temp./time	α-Chloro-β,β-difluorostyrenes	NMR yield	Yield (%)[a]
1	C_6H_5I	65 °C, 4 h	$C_6H_5CCl{=}CF_2$	94	77
2	*p*-FC_6H_4I	rt, 14 h	*p*-$FC_6H_4CCl{=}CF_2$	97	81
3	*p*-MeC_6H_4I	rt, 12 h	*p*-$MeC_6H_4CCl{=}CF_2$	99	83
4	*p*-$EtO_2CC_6H_4I$	65 °C, 3 h	*p*-$EtO_2CC_6H_4CCl{=}CF_2$	91	70
5[b]	*p*-$(MeCO)C_6H_4I$	65 °C, 3 h	*p*-$(MeCO)C_6H_4CCl{=}CF_2$	40	–
6	*m*-$NO_2C_6H_4I$	rt, 15 h	*m*-$O_2NC_6H_4CCl{=}CF_2$	90	77
7[c]	*m*-$MeOC_6H_4I$	60 °C, 4 h	*m*-$MeOC_6H_4CCl{=}CF_2$	94	79
8	*m*-$CF_3C_6H_4I$	rt, 12 h	*m*-$CF_3C_6H_4CCl{=}CF_2$	89	67
9	*o*-$F_3CC_6H_4I$	65 °C, 48 h	*o*-$F_3CC_6H_4CCl{=}CF_2$	88	69
10	*o*-$(CH_3)_2CHC_6H_4I$	65 °C, 12 h	*o*-$(CH_3)_2CHC_6H_4CCl{=}CF_2$	95	75
11	*o*-Me-*o*'-$O_2NC_6H_4I$	65 °C, 3 h	*o*-Me-*o*'-$O_2NC_6H_4CCl{=}CF_2$	96	90
12[c,d]	*p*-MeO-*m*-$O_2NC_6H_4I$	65 °C, 3;h	*p*-MeO-*m*-$O_2NC_6H_4CCl{=}CF_2$	87	80
13	*p*-ClC_6H_4I	rt, 15 h	*p*-$ClC_6H_4CCl{=}CF_2$	95	76
14[e]	*m*-BrC_6H_4I	rt, 18 h	*m*-$BrC_6H_4CCl{=}CF_2$	96	85
15	*p*-IC_6H_4I	rt, 24 h	*p*-$CF_2{=}CFC_6H_4CCl{=}CF_2$	86	64
16		rt 4 h then 60 °C, 3 h		87	65

[a] Isolated yields of pure products.

[b] The major product was the reduced product $CF_2{=}CHCl$.

[c] Purified by column chromatography.

[d] The product styrene was only 95% pure.

[e] 1% of the *bis* styrene was formed.

bromo substituted styrene was formed in 85% along with 1% *bis* styrene resulting from the coupling at both the bromine and iodine site (entry 14).

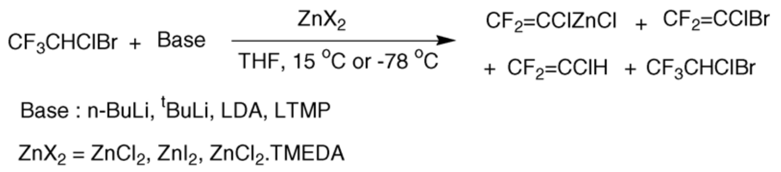
The *bis* styrene was produced in 64% isolated yield from 1,4-diiodobenzene by treatment with zinc reagent and palladium catalyst at rt for 24 h (entry 15). The heterocyclic iodide, 2-iodothiophene reacted with zinc reagent within 4 h under normal coupling reaction conditions to produce the styrene in 65% isolated yield.

2.3. Metallation of 1-bromo-1-chloro-2,2,2-trifluoroethane (Halothane^{TM})

Simultaneously with our metallation reactions of HCFC-133a, we have also considered other commercially available precursors for the synthesis of the chlorodifluorovinylzinc reagent. 1-Bromo-1-chloro-2,2,2-trifluoroethane (Halothane^{TM}) was chosen as an alternative precursor (being a liquid) and its availability as a commercial anesthetic. It was anticipated that the metallation of Halothane^{TM} using a lithium base in the presence of a zinc salt could generate the corresponding chlorodifluorovinylzinc reagent, which can easily couple with aryl iodides to produce the corresponding α-chloro-β,β-difluorostyrenes. Thus, as per the conditions standardized for the metallation of HFC-134a, the metallation of Halothane^{TM} was carried out using LDA at 15 °C in the presence of zinc chloride. This reaction produced a black reaction mixture and the ^{19}F NMR spectrum showed a set of peaks, which indicated the formation of many products along with a large amount of unreacted Halothane^{TM}. The products formed in this reaction were identified as $CF_2{=}CClZnCl$ (25%), $CF_2{=}CClBr$ (9%), $CF_2{=}CClH$ (4%). The unreacted Halothane^{TM} was recovered in 40% yield (Scheme 4).

The ^{19}F NMR chemical shift values for the zinc reagent obtained by the metallation of Halothane^{TM} ($CF_2{=}CClZnCl$) matched exactly for the zinc reagent generated by the metallation of HCFC-133a. In order to improve the yield of the zinc reagent, metallation of Halothane^{TM} was performed with various bases (*n*-BuLi, ^{t}BuLi, 4-methoxy-2,2,6,6-tetramethylpiperidine, LHMDS), varying the zinc salt (ZnI_2, $ZnCl_2$,TMEDA) and by performing the reaction at low temperature. But none of these trials yielded a very good yield of the zinc reagent, but instead produced a mixture with varying amount of zinc reagent. With 2 equiv. of LHMDS as base, 1-bromo-1-chloro-2,2-difluoroethylene was produced in 95% yield (by ^{19}F NMR) and no zinc reagent formation was detected. Butyl lithium bases were expected to give a better reaction towards the metal halogen exchange but the major reaction was the *trans* metallation to the corresponding butylzinc chloride as indicated by the poor yield of the desired zinc reagent. Even the more sterically hindered, ^{t}BuLi, produced only 27% yield of the chlorodifluorovinylzinc reagent at −78 °C. The best yield of the zinc reagent (43%) was observed when 3 equiv. of LDA was used as a base at −78 °C in this metallation reaction. Our observations differ with the results reported by Kumudaki during the metallation of Halothane^{TM} in the presence of zinc chloride [20–22]. We have not observed any species corresponding to his reported new zinc reagent and the small amount of zinc reagent formed was spectroscopically similar to the chlorodifluorovinylzinc reagent generated by the metallation of CF_3CH_2Cl [23]. The yield of the zinc reagent formed during the metallation of Halothane^{TM} was not mentioned in his report [22]. It is also not clear why a large excess of zinc reagent (4 equiv.) is used for the coupling reactions with aryl iodides (1 equiv.) though half equiv of zinc reagent is enough based on the assigned *bis* structure. In most cases the ^{19}F NMR yields of the styrene are moderate to good at best (no isolated yields reported). The argument that the new zinc reagent is formed by a different mechanism during the ^{s}BuLi mediated matallation at −60 °C in comparison to our metallation reaction conditions and the temporarily assigned *bis* structure for the new zinc reagent based on their observed chemical shifts is unexplainable [22]. We have unequivocally assigned the ^{19}F NMR chemical shifts for the *bis* zinc reagent (which appeared as shoulders along with the *mono* zinc reagent) by performing the Schlenk equilibrium experiments described in Section 2.1 (Scheme 2, Figs. 2 and 3) and structural assignment of their zinc reagent as the *bis* zinc reagent [$(CF_2{=}CCl)_2Zn$] does not agree with our data.

In conclusion, a room temperature preparation of [$CF_2{=}CClZnCl$] has been achieved from commercially available HCFC-133a via the in situ capture of [$CF_2{=}CClLi$] with zinc halide utilizing LDA as a base. Corresponding reaction with Halothane^{TM} produced a poor yield of [$CF_2{=}CClZnCl$]. Subsequent Pd(0) coupling of the zinc reagent with aryl iodides gives the resultant α-chloro-β,β-difluorostyrenes derivatives in excellent yields. The metallation–coupling process could be performed either as a 'one-pot' reaction or a stock solution of the zinc reagent prepared could be used for separate coupling reactions. The intermediate [$CF_2{=}CClLi$] was found to be thermally more stable than [$CF_2{=}CFLi$]. ^{19}F NMR chemical shifts of the *mono* and *bis* zinc reagents were unequivocally assigned by



Scheme 4. Metallation of Halothane^{TM} using various bases in presence of $ZnCl_2$.

performing Schlenk equilibrium experiments on the corresponding TMEDA complexes.

3. Experimental

^{1}H, {^{1}H}^{13}C and ^{19}F NMR spectra were recorded on a Brucker AC-300 or a WM 360 Spectrometer. Chemical shifts have been reported in ppm relative to an internal reference ($CDCl_3$, $CFCl_3$ or TMS). Unless noted otherwise, $CDCl_3$ was used as the NMR lock solvent. Low Resolution Mass spectra were obtained using a Voyeger GC-MS instrument operated at 70 eV in the electron impact mode, using a 15 m CB-5 column. The reported fragment peaks correspond to the most abundant ions, in addition to the parent ion(s). High-resolution mass spectra (HRMS) were obtained by the University of Iowa High Resolution Mass Spectrometry Facility. Column chromatography was carried out using silica gel purchased from Em Science (Silica Gel 60, particle size 63–200 microns). Tetrahydrofuran (THF) was dried by distillation from sodium benzophenone/ketyl at atmospheric pressure immediately prior to use. $Pd(PPh_3)_4$ was prepared by Coulson's procedure [30]. N_2 was used without further purification. All other reagents and chemicals were obtained from commercial sources and used directly. All boiling points were measured during distillation and are uncorrected.

3.1. General procedure for the synthesis of α-chloro-β,β-difluorovinylzinc reagent from HCFC-133a

A 250 mL three-necked RB fitted with a dry-ice/isopropanol condenser, septum and a thermometer were charged with $ZnCl_2$ (20.4 g, 150.0 mmol) and THF (110.0 mL) under N_2 atmosphere. The suspension was cooled to 15 °C and HCFC-133a (14.0 mL, 165.0 mmol) was condensed into the slurry. Then an LDA solution [generated from diisopropylamine (42.0 mL, 300.0 mmol) and *n*-BuLi (120.0 mL, 2.5 M, 300.0 mmol) in THF (120 mL) at 0 °C] solution was slowly added (1.5 h) through a cannula to the HCFC-133a/$ZnCl_2$ slurry while keeping the temperature at 15–20 °C (the tip of the cannula was dipped into the THF to avoid decomposition of the chlorodifluorovinyllithium, formed by the reaction of gaseous HCFC-133a with LDA, at the tip). The pale yellow reaction mixture was stirred for 2 h at 20 °C and then allowed to settle. The ^{19}F NMR analysis of the reaction mixture showed 91% yield of the chlorodifluorovinylzinc reagent.

3.2. General procedure for the coupling reaction of the α-chloro-β,β-difluorovinylzinc reagent with aromatic iodides

An amount of 25.0 mmol of the zinc reagent generated in the previous experiment [$CF_2{=}CIZnCl$] was added the aromatic iodide (typically 0.80–0.85 equiv.) and the tetrakistriphenylphosphinepalladium (1.5 mol%). The mixture was stirred at rt or heated at 60 °C. The reaction progress was monitored using ^{19}F NMR by sampling small aliquots of the reaction mixture. After complete conversion, the reaction mixture was triturated several times with pentane or hexane and the combined extracts evaporated on a rotary evaporator. The crude product was purified by distillation under reduced pressure or by column chromatography over silica gel.

3.3. Synthesis of $C_6H_5CCl{=}CF_2$

Iodobenzene (4.33 g, 21.25 mmol) and $Pd(PPh_3)_4$ (0.423 g, 1.5 mol%) were added to the zinc reagent (25.0 mmol). The reaction mixture was heated at 65 °C for 4 h. ^{19}F NMR of the reaction mixture showed complete conversion of the zinc reagent to the corresponding styrene (94% based on ^{19}F NMR). The reaction mixture was then triturated with pentane (7 × 20 mL). The combined pentane extracts were subjected to rotary evaporated under vacuum. The crude mixture was then carefully distilled under reduced pressure through a 8 cm vigreux column to obtain the pure α-chloro-β,β-styrene as a clear liquid in 77% (2.86 g, 16.4 mmol) yield.

bp: 44–46 °C at 9 mm Hg (reported 100 °C at 100 mm Hg) [5].

^{19}F NMR ($CDCl_3$): δ −83.8 (d, $J = 33$ Hz, 1F), −89.4 (d, $J = 33$ Hz, 1F); ^{1}H NMR ($CDCl_3$): δ 7.50 (m, 2H), 7.33 (m, 3H); ^{13}C NMR ($CDCl_3$): δ 154.0 (dd, $J = 292$, 290 Hz), 130.7 (d, $J = 5$ Hz), 128.8 (s), 128.5 (s), 127.7 (t, $J = 4$ Hz), 92. 9 (dd, $J = 36$, 23, Hz); GC/MS: 176 (M + 2) (54), 174 (M^+) (100), 139 (88), 119 (75), 99 (32), 89 (45).

3.4. Synthesis of *p*-$FC_6H_4CCl{=}CF_2$

Following the general procedure for the coupling reaction, 1-fluoro-4-iodobenzene (4.72 g, 21.25 mmol), zinc reagent (25.0 mmol) and $Pd(PPh_3)_4$ (0.423 g, 1.5 mol%) were stirred at rt for 14 h to give the corresponding styrene in 97% yield (by ^{19}F NMR). The reaction mixture was triturated several times with pentane. Evaporation of the solvent followed by careful distillation under reduced pressure afforded the *p*-fluoro-α-chloro-β,β-difluorostyrene as a clear liquid in 81% (3.30 g, 17.2 mmol) yield.

bp: 51–52 °C at 9 mm Hg.

^{19}F NMR ($CDCl_3$): δ −84.1 (dd, $J = 35$, 2 Hz 1F), −89.6 (d, $J = 35$ Hz, 1F), −112.2 (m, 1F); ^{1}H NMR ($CDCl_3$): δ 7.45 (m, 2H), 7.05 (m, 2H); ^{13}C NMR ($CDCl_3$): δ 162.7 (d, $J = 250$ Hz), 153.9 (dd, $J = 292$, 289 Hz), 129.7 (m), 126.7 (t, $J = 4$ Hz), 115.7 (d, $J = 22$ Hz), 92.0 (dd, $J = 37$, 24 Hz); GC/MS: 194 (M + 2) (42), 192 (M^+) (100), 157 (98), 137 (64), 107 (51); HRMS: calcd. for $C_8H_4F_3{}^{35}Cl$ 191.9954, found 191.9956 calcd. for $C_8H_4F_3{}^{37}Cl$ 193.9924, found 193.9926.

3.5. Synthesis of *p*-$MeC_6H_4CCl{=}CF_2$

Following the general procedure for the coupling reaction, 4-iodotoluene (4.64 g, 21.25 mmol), zinc reagent (25.0 mmol) and $Pd(PPh_3)_4$ (0.423 g, 1.5 mol%) were stirred at rt for 12 h to give the corresponding styrene in 99% yield (by ^{19}F NMR). The reaction mixture was triturated several times with pentane. Evaporation of the solvent followed by careful distillation under reduced pressure yielded the *p*-methyl-α-chloro-β,β-styrene as a clear liquid in 83% (3.33 g, 17.7 mmol) yield.

bp: 51 °C at 9 mm Hg.

^{19}F NMR ($CDCl_3$): δ −84.6 (d, *J* = 35 Hz, 1F), −89.9 (d, *J* = 35 Hz, 1F); ^{1}H NMR ($CDCl_3$): δ 7.39 (d, *J* = 8 Hz, 2H), 7.18 (dd, *J* = 8.1 Hz, 2H), 2.34 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 153.9 (dd, *J* = 292, 287 Hz), 138.9 (s), 129.3 (s), 127.8 (d, *J* = 6 Hz), 127.6 (dd, *J* = 5, 3 Hz), 93.4 (dd, *J* = 38, 23 Hz), 21.9 (s); GC/MS: 190 (M + 2) (32), 188 (M^+) (100), 153 (48), 133 (85); HRMS: calcd. for $C_9H_7{}^{35}ClF_2$ 188.0204 found 188.0204, calcd. for $C_9H_7{}^{37}Cl\ F_2$ 190.0175, found 190.0180.

3.6. Synthesis of *p*-$EtO_2CC_6H_4CCl{=}CF_2$

Following the general procedure for the coupling reaction, ethyl-4-iodobenzoate (3.2 g, 11.59 mmol), zinc reagent (14.0 mmol) and $Pd(PPh_3)_4$ (0.230 g, 1.5 mol%) were stirred at 65 °C for 3 h to give the corresponding styrene in 91% yield (by ^{19}F NMR). The reaction mixture was triturated several times with hexanes. Evaporation of the solvent followed by distillation under reduced pressure afforded the *p*-ethoxycarbonyl-α-chloro-β,β-styrene as a pale yellow liquid in 70% (2.0 g, 8.1 mmol) yield.

bp: 109–110 °C at 10 mm Hg.

^{19}F NMR ($CDCl_3$): δ −81.1 (d, *J* = 28 Hz, 1F), −86.6 (d, *J* = 28 Hz, 1F); ^{1}H NMR ($CDCl_3$): δ 8.05 (dm, *J* = 8, 2 Hz, 2H), 7.58 (dm, *J* = 8, 2 Hz, 2H), 4.39 (q, *J* = 7 Hz, 2H), 1.39 (t, *J* = 7 Hz, 3H); ^{13}C NMR ($CDCl_3$): δ 165.8 (s), 154.4 (dd, *J* = 295, 291, Hz), 134.9 (d, *J* = 5 Hz), 130.6 (s), 129.7 (s), 127.5 (q, *J* = 4 Hz), 92.6 (dd, *J* = 36, 24 Hz), 61.2 (s), 14.3 (s); HRMS: calcd. for $C_{11}H_9{}^{35}ClF_2O_2$ 246.0259, found 246.0260, calcd. for $C_{11}H_9{}^{37}Cl\ F_2O_2$ 248.0220, found 248.0223.

3.7. Synthesis of *m*-$O_2NC_6H_4CCl{=}CF_2$

Following the general procedure for the coupling reaction, 1-iodo-3-nitrobenzene (5.29 g, 21.25 mmol), zinc reagent (25.0 mmol) and $Pd(PPh_3)_4$ (0.423 g, 1.5 mol%) were stirred at rt for 15 h to give the corresponding styrene in 90% yield (by ^{19}F NMR). The reaction mixture was triturated several times with hexanes. Evaporation of the solvent followed by distillation under reduced pressure afforded the *m*-nitro-α-chloro-β,β-styrene as a pale yellow liquid in 77% (3.6 g, 16.4 mmol) yield.

bp: 95–96 °C at 9 mm Hg.

^{19}F NMR ($CDCl_3$): δ −80.3 (d, *J* = 27 Hz, 1F), −86.0 (d, *J* = 27 Hz, 1F); ^{1}H NMR ($CDCl_3$): δ 8.40 (t, *J* = 2 Hz, 1H), 8.21 (dm, *J* = 8, 1 Hz, 1H), 7.89 (dm, *J* = 8, 1 Hz, 1H), 7.63 (t, *J* = 8 Hz, 1H); ^{13}C NMR ($CDCl_3$): δ 154.7 (dd, *J* = 294, 293 Hz), 148.5 (s), 133.3 (dd, *J* = 6, 4 Hz). 132.6 (d, *J* = 5 Hz), 129.8 (s), 123.6 (s), 122.7 (t, *J* = 5 Hz), 91.6 (dd, *J* = 38, 25 Hz); HRMS: calcd. for $C_8H_4{}^{35}ClF_2NO_2$ 218.9899, found 218.9899, calcd. for $C_8H_4{}^{37}Cl\ F_2NO_2$ 220.9869, found 220.9860.

3.8. Synthesis of *m*-$MeOC_6H_4CCl{=}CF_2$

Following the general procedure for the coupling reaction, 3-iodoanisol (4.07 g, 17.4 mmol), zinc reagent (20.5 mmol) and $Pd(PPh_3)_4$ (0.348 g, 1.5 mol%) at 60 °C for 4 h to give the corresponding styrene in 94% yield (by ^{19}F NMR). The mixture was triturated many times with hexanes. Evaporation of the solvent followed by purification by silica gel column chromatography (eluent: 2% ethyl acetate-hexanes) afforded the *m*-methoxy-α-chloro-β,β-styrene as a clear liquid in 79% (2.8 g, 13.7 mmol) yield.

^{19}F NMR ($CDCl_3$): δ −83.4 (d, *J* = 32 Hz, 1F), −88.5 (d, *J* = 32 Hz, 1F); ^{1}H NMR ($CDCl_3$): δ 7.29 (t, *J* = 8 Hz, 1H), 7.10 (dm, *J* = 8, 2 Hz, 1H), 7.05 (bs, 1H), 6.87 (dd, *J* = 8, 2 Hz, 2H), 3.80 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 159.7 (s), 154.1 (dd, *J* = 292, 289 Hz), 132.0 (d, *J* = 4 Hz), 129.6 (s), 120.2 (dd, *J* = 4, 3 Hz), 114.5 (s), 113.6 (t, *J* = 5 Hz), 92.9 (dd, *J* = 22, 35 Hz), 55.4 (s). GC/MS: 206 (M + 2) (38), 204 (M^+) (100), 174 (17), 161 (44), 139 (44); HRMS: calcd. for $C_9H_7{}^{35}ClF_2O$ 204.0153, found 204.0155, calcd. for $C_9H_7{}^{37}ClF_2O$ 206.0124 found 206.0120.

3.9. Synthesis of *m*-$CF_3C_6H_4CCl{=}CF_2$

Following the general procedure for the coupling reaction, 3-iodobenzotrifluoride (5.78 g, 21.25 mmol), zinc reagent (25.0 mmol) and $Pd(PPh_3)_4$ (0.423 g, 1.5 mol%) were stirred at rt for 12 h to give the corresponding styrene in 89% yield (by ^{19}F NMR). The reaction mixture was triturated several times with hexanes. Evaporation of the solvent followed by careful distillation under reduced pressure afforded the *m*-trifluoromethyl-α-chloro-β,β-styrene as a pale yellow liquid in 67% (3.46 g, 14.3 mmol) yield.

bp: 44–45 °C at 9 mm Hg.

^{19}F NMR ($CDCl_3$): δ −63.3 (s, 3F), −81.8 (d, *J* = 29 Hz, 1F), −87.5 (d, *J* = 30 Hz, 1F); ^{1}H NMR ($CDCl_3$): δ 7.78 (d, *J* = 1 Hz, 1H), 7.70 (dm, *J* = 8, 1 Hz, 1H), 7.60 (d, *J* = 8 Hz, 1H), 7.51 (t, *J* = 8 Hz, 1H); ^{13}C NMR ($CDCl_3$): δ 154.5 (dd, *J* = 294, 291 Hz), 131.8 (d, *J* = 6 Hz), 131.3 (q, *J* = 32 Hz), 130.9 (bs), 129.4 (s), 125.6 (d, *J* = 3 Hz), 124.7 (m), 123.8 (q, *J* = 272 Hz), 92.1 (dd, *J* = 37, 26 Hz); GC/MS: 244 (M + 2) (32), 242 (M^+) (100), 207 (40), 187 (48), 138 (45).

3.10. Synthesis of *o*-$CF_3C_6H_4CCl{=}CF_2$

Following the general procedure for the coupling reaction, 2-iodobenzotrifluoride (5.78 g, 21.25 mmol), zinc reagent (25.0 mmol) and $Pd(PPh_3)_4$ (0.423 g, 1.5 mol%) were stirred at 65 °C for 48 h to give the corresponding styrene in 88% yield (by ^{19}F NMR). The reaction mixture was triturated several times with hexanes. Evaporation of the solvent followed by distillation under reduced pressure afforded the *o*-trifluoromethyl-α-chloro-β,β-styrene as a colorless liquid in 69% (3.54 g, 14.6 mmol) yield.

bp: 65–67 °C at 9 mm Hg.

^{19}F NMR ($CDCl_3$): δ −61.3 (d, *J* = 5 Hz, 3F), −86.3 (d, *J* = 33 Hz, 1F), −86.6 (dq, *J* = 33, 5 Hz, 1F); ^{1}H NMR ($CDCl_3$): δ 7.73 (dd, *J* = 8, 1 Hz, 1H), 7.55 (m, 2H), 7.46 (dd, *J* = 8, 1 Hz, 1H); ^{13}C NMR ($CDCl_3$): δ 153.7 (dd, *J* = 291, 289 Hz), 132.8 (s), 132.4 (s), 130.4 (s), 129.2 (s), 126.7 (q, *J* = 5 Hz), 123.6 (q, *J* = 273 Hz), 87.8 (dd, *J* = 44, 27 Hz); GC/MS; 244 ($M^+ + 2$) (32), 242 (M^+) (88), 207 (100), 187 (44), 157 (37), 138 (46); HRMS: calcd. for $C_9H_4{}^{35}ClF_5$ 241.9922, found 241.9921, calcd. for $C_9H_4{}^{37}ClF_5$ 243.9892 found 243.9890.

3.11. Synthesis of *o*-$(CH_3)_2CHC_6H_4CCl{=}CF_2$

Following the general procedure for the coupling reaction, 2-isopropyliodobenzene (5.23 g, 21.25 mmol), zinc reagent (25.0 mmol) and $Pd(PPh_3)_4$ (0.423 g, 1.5 mol%) were stirred at 65 °C for 12 h to give the corresponding styrene in 95% yield (by ^{19}F NMR). The reaction mixture was triturated several times with hexanes. Evaporation of the solvent followed by distillation under reduced pressure afforded the *o*-isopropyl-α-chloro-β,β-styrene as a colorless liquid in 75% (3.45 g, 15.9 mmol) yield.

bp: 68–70 °C at 9 mm Hg.

^{19}F NMR ($CDCl_3$): δ −87.0 (d, *J* = 38 Hz, 1F), −89.4 (d, *J* = 38 Hz, 1F); ^{1}H NMR ($CDCl_3$): δ 7.37 (m, 2H), 7.21 (m, 2H), 3.14 (septet, *J* = 7 Hz, 1H), 1.23 (d, *J* = 7 Hz, 6H); ^{13}C NMR ($CDCl_3$): δ 153.7 (dd, *J* = 291, 284 Hz), 148.9 (d, *J* = 3 Hz), 130.6 (s), 130.5 (s), 128.9 (s), 126.1 (s), 90.3 (dd, *J* = 45, 21 Hz), 30.3 (s), 23.9 (s); GC/MS: 218 (M + 2) (34), 216 (M^+) (100), 167 (52), 165 (78), 146 (55), 129 (68), 115 (51); HRMS: calcd. for $C_{11}H_{11}{}^{35}ClF_2$ 216.0517, found 216.0516, calcd. for $C_{11}H_{11}{}^{37}ClF_2$ 218.0488, found 218.0483.

3.12. Synthesis of 2-Me-6-$NO_2C_6H_4CCl{=}CF_2$

Following the general procedure for the coupling reaction, 2-iodo-3-nitrotoluene (4.47 g, 17.0 mmol), zinc reagent (20.0 mmol) and $Pd(PPh_3)_4$ (0.338 g, 1.5 mol%) were stirred at 65 °C for 3 h to give the corresponding styrene in 96% yield (by ^{19}F NMR). The reaction mixture was triturated several times with hexanes. Evaporation of the solvent followed by distillation under reduced pressure afforded the corresponding styrene as a pale yellow solid in 90% (3.58 g, 15.36 mmol) yield.

bp: 111 °C at 9 mm Hg.

mp: 67.5–69 °C.

^{19}F NMR ($CDCl_3$): δ −85.5 (d, *J* = 32 Hz, 1F), −86.7 (d, *J* = 32 Hz, 1F); ^{1}H NMR ($CDCl_3$): δ 8.13 (s, 1H), 8.08 (d, *J* = 8 Hz, 1H), 7.51 (d, *J* = 8 Hz, 1H), 2.44 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 153.8 (dd, *J* = 294, 289 Hz), 148.6 (s), 140.2 (s), 136.4 (d, *J* = 3 Hz), 131.6 (s), 125.4 (s), 121.2 (s), 88.9 (dd, *J* = 44, 25 Hz), 19.5 (s); HRMS: calcd. for $C_9H_6{}^{35}ClF_2NO_2$ 233.0055, found 233.0052, calcd. for $C_9H_6{}^{37}ClF_2NO_2$ 235.0026, found 235.0024.

3.13. Synthesis of *m*-NO_2-*p*-$OMeC_6H_4CCl{=}CF_2$

Following the general procedure for the coupling reaction, 2-nitro-4-iodoanisol (3.34 g, 12.0 mmol), zinc reagent (15.0 mmol) and $Pd(PPh_3)_4$ (0.238 g, 1.5 mol%) were stirred at 65 °C for 3 h to give the corresponding styrene in 87% yield (by ^{19}F NMR). The mixture was triturated several times with hexanes. Evaporation of the solvent followed by purification by column chromatography (silica gel, using 5% ethyl acetate-hexane as eluent) afforded the *p*-methoxy-*m*-nitro-α-chloro-β,β-styrene as pale yellow oil in 80% (2.4 g, 9.6 mmol) yield.

^{19}F NMR ($CDCl_3$): δ −86.0 (d, *J* = 34 Hz, 1F), −88.5 (d, *J* = 34 Hz, 1F); ^{1}H NMR ($CDCl_3$): δ 7.56 (d, *J* = 3 Hz, 1H), 7.43 (d, *J* = 9 Hz, 1H), 7.20 (dd, *J* = 9, 3 Hz, 1H), 3.91 (s, 3H); ^{13}C NMR ($CDCl_3$): δ 161.2 (s), 153.8 (dd, *J* = 292, 288 Hz), 148.9 (s), 133.6 (d, *J* = 3 Hz), 122.2 (s), 119.4(s), 110.5 (s), 88.1 (dd, *J* = 42, 26 Hz), 56.1 (s); HRMS: calcd. for $C_9H_6{}^{35}ClF_2NO_3$ 249.0004, found 248.9995, calcd. for $C_9H_6{}^{37}ClF_2NO_3$ 250.9975 found 250.9980.

3.14. Synthesis of *p*-$ClC_6H_4CCl{=}CF_2$

Following the general procedure for the coupling reaction, 1-chloro-4-iodobenzene (5.06 g, 21.25 mmol), zinc reagent (25.0 mmol) and $Pd(PPh_3)_4$ (0.423 g, 1.5 mol%) were stirred at rt for 15 h generated the styrene in 95% yield (by ^{19}F NMR). The reaction mixture was triturated several times with hexanes. Evaporation of the solvent followed by distillation under reduced pressure afforded the *p*-methyl-α-chloro-β,β-styrene as a clear liquid in 76% (3.34 g, 16.0 mmol) yield.

bp: 67–68 °C at 9 mm Hg.

^{19}F NMR ($CDCl_3$): δ −82.9 (d, *J* = 32 Hz, 1F), −88.3 (d, *J* = 32 Hz, 1F); ^{1}H NMR ($CDCl_3$): δ 7.44 (dm, *J* = 8, 0.6 Hz, 2H), 7.36 (dm, *J* = 9, 2 Hz, 2H); ^{13}C NMR ($CDCl_3$): δ 154.0 (dd, *J* = 295, 290 Hz), 134.8 (s), 129.2 (d, *J* = 6 Hz), 128.9 (dd, *J* = 6, 4 Hz), 128.8 (s), 92.2 (dd, *J* = 36, 23 Hz); GC/MS: 212 (M + 4) (16), 210 (M + 2) (76), 208 (M^+) (100), 175 (32), 173 (85), 138 (95), 128 (28); HRMS: calcd. for $C_8H_4{}^{35}Cl_2F_2$ 207.9658, found 207.9658, calcd. for $C_8H_4{}^{35}Cl^{37}ClF_2$ 209.9629, found 209.9633, calcd. for $C_8H_4{}^{37}Cl_2F_2$ 211.9599, found 211.9596.

3.15. Synthesis of *m*-$BrC_6H_4CCl{=}CF_2$

Following the general procedure for the coupling reaction 1-bromo-3-iodobenzene (6.0 g, 21.25 mmol), zinc reagent (25.0 mmol) and $Pd(PPh_3)_4$ (0.423 g, 1.5 mol%) were stirred at rt for 18 h to give the styrene in 96% yield (by ^{19}F NMR). The reaction mixture was triturated several times with hexanes. Evaporation of the solvent followed by distillation under reduced pressure afforded the *m*-bromo-α-chloro-β,β-styrene as a clear liquid in 85% (4.56 g, 18.0 mmol) yield.

bp: 62–63 °C at 9 mm Hg.

^{19}F NMR ($CDCl_3$): δ −82.1 (d, $J = 30$ Hz, 1F), −87.5 (d, $J = 30$ Hz, 1F); ^{1}H NMR ($CDCl_3$): δ 7.66 (m, 1H), 7.44 (m, 2H), 7.24 (t, $J = 8$ Hz, 1H); ^{13}C NMR ($CDCl_3$): δ 154.3 (dd, $J = 294, 291$ Hz), 132.7 (d, $J = 5$ Hz), 131.9 (s), 130.7 (dd, $J = 5, 4$ Hz), 130.0 (s), 126.3 (dd, $J = 6, 2$ Hz), 122.7 (s), 92.2 (dd, $J = 36, 23$ Hz); GC/MS: 256 (M + 4) (32), 254 (M + 2) (85), 252 (M^+) (69), 173 (54), 138 (100); HRMS: calcd. for $C_8H_4{}^{79}Br^{35}ClF_2$ 251.9153, found 251.9158, calcd. for $C_8H_4{}^{81}Br^{35}ClF_2$ 253.9132, found 253.9150, calcd. for $C_8H_4{}^{79}Br^{37}ClF_2$ 253.9123 found 253.9150, calcd. for $C_8H_4{}^{81}Br^{37}ClF_2$ 255.9103, found 255.9116.

3.16. Synthesis of *p*-$F_2C{=}ClCC_6H_4CCl{=}CF_2$

Following the general procedure for the coupling reaction, 1,4-diiodobenzene (3.5 g, 10.6 mmol), zinc reagent (25.0 mmol) and $Pd(PPh_3)_4$ (0.423 g, 1.5 mol%) were stirred at rt for 24 h generated the styrene in 86% yield (by ^{19}F NMR). The reaction mixture was triturated several times with hexanes. Evaporation of the solvent followed by distillation under reduced pressure yielded the *bis*-α-chloro-β,β-styrene as a low melting solid 64% (1.84 g, 6.8 mmol).

bp: 76–78 °C at 9 mm Hg.

^{19}F NMR ($CDCl_3$): δ −82.1 (d, $J = 31$ Hz, 2F), −87.6 (d, $J = 31$ Hz, 2F); ^{1}H NMR ($CDCl_3$): δ 7.56 (s, 4H); ^{13}C NMR ($CDCl_3$): δ 154.3 (dd, $J = 295, 294$ Hz), 131.0 (d, $J = 5$ Hz), 127.7 (t, distorted), 92.4 (dd, $J = 23, 37$ Hz); GC/MS: 274 (M + 4) (12), 272 (M + 2) (70), 270 (M^+) (100), 237 (18), 235 (48), 200 (91), 185 (28); HRMS: calcd. for $C_{10}H_4{}^{35}Cl_2F_4$ 269.9626, found 269.9623, calcd. for $C_{10}H_4{}^{35}Cl^{37}ClF_4$ 271.9597, found 271.9584, calcd. for $C_{10}H_4{}^{37}Cl_2F_4$ 273.9567, found 273.9567.

3.17. Synthesis of 2-(2-chloro-1,1-difluoroethenyl)thiophene

Following the general procedure for the coupling reaction, 2-iodothiophene (4.46 g, 21.25 mmol), zinc reagent (25.0 mmol) and $Pd(PPh_3)_4$ (0.423 g, 1.5 mol%) were stirred at rt for 4 h (^{19}F NMR showed only 45% conversion). The mixture was then heated at 65 °C for 3 h to obtain the corresponding styrene in 87% yield (by ^{19}F NMR). The reaction mixture was triturated many times with hexanes. Evaporation of the solvent followed by careful distillation under reduced pressure yielded the 2-(2-chloro-1,1-difluoroethenyl)thiophene as a clear liquid in 65% (2.48 g, 13.77 mmol) yield.

bp: 39–40 °C at 9 mm Hg.

^{19}F NMR ($CDCl_3$): δ −85.0 (d, $J = 29$ Hz, 1F), −86.3 (d, $J = 29$ Hz, 1F); ^{1}H NMR ($CDCl_3$): δ 7.33 (dd, $J = 5, 1$ Hz, 1H), 7.22 (dd, $J = 4, 1$ Hz, 1H), 7.0 (ddd, $J = 5, 4, 1$ Hz, 1H); ^{13}C NMR ($CDCl_3$): δ 153.6 (dd, $J = 293, 291$ Hz), 132.9 (d, $J = 6$ Hz), 127.3 (s), 127.1 (t, $J = 5$ Hz), 126.9 (dd, $J = 5, 3$ Hz), 89.5 (dd, $J = 39, 28$ Hz); GC/MS: 182 (M + 2) (41), 180 (M^+) (82), 145 (100), 101 (54); HRMS: calcd. for $C_6H_3{}^{35}ClF_2S$ 179.9612, found 179.9615, calcd. for $C_6H_3{}^{37}ClF_2S$ 181.9583 found 181.9581.

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