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Stereospecific synthesis of (*E*)- and (*Z*)-1-chloro-1,2-difluorostyrenes☆

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Dedicated to Dr. Teruo Umemoto.

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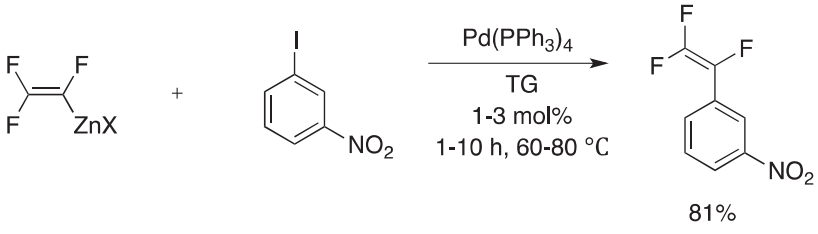
ABSTRACT

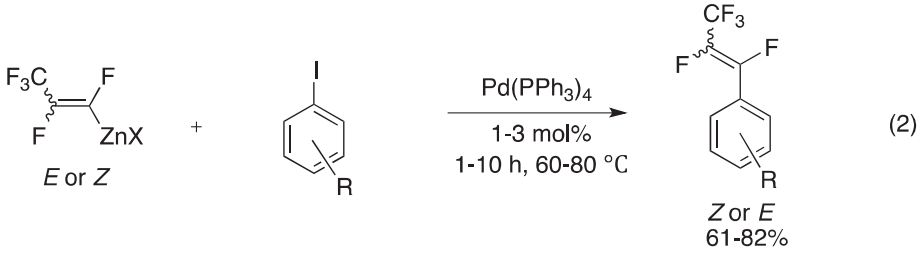
(*Z*)-2-chloro-1,2-difluoro-1-iodoethene and (*E*)-2-chloro-1,2-difluoro-1-iodoethene successfully form stable zinc reagents. The zinc reagents successfully undergo Negishi coupling reactions with substituted aryl iodides to form (*E*)- and (*Z*)-1-chloro-1,2-difluorostyrenes.

1. Introduction

Metal coupling catalyzed reactions have been successful in the stereospecific synthesis of 1,2-difluorinated ethenyl synthons. Various metals have been employed in these processes. The best success has been achieved with organo Zinc reagents (Negishi-coupling) or Suzuki-coupling with use of boronic acids as the coupling partner. Organo stannanes have also allowed some success in the preparation of organo fluoro olefins [1]. The success of the Negishi reaction was simplified by the direct insertion of activated Zinc into the carbon halogen bond by Hansen et al. [2]. Heinze utilized this methodology to achieve the first useful preparation of α,β,β-trifluorostyrenes and achieve the stereospecific preparation of 1-arylperfluoropropenes [3] (Eqs. (1) and (2)):



(1)



(2)

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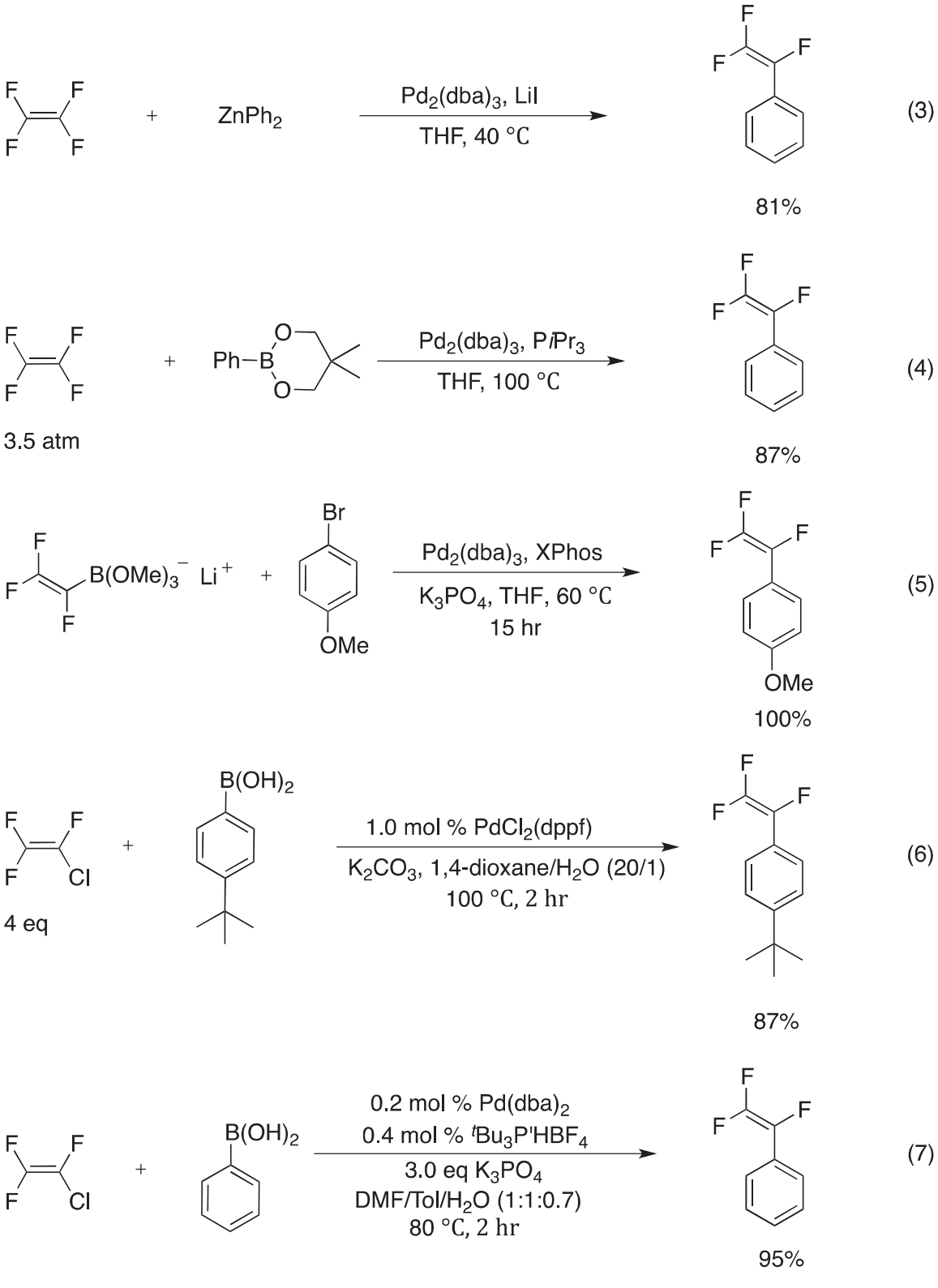
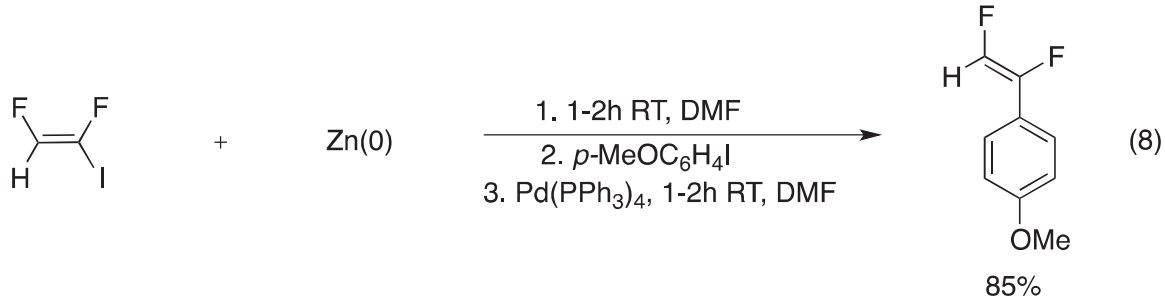
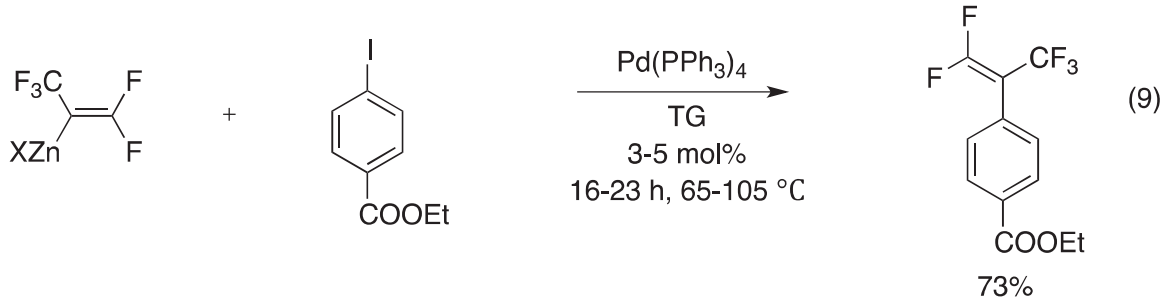
0022-1139/

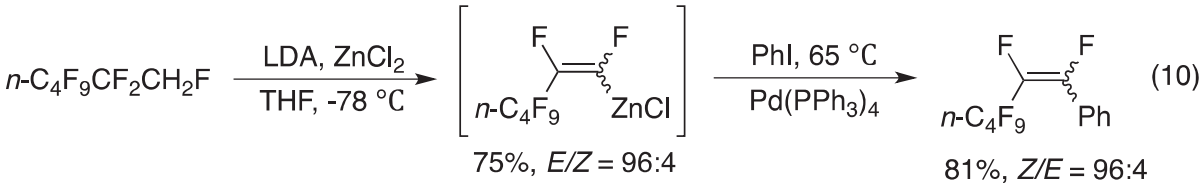
Heinze showed that solvents such as DMF, THF, or triglyme gave good yields of the titled olefins. Raghavanpillai later demonstrated that the trifluorostyrenes could be more economically prepared from HFC-134a [4,5]. Other workers have also reported further improvements for the preparation of trifluorostyrenes. Ogoshi et al. [6] reported the palladium-catalyzed coupling of tetrafluoroethylene (TFE) with arylzinc compounds (Eq. (3)) while discussing the crystal structure for the coordination TFE/Pd complex. In addition, Ogoshi et al. [7] utilized base-free Suzuki coupling reactions for the preparation of trifluorostyrenes (Eq. (4)). Lentz and coworkers [8] also reported the synthesis of trifluorostyrene derivatives by palladium-catalyzed coupling of lithium trimethoxy(trifluorovinyl)borate with aryl bromides (Eq. (5)). Yamakawa and coworkers [9] also reported the Pd-catalyzed arylation of chlorotrifluoroethylene using arylboronic acids (Eq. (6)). Subsequently, Long Lu et al. [10] prepared trifluorostyrenes *via* Pd-catalyzed coupling of arylboronic acids with chloro- and bromotrifluoroethylene (Eq. (7)):



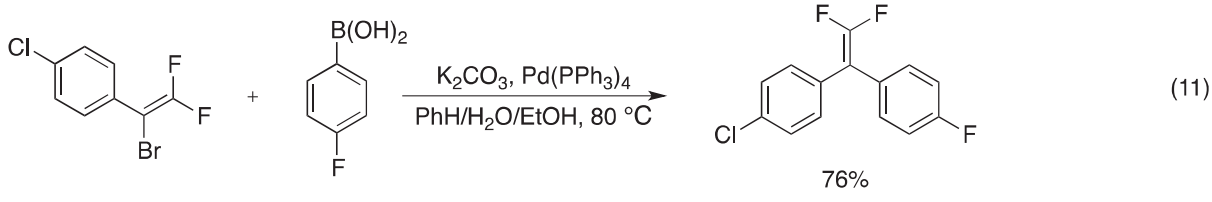
Later, Davis and Burton [11] developed a stereospecific preparation of (*Z*)-α,β-difluorostyrenes *via* Negishi coupling reaction (Eq. (8)). Morken and Burton [12] showed that (2,2-dibromo)hexafluoropropane could also be used to generate the internal propenylzinc reagent *in situ*, which could be utilized (Negishi coupling) for the preparation of β,β-difluoro-α-(trifluoromethyl)styrenes (Eq. (9)). Morken et al. [13] also demonstrated that the propenylzinc reagent could also be coupled with $CuBr_2$, Cu(I)Br with oxygen, or $FeCl_3$ to give the corresponding hexafluoro-1,3-butadiene. An alternative route to (*Z*)-perfluoroalkenylzinc reagents by metalation of 1H,1H-perfluoroalkanes and their derivatization to form (*Z*)-1-arylperfluoroalkenes [(*Z*)-R_FCF=CFAr] was readily accomplished by Raghavanpillai and Burton [14] (Eq. (10)):

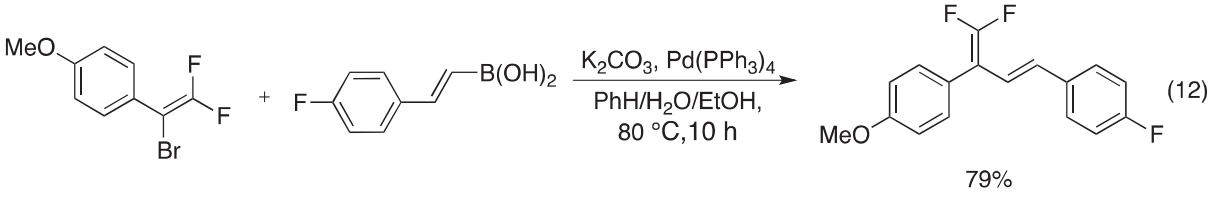


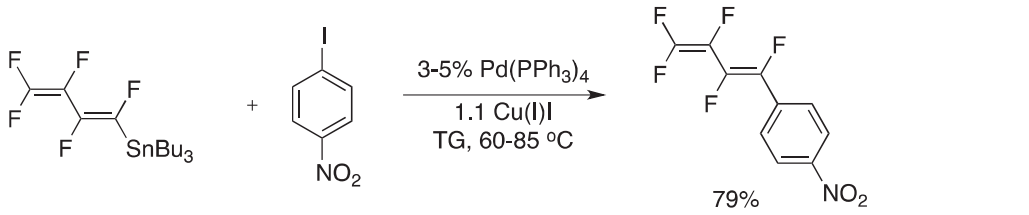




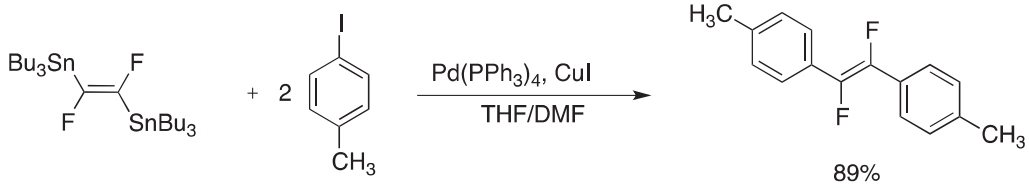
Suzuki coupling has also been used to prepare 2,2-diaryl-1,1-difluoro-1-alkenes and 1,1-difluoro-2-aryl-1,3-dienes [15] (Eqs. (11) and (12)). Stannanes are also useful intermediates in Pd(0) cross-coupling reactions. Pedersen and Burton [16] utilized (*Z*)-1-tri-*n*-butylstannyl-1,2,3,4,4-pentafluoro-1,3-butadiene to develop the stereospecific preparation of (*E*)-1-aryl-F-1,3-butadienes (Eq. (13)). Liu and Burton [17] utilized a *bis*-stannane to achieve the high yield synthesis of symmetrical stilbenes (Eq. (14)):







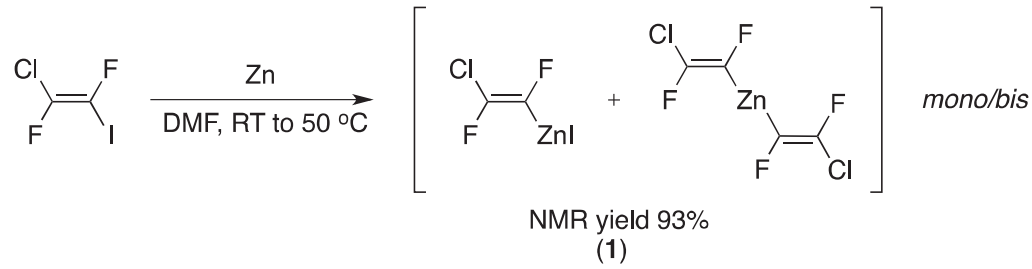
(13)



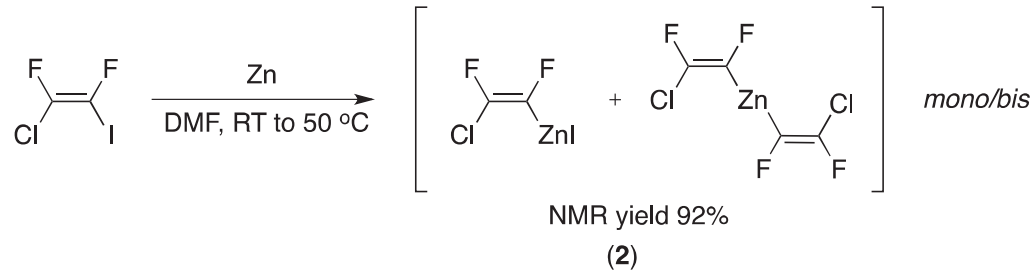
(14)

2. Results and discussion

As noted in the introduction, Pd(0) coupling reactions can be utilized in the Negishi coupling, Suzuki coupling and coupling to vinyl stannanes. Of the three methods, we prefer the Negishi coupling reaction of organo zinc reagents with Pd(0) to prepare fluoroolefins [3,11,12]. The Negishi coupling reaction utilizes aryl iodides as the coupling partner, whereas the Suzuki reaction employs boronic acids, which are less available and more expensive. The stannane coupling reaction necessitates the preparation of the stannane and generally requires several steps. The preparation of the zinc reagent from (*E*)-2-chloro-1,2-difluoro-1-iodoethene (**1**) is presumably selective for reaction with only the vinyl iodide, similar to the previous work reported from this laboratory (Eq. (15)) [2,3]. The (*Z*)-2-chloro-1,2-difluoro-1-iodoethene reacted similarly generating **2** (Eq. (16)):

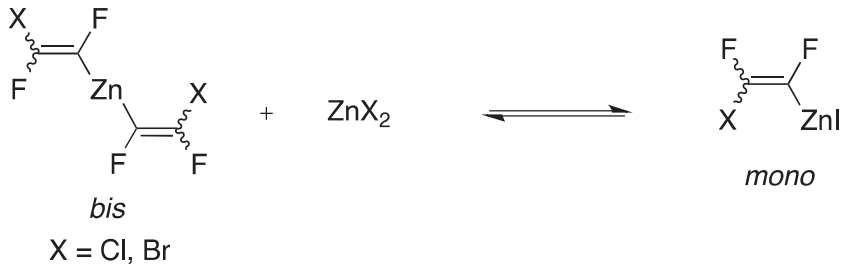


mono/bis = 60/40 (15)

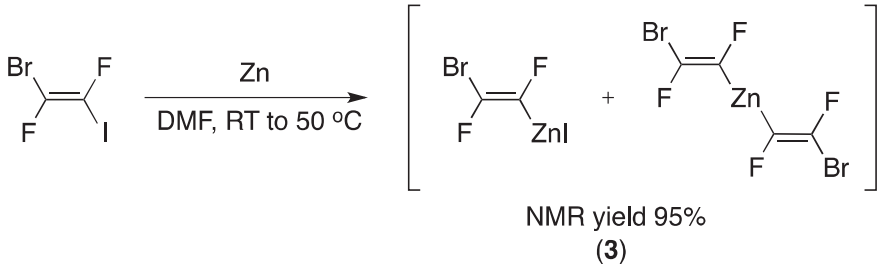


mono/bis = 70/30 (16)

The *mono*/*bis* ratio was determined by the addition of zinc halide to the *mono*/*bis* reaction mixture and noting the effect on the equilibrium – generating more *mono* reagent as determined by ^{19}F NMR of the reaction mixture (Eq. (17)). A similar *mono*/*bis* ratio was noted in the reaction (*E*)-2-bromo-1,2-difluoro-1-iodoethene with Zn and DMF (Eq. (18)):



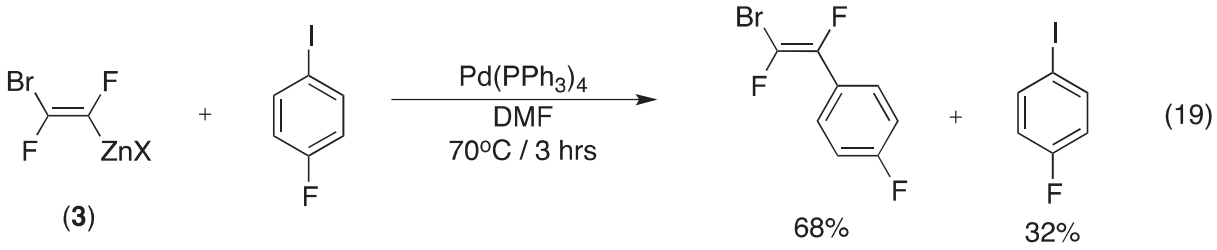
(17)

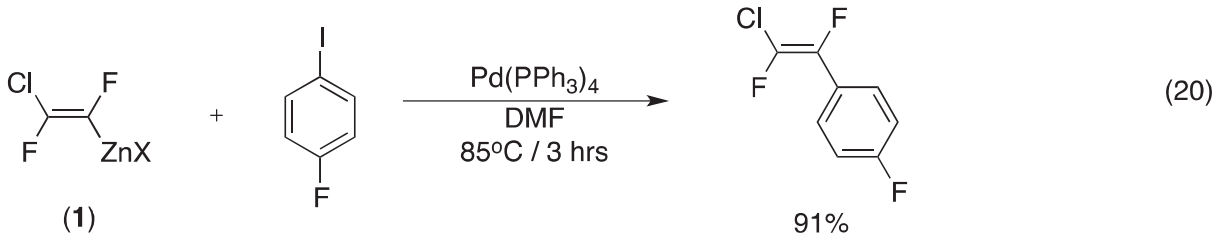


Note that the zinc reagent was formed stereospecifically as determined by ^{19}F NMR and the magnitude of $^{3}J_{FF}$ [18]. Even though the (*E*)- and (*Z*)- both gave stable zinc reagents in their preparation, usually the Pd(0) coupling reactions are carried out at slightly higher temperatures. Therefore we investigated the long-term thermal stability of the reagents. An aliquot **1** and **2** were sealed in an NMR tube with benzotrifluoride and heated at 70 °C for extended periods of time. The **1** and **2** exhibited excellent thermal stability at this temperature for at least 16 h. When **1** or **2** was treated with 4-fluoroiodobenzene in a Negishi coupling reaction at 85 °C for 3 h a 91% yield and 84% isolated yield formed respectively of the chlorostyrenes (Eqs. (20) and (21)). However, when **3** was treated with 4-fluoroiodobenzene in a Negishi coupling reaction at 70 °C for 3 h only a 68% yield of the bromostyrene was achieved (Eq. (19)). Further reaction gave no significant increase in the yield of the bromostyrene. It was not clear if **3** had undergone elimination or formed an oligomeric product *via* a Pd-catalyzed reaction of bromodifluorostyrene with additional zinc reagent:

We occasionally detected 1-chloro-1,2,3,4-tetrafluoro-4-aryl-butadiene as a byproduct. The structure of the diene was assigned by either ^{19}F NMR and/or a combination of ^{19}F NMR and HRMS. Presumably the diene was formed by reaction of the zinc reagent with a chlorostyrene, indicating the reactivity of the chlorine in the chlorostyrenes.

Since McCarthy et al. [19] had shown that the –I electron withdrawing effect of the fluorine in 1-chloro-1-fluorostyrenes increased the reactivity of the vinyl chloride, it would not be surprising that two vinyl fluorines would increase the reactivity of **1** and **2**. McCarthy also showed the –I electron withdrawing effect increased the reactivity of 1-bromo-1-fluorostyrenes, and thus the reactivity of the bromo substituent in **3** would be significantly increased due to the presence of two vinyl fluorines. The increased reactivity of **3** could be attributed to the lower yield in the Negishi coupling reactions because of the decomposition and/or formation of oligomeric products from **3**. Therefore, since we were interested in using chlorostyrenes for the preparation of unsymmetrical 1,2-difluorostilbenes, we decided to investigate





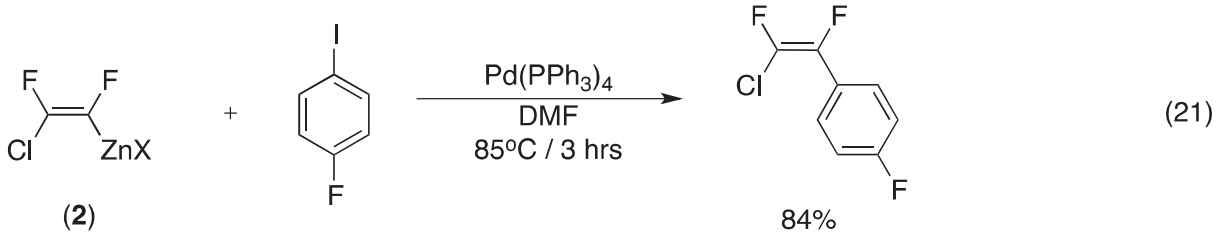
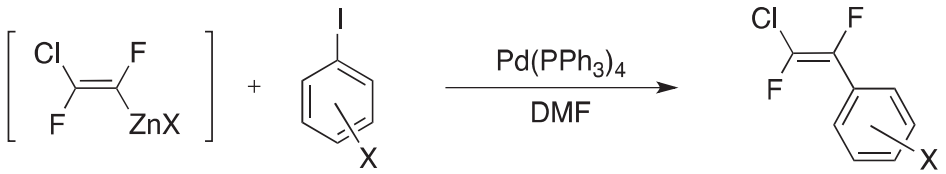


Table 1
Stereospecific synthesis of (*Z*)-1-chloro-1,2-difluorostyrenes.



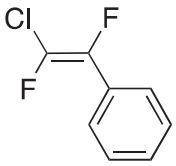
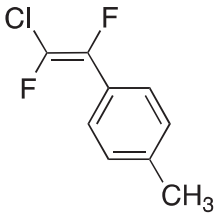
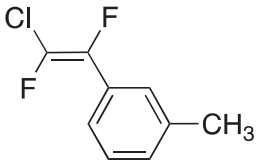
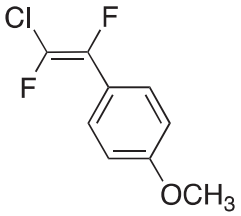
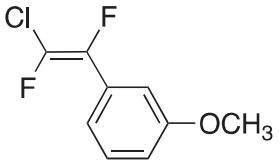
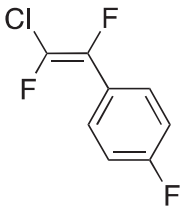
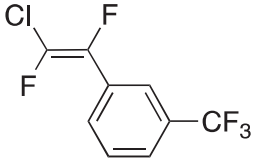
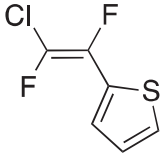
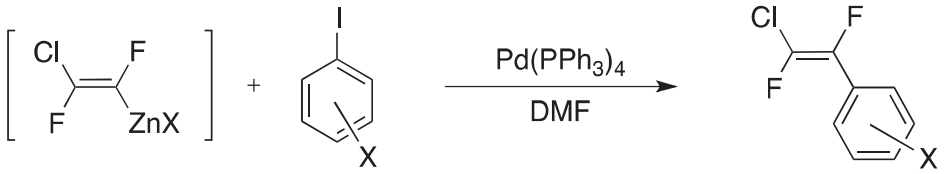
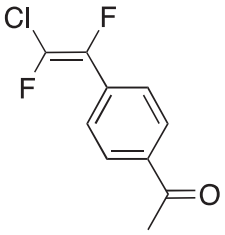
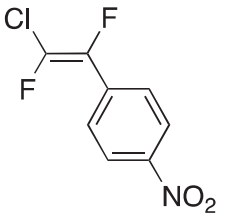
Compound #	X = substituent	*T* (h)	Temp (C)	Structure of product	Yield of product[a]
4	H	3	85		90
5	4-Me	3	85		88
6	3-Me	3	85		95
7	4-OMe	5	85		86
8	3-OMe	5	85		97
9	4-F	3	85		91
10	3-CF_3	3	85		88
11	2-thienyl	3	85		87

Table 1 (*Continued*)



Compound #	X = substituent	*T* (h)	Temp (C)	Structure of product	Yield of product[a]
12	4-$COCH_3$	3	95		90
13	4-NO_2	3	95		96

[a] Isolated yield.

the preparation of the chlorostyrenes in detail. We did not investigate **3** further.

Previous workers have also reported the formation of chlorofluoroethenes by the reaction of phenyl lithium with chlorotrifluoroethylene [20–22].

Tables 1 and 2 detail the scope of our investigation with (*E*)- and (*Z*)-1-chloro-1,2-difluorostyrenes with aryl iodides. Note that both electron donating groups and electron withdrawing groups were successful in the Negishi coupling process.

3. Experimental

3.1. General experimental procedures

Routine ^{19}F NMR spectra were recorded on a JEOL FX90Q Spectrometer (83.81 MHz) and high resolution data was obtained on a Bruker AC-300 Spectrometer (282.41 MHz). Chemical shifts have been reported in ppm relative to internal $CFCl_3$. Spectra of reaction mixtures were obtained in the ^7Li external lock mode. Quantitative determinations were carried out by integration relative to internal benzotrifluoride. Unless noted otherwise, $CDCl_3$ was used as the NMR lock solvent. Routine ^1H NMR (300.17 MHz) spectra and high-resolution data were generally obtained on a Bruker AC-300 Spectrometer. Chemical shifts have been reported in ppm relative to internal TMS. Unless otherwise noted, $CDCl_3$ was used as the NMR lock solvent. High resolution $\{^1H\}$ ^{13}C NMR spectra were recorded on a Bruker AC-300 Spectrometer (75.48 MHz). Chemical shifts have been reported in ppm relative to internal TMS. Unless otherwise noted, $CDCl_3$ was used as the NMR lock solvent. Low-resolution mass spectra were obtained using a TRIO-1 GC–MS instrument operated at 70 eV in the electron impact mode using a DB-1 column (0.25 mm ID × 15 m). High-resolution mass spectra were obtained by the University of Iowa High Resolution Mass Spectrometry Facility.

DMF was dried overnight over CaH_2 and then distilled at reduced pressure. $Pd(PPh_3)_4$ was prepared by Coulson's procedure [23]. Silica gel was purchased from EM Science (Silica Gel 60, particle sized 0.063–0.200 μm, 70–230 Mesh, ASTM). (*E*)-2-chloro-1,2-difluoro-1-iodoethene, (*Z*)-2-chloro-1,2-difluoro-1-iodoethene, and (*E*)-2-bromo-1,2-difluoro-1-iodoethene were prepared by the previous described method [24]. Substituted aryl halides were obtained from commercial vendors and used directly.

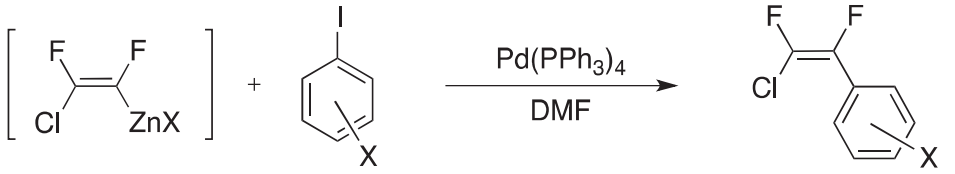
3.2. Preparation of the zinc reagent from (E)-2-chloro-1,2-difluoro-1-iodoethene (*1*) [25,26]

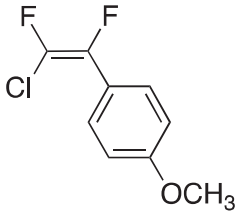
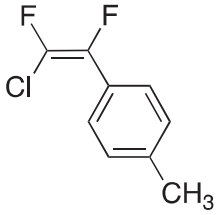
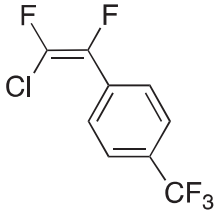
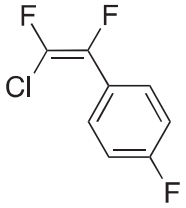
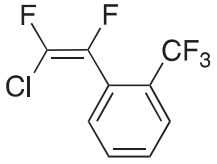
A 100 mL 3-necked round-bottomed flask equipped with a thermometer, a condenser, a magnetic stirring bar, a nitrogen tee, and septa was charged with acid-washed zinc metal (2.35 g, 36 mmol, zinc dust less than 10 micron, Aldrich) and 40 mL of dry DMF. To the above zinc suspension, (*E*)-2-chloro-1,2-difluoro-1-iodoethene (6.73 g, 30 mmol) was slowly added dropwise *via* a syringe at room temperature. An exotherm initiated and a water bath was employed. The rate of addition of (*E*)-2-chloro-1,2-difluoro-1-iodoethene was controlled in order to maintain the temperature of the reaction mixture below 50 °C. After stirring for 1 h, ^{19}F NMR was taken in order to confirm the completion of reaction. The concentration of the zinc reagent was determined by an internal standard; 0.4 mL of the reaction mixture was transferred to a NMR tube *via* syringe, and 3 μL of trifluorotoluene was added into the NMR tube as an internal standard (δ = −63.1 ppm). The calculated concentration based on this internal standard method was 0.63 M (NMR yield = 93%). The zinc reagent consisted of the mono- and *bis*-reagents in a 60/40 ratio; ^{19}F NMR (DMF): −129.9 (d, $^3J_{FF}$ = 116.5 Hz, 1F, mono-reagent), −131.2 (d, $^3J_{FF}$ = 114.2 Hz, 1F, *bis*-reagent), −151.2 (d, $^3J_{FF}$ = 115.9 Hz, 1F, mono-reagent), −151.3 (d, $^3J_{FF}$ = 113.6 Hz, 1F, *bis*-reagent).

3.3. Preparation of the zinc reagent from (Z)-2-chloro-1,2-difluoro-1-iodoethene (*2*)

A 100 mL 3-necked round-bottomed flask equipped with a thermometer, a condenser, a magnetic stirring bar, a nitrogen tee,

Table 2
Stereospecific synthesis of (*E*)-1-chloro-1,2-difluorostyrenes.



Compound #	X = substituent	*T* (h)	Temp (C)	Structure of product	Yield of product[a]
14	4-OMe	5	85		85
15	4-Me	3	85		81
16	4-CF_3	3	85		84
17	4-F	3	85		84
18	2-CF_3	24	60		68

[a] Isolated yield.

and septa was charged with acid-washed zinc metal (2.0 g, 29 mmol, zinc dust less than 10 micron, Aldrich) and 36 mL of dry DMF. To the above zinc suspension, (*Z*)-2-chloro-1,2-difluoro-1-iodoethene (5.4 g, 24 mmol) was slowly added dropwise *via* a syringe at room temperature. An exotherm initiated and a water bath was employed. The rate of addition of (*Z*)-2-chloro-1,2-difluoro-1-iodoethene was controlled in order to maintain the temperature of the reaction mixture below 50 °C. After stirring for 1 h, ^{19}F NMR was taken in order to confirm the completion of reaction. The concentration of the zinc reagent was determined by an internal standard; 0.4 mL of the reaction mixture was transferred to a NMR tube *via* syringe, and 3 μL of trifluorotoluene was added into the NMR tube as an internal standard ($\delta = -63.1$ ppm). The calculated concentration based on this internal standard method was 0.55 M (NMR yield = 92%). The zinc reagent consisted of the mono- and *bis*-reagents in a 70/30 ratio; ^{19}F NMR (DMF): −95.8 (d, $^3J_{FF}$ = 14.0 Hz, 1F, mono-reagent), −96.2 (d, $^3J_{FF}$ = 15.2 Hz, 1F, *bis*-reagent), −136.1 (d, $^3J_{FF}$ = 14.4 Hz, 1F, *bis*-reagent), −136.4 (d, $^3J_{FF}$ = 14.0 Hz, 1F, mono-reagent).

3.4. Preparation of the zinc reagent from (E)-2-bromo-1,2-difluoro-1-iodoethene (**3**)

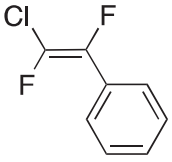
In a procedure similar to Section 3.1: acid-washed zinc metal (0.78 g, 12 mmol), 15 mL of dry DMF were combined in a 50 mL flask. (*E*)-2-bromo-1,2-difluoro-1-iodoethene (2.69 g, 10 mmol) was added. The calculated concentration based on the internal standard method was 0.63 M (NMR yield = 95%). The zinc reagent

consisted of the mono- and *bis*-reagents in about a 70/30 ratio; ^{19}F NMR (DMF): −127.9 (d, $^{3}J_{FF}$ = 119.2 Hz, 1F, mono-reagent), −129.1 (d, $^{3}J_{FF}$ = 119.2 Hz, 1F, *bis*-reagent), −144.0 (d, $^{3}J_{FF}$ = 119.0 Hz, 1F, mono-reagent), −143.9 (d, $^{3}J_{FF}$ = 116.8 Hz, 1F, *bis*-reagent).

3.5. Thermal stability of the zinc reagents

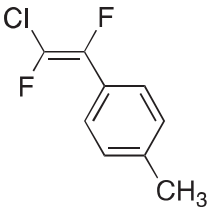
One big advantage of the zinc reagents over lithium or Grignard reagents is their thermal stability. In addition to the ability of lithium or Grignard reagents to generate unwanted byproducts by an elimination reaction, their poor thermal stability often becomes a serious problem. However, the zinc reagents are relatively free from side reactions and thermally much more stable. This allows us to enjoy far less complicated reactions and much wider temperature ranges in reaction conditions, which is a big plus. Therefore, it is important to check the thermal stabilities of each zinc reagent generated from the new synthons, since they have good leaving groups on the β-position (Cl or Br). The thermal stability of the zinc reagent generated from (*E*)- and (*Z*)-2-chloro-1,2-difluoro-1-iodoethene was checked by monitoring the ^{19}F NMR peak ratio changes between the zinc reagent and the internal standard (trifluorotoluene) in a sealed NMR tube over 36 h at 70 °C. The thermal stability of the zinc reagents generated from (*E*)- and (*Z*)-2-chloro-1,2-difluoro-1-iodoethene was different depending upon the stereochemistry of the zinc reagent. The zinc reagent of (*E*)-2-chloro-1,2-difluoro-1-iodoethene showed slightly less thermal stability compared to the (*Z*)-analogue, probably because the (*E*)-structure has a more suitable geometry for the β-elimination of zinc chloride. However, in both cases, more than 95% of the zinc reagent survived even after 16 h at 70 °C. Thus, as long as the Negishi coupling reaction of these zinc reagents can be completed within 16 h, the relativity less thermal stability of the zinc reagent from (*E*)-2-chloro-1,2-difluoro-1-iodoethene would not hinder the coupling reaction. The thermal stability of **1** and **2** allowed us to prepare stock solutions for studying Negishi coupling reaction.

3.6. Synthesis of (Z)-1-chloro-1,2-difluoro-2-phenylethene (*4*)

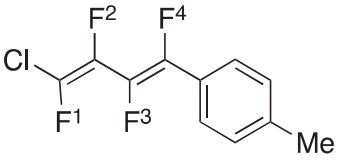


A 25 mL 3-necked round bottomed flask equipped with a nitrogen tee, a thermometer, a condenser, a magnetic stirring bar, and septa was charged with iodobenzene (0.54 mL, 1.0 g, 5 mmol), $Pd(PPh_3)_4$ (0.3 g, 0.25 mmol), and 2 mL of dry DMF. Then, the **1** (9.5 mL, .063 M, 6 mmol) was added *via* syringe to the reaction flask at room temperature. The reaction mixture was stirred for 3 h at 85 °C. The completion of the reaction was determined by ^{19}F NMR. The reaction mixture was directly poured onto a silica gel chromatographic column for separation. Hexane was used as an eluent to isolate (*Z*)-1-chloro-1,2-difluoro-2-phenylethene as a colorless liquid (0.79 g, 4.5 mmol, 90% isolated yield, R_f = 0.65, purity by ^{1}H NMR = 99%); ^{1}H NMR ($CDCl_3$): 7.55 (dm, $^{3}J_{HH}$ = 9.0 Hz, 2H), 7.40 (m, 3H); ^{13}C NMR ($CDCl_3$): 145.2 (dd, $^{1}J_{CF}$ = 235.7 Hz, $^{2}J_{CF}$ = 43 Hz), 138.8 (dd, $^{1}J_{CF}$ = 292.6 Hz, $^{2}J_{CF}$ = 60 Hz), 128.2 (dd, $^{2}J_{CF}$ = 23.9 Hz, $^{3}J_{CF}$ = 6.9 Hz), 125.2 (dd, $^{3}J_{CF}$ = 7.8 Hz, $^{4}J_{CF}$ = 6.5 Hz), 128.7 (d, $^{4}J_{CF}$ = 2.0 Hz), 129.5 (d, $^{5}J_{CF}$ = 2.1 Hz); ^{19}F NMR ($CDCl_3$): −118.5 (d, $^{3}J_{FF}$ = 126.3 Hz, 1F), −148.2 (d, $^{3}J_{FF}$ = 126.3 Hz, 1F); GC–MS, *m*/*z* (relative intensity): 176 (M^++2, 30), 174 (M^+, 100), 139 (57), 119 (37); HRMS: $C_8H_5F_2{}^{35}Cl$ (calculated: 174.0048; found: 174.0046).

3.7. Synthesis of (Z)-1-chloro-1,2-difluoro-2-(4-methylphenyl) ethene (*5*)

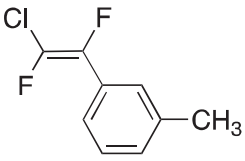


Similar to the procedure described in Section 3.6. 4-Iodotoluene (1.1 g, 5 mmol), DMF (2 mL), $Pd(PPh_3)_4$ (0.3 g, 0.25 mmol), and **1** (9.5 mL, 6 mmol, 0.63 M) gave after silica gel chromatographic isolation **5** as a colorless liquid (0.83 g, 4.4 mmol, 88% isolated yield, R_f = 0.6, purity by ^{1}H NMR = 95%); ^{1}H NMR ($CDCl_3$): 7.44 (broad d, $^{3}J_{HH}$ = 8.3 Hz, 2H), 7.22 (broad d, $^{3}J_{HH}$ = 8.1 Hz, 2H), 2.37 (s, 3H); ^{13}C NMR ($CDCl_3$): 145.4 (dd, $^{1}J_{CF}$ = 234.7 Hz, $^{2}J_{CF}$ = 43.3 Hz), 138.2 (dd, $^{1}J_{CF}$ = 292.2 Hz, $^{2}J_{CF}$ = 59.5 Hz), 125.4 (dd, $^{2}J_{CF}$ = 24.1 Hz, $^{3}J_{CF}$ = 7.0 Hz), 125.1 (dd, $^{3}J_{CF}$ = 8.0 Hz, $^{4}J_{CF}$ = 6.4 Hz), 129.3 (d, $^{4}J_{CF}$ = 1.8 Hz), 139.6 (d, $^{5}J_{CF}$ = 2.5 Hz), 21.4 (s); ^{19}F NMR ($CDCl_3$): −119.6 (d, $^{3}J_{FF}$ = 126.6 Hz, 1F), −1148.0 (d, $^{3}J_{FF}$ = 126.7 Hz, 1F); GC–MS, *m*/*z* (relative intensity); 190 (M^++2, 25), 188 (M^+, 100), 153 (42), 133 (90); HRMS: $C_9H_7F_2{}^{35}Cl$ (calculated: 188.0204; found: 188.0204).



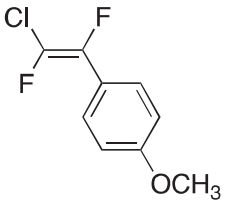
A minor amount (2%) of byproduct, (1*Z*,3*E*)-1-chloro-1,2,3,4-tetrafluoro-4-(4-methylphenyl)butadiene was detected by ^{19}F NMR ($CDCl_3$): −107.7 (ddd, $^{3}J_{FF(1,2)}$ = 131.3 Hz, $^{5}J_{FF(1,4)}$ = 26.7 Hz, $^{4}J_{FF(1,3)}$ = 13.5 Hz, 1F), −154.0 (ddd, $^{3}J_{FF(2,1)}$ = 132.1 Hz, $^{3}J_{FF(2,3)}$ = 36.2 Hz, $^{4}J_{FF(2,4)}$ = 11.6 Hz, 1F), −161.5 (ddd, $^{3}J_{FF(3,4)}$ = 130.6 Hz, $^{3}J_{FF(3,2)}$ = 36.1 Hz, $^{4}J_{FF(3,1)}$ = 13.2 Hz, 1F), −142.3 (ddd, $^{3}J_{FF(4,3)}$ = 131.0 Hz, $^{5}J_{FF(4,1)}$ = 26.8 Hz, $^{4}J_{FF(4,2)}$ = 11.9 Hz, 1F).

3.8. Synthesis of (Z)-1-chloro-1,2-difluoro-2-(3-methylphenyl) ethene (*6*)

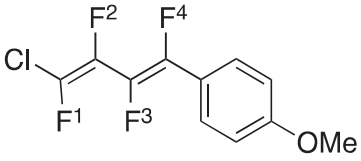


Similar to the procedure described in Section 3.6. 3-Iodotoluene (1.1 g, 5 mmol), DMF (2 mL), $Pd(PPh_3)_4$ (0.3 g, 0.25 mmol), and **1** (9.5 mL, 6 mmol, 0.63 M) gave after silica gel chromatographic isolation **6** as a colorless liquid (0.90 g, 4.75 mmol, 95% isolated yield, R_f = 0.64, purity by ^{1}H NMR = 99%); ^{1}H NMR ($CDCl_3$): 7.37–7.35 (m, 2H), 7.31 (broad t, $^{3}J_{HH}$ = 7.9 Hz, 1H), 7.18 (broad d, $^{3}J_{HH}$ = 7.5 Hz, 1H), 2.38 (s, 3H); ^{13}C NMR ($CDCl_3$): 145.3 (dd, $^{1}J_{CF}$ = 235.4 Hz, $^{2}J_{CF}$ = 43.0 Hz), 138.6 (dd, $^{1}J_{CF}$ = 292.8 Hz, $^{2}J_{CF}$ = 59.9 Hz), 128.1 (dd, $^{2}J_{CF}$ = 23.9 Hz, $^{3}J_{CF}$ = 6.7 Hz), 125.7 (dd, $^{3}J_{CF}$ = 6.9 Hz, $^{4}J_{CF}$ = 6.0 Hz), 138.4 (d, $^{4}J_{CF}$ = 1.5 Hz), 130.3 (d, $^{5}J_{CF}$ = 2.0 Hz), 128.6 (d, $^{4}J_{CF}$ = 1.9 Hz), 122.4 (dd, $^{3}J_{CF}$ = 7.7 Hz, $^{4}J_{CF}$ = 6.4 Hz), 21.5 (s); ^{19}F NMR ($CDCl_3$): −118.6 (d, $^{3}J_{FF}$ = 127.2 Hz, 1F), −147.8 (d, $^{3}J_{FF}$ = 126.4 Hz, 1F); GC–MS, *m*/*z* (relative intensity): 190 (M^++2, 3), 188 (M^+, 14), 151 (26), 133 (100), 50 (56); HRMS: $C_9H_7F_2{}^{35}Cl$ (calculated: 188.0204; found: 188.0206).

3.9. Synthesis of (Z)-1-chloro-1,2-difluoro-2-(4-methoxyphenyl) ethene (**7**)

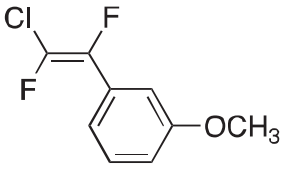


Similar to the procedure described in Section 3.6. 4-Iodoanisole (1.17 g, 5 mmol), DMF (2 mL), $Pd(PPh_3)_4$ (0.3 g, 0.25 mmol), and **1** (9.8 mL, 6 mmol, 0.61 M) were stirred for 5 h at 85 °C. Hexane and ethyl acetate (3:1) was used as an eluent to isolate **7** as a colorless liquid (0.88 g, 4.3 mmol, 86% isolated yield, R_f = 0.35, purity by ^{1}H NMR = 97%); ^{1}H NMR ($CDCl_3$): 7.49 (broad d, $^3J_{HH}$ = 8.7 Hz, 2H), 6.93 (broad d, $^3J_{HH}$ = 8.6 Hz, 2H), 3.83 (s, 3H); ^{13}C NMR ($CDCl_3$): 145.3 (dd, $^1J_{CF}$ = 234.3 Hz, $^2J_{CF}$ = 43.8 Hz), 137.5 (dd, $^1J_{CF}$ = 290.4 Hz, $^2J_{CF}$ = 60.3 Hz), 120.8 (dd, $^2J_{CF}$ = 24.8 Hz, $^3J_{CF}$ = 6.6 Hz), 126.8 (dd, $^3J_{CF}$ = 7.6 Hz, $^4J_{CF}$ = 5.9 Hz), 114.1 (d, $^4J_{CF}$ = 2.16 Hz), 160.3 (d, $^5J_{CF}$ = 2.5 Hz), 55.3 (s); ^{19}F NMR ($CDCl_3$): −121.4 (d, $^3J_{FF}$ = 126.6 Hz, 1F), −147.5 (d, $^3J_{FF}$ = 126.5 Hz, 1F); GC–MS, *m/z* (relative intensity): 206 (M^++2, 35), 204 (M^+, 100); HRMS: $C_9H_7OF_2{}^{35}Cl$ (calculated: 204.0153; found: 204.0154).



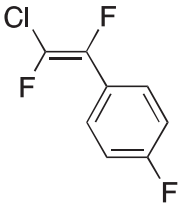
A minor amount (2%) of byproduct, (1*Z*,3*E*)-1-chloro-1,2,3,4-tetrafluoro-4-(4-methoxyphenyl)butadiene was detected by ^{19}F NMR ($CDCl_3$): −108.0 (ddd, $^3J_{F(1,2)}$ = 132.6 Hz, $^5J_{F(1,4)}$ = 26.9 Hz, $^4J_{F(1,3)}$ = 13.4 Hz, 1F), −153.7 (ddd, $^3J_{F(2,1)}$ = 132.2 Hz, $^3J_{F(2,3)}$ = 35.9 Hz, $^4J_{F(2,4)}$ = 12.2 Hz, 1F), −163.0 (ddd, $^3J_{F(3,4)}$ = 130.0 Hz, $^3J_{F(3,2)}$ = 35.9 Hz, $^4J_{F(3,1)}$ = 13.2 Hz, 1F), −139.6 (ddd, $^3J_{F(4,3)}$ = 131.4 Hz, $^5J_{F(4,1)}$ = 27.2 Hz, $^4J_{F(4,2)}$ = 11.9 Hz, 1F).

3.10. Synthesis of (Z)-1-chloro-1,2-difluoro-2-(3-methoxyphenyl) ethene (**8**)



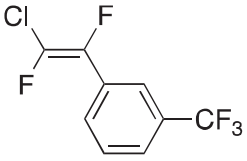
Similar to the procedure described in Section 3.6. 3-Iodoanisole (0.6 mL, 1.17 g, 5 mmol), DMF (2 mL), $Pd(PPh_3)_4$ (0.3 g, 0.25 mmol), and **1** (9.5 mL, 6 mmol, 0.63 M) were stirred for 5 h at 85 °C. Hexane and ethyl acetate (3:1) was used as an eluent to isolate **8** as a colorless liquid (1.0 g, 4.9 mmol, 97% isolated yield, R_f = 0.35, purity by ^{1}H NMR = 99%); ^{1}H NMR ($CDCl_3$): 7.15 (dd, $^4J_{HH}$ = 2.4 Hz, $^5J_{HH}$ = 2.0 Hz, 1H), 6.99 (ddd, $^3J_{HH}$ = 8.3 Hz, $^6J_{HF}$ = 2.6 Hz, $^7J_{HF}$ = 0.9 Hz, 1H), 7.40 (broad t, $^3J_{HH}$ = 8.0 Hz, 1H), 7.22 (dm, $^3J_{HH}$ = 7.9 Hz, 1H), 3.88 (s, 3H); ^{13}C NMR ($CDCl_3$): 145.1 (dd, $^1J_{CF}$ = 235.3 Hz, $^2J_{CF}$ = 43.0 Hz), 139.0 (dd, $^1J_{CF}$ = 293.0 Hz, $^2J_{CF}$ = 59.5 Hz), 129.4 (dd, $^2J_{CF}$ = 24.0 Hz, $^3J_{CF}$ = 6.7 Hz), 117.7 (dd, $^3J_{CF}$ = 9.1 Hz, $^4J_{CF}$ = 6.7 Hz), 159.7 (d, $^4J_{CF}$ = 2.1 Hz), 115.3 (d, $^5J_{CF}$ = 1.5 Hz), 129.8 (d, $^4J_{CF}$ = 1.4 Hz), 110.6 (dd, $^3J_{CF}$ = 7.8 Hz, $^4J_{CF}$ = 7.1 Hz), 55.3 (s); ^{19}F NMR ($CDCl_3$): −117.6 (d, $^3J_{FF}$ = 126.5 Hz, 1F), −147.6 (d, $^3J_{FF}$ = 126.5 Hz, 1F); GC–MS, *m/z* (relative intensity): 206 (M^++2, 23), 204 (M^+, 100), 161 (39), 125 (45); HRMS: $C_9H_7OF_2{}^{35}Cl$ (calculated: 204.0153; found: 204.0152).

3.11. Synthesis of (Z)-1-chloro-1,2-difluoro-2-(4-fluorophenyl)ethene (**9**)



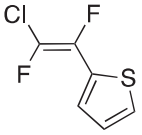
Similar to the procedure described in Section 3.6. 1-Fluoro-4-iodobenzene (1.11 g, 5 mmol), DMF (2 mL), $Pd(PPh_3)_4$ (0.3 g, 0.25 mmol), and **1** (9.5 mL, 6 mmol, 0.63 M) gave after silica gel chromatographic isolation **9** as a colorless liquid (0.88 g, 4.55 mmol, 91% isolated yield, R_f = 0.7, purity by ^{1}H NMR = 98%); ^{1}H NMR ($CDCl_3$): 7.56 (ddd, $^3J_{HH}$ = 9.2 Hz, $^4J_{HF}$ = 5.3 Hz, $^4J_{HF}$ = 3.0 Hz, 2H), 7.13 (ddd, $^3J_{HH}$ = 9.0 Hz, $^3J_{HF}$ = 8.6 Hz, $^5J_{HF}$ = 2.2 Hz, 2H); ^{13}C NMR ($CDCl_3$): 144.6 (dd, $^1J_{CF}$ = 235.1 Hz, $^2J_{CF}$ = 43.2 Hz), 138.6 (ddd, $^1J_{CF}$ = 292.0 Hz, $^2J_{CF}$ = 59.2 Hz, $^5J_{CF}$ = 2.2 Hz), 124.4 (ddd, $^2J_{CF}$ = 24.4 Hz, $^3J_{CF}$ = 6.7 Hz, $^4J_{CF}$ = 3.3), 127.3 (dt, $^3J_{CF}$ = 8.2 Hz, $^{3,4}J_{CF}$ = 6.5 Hz), 115.9 (dd, $^2J_{CF}$ = 21.9 Hz, $^4J_{CF}$ = 1.8 Hz), 163.0 (dd, $^1J_{CF}$ = 250.7 Hz, $^5J_{CF}$ = 2.7 Hz); ^{19}F NMR ($CDCl_3$): −119.3 (d, $^3J_{FF}$ = 127.2 Hz, 1F), −147.6 (d, $^3J_{FF}$ = 127.2 Hz, 1F), −110.7 (m, 1F); GC–MS, *m/z* (relative intensity): 194 (M^++2, 49), 192 (M^+, 76), 157 (100), 137 (61); HRMS: $C_8H_4F_3{}^{35}Cl$ (calculated: 191.9954; found: 191.9955).

3.12. Synthesis of (Z)-1-chloro-1,2-difluoro-2-(3-trifluoromethylphenyl)ethene (**10**)



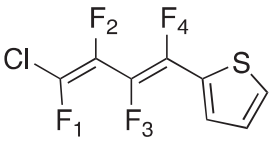
Similar to the procedure described in Section 3.6. 3-Iodobenzotrifluoride (1.36 g, 5 mmol), DMF (2 mL), $Pd(PPh_3)_4$ (0.3 g, 0.25 mmol), and **1** (9.8 mL, 6 mmol, 0.61 M) gave after silica gel chromatographic isolation **10** as a colorless liquid (1.07 g, 4.4 mmol, 88% isolated yield, R_f = 0.65, purity by ^{1}H NMR = 98%); ^{1}H NMR ($CDCl_3$): 7.82 (broad s, 1H), 7.74 (broad d, $^3J_{HH}$ = 7.9 Hz, 1H), 7.56 (broad t, $^{3,3'}J_{HH}$ = 7.9 Hz, 1H), 7.64 (broad d, $^3J_{HH}$ = 7.9 Hz, 1H); ^{13}C NMR ($CDCl_3$): 144.2(dd, $^1J_{CF}$ = 235.6 Hz, $^2J_{CF}$ = 43.1 Hz), 140.0 (dd, $^1J_{CF}$ = 294.1 Hz, $^2J_{CF}$ = 58.5 Hz), 129.1 (dd, $^2J_{CF}$ = 24.3 Hz, $^3J_{CF}$ = 6.7 Hz), 122.0 (qd, $^3J_{CF}$ = 5.8 Hz, $^3J_{CF}$ = 3.2 Hz), 131.5 (qd, $^2J_{CF}$ = 32.9 Hz, $^4J_{CF}$ = 2.4 Hz), 126.1 (broad q, $^3J_{CF}$ = 2.1 Hz), 129.4 (d, $^4J_{CF}$ = 2.0 Hz), 128.1 (dd, $^3J_{CF}$ = 7.0 Hz, $^4J_{CF}$ = 6.3 Hz), 123.7 (q, $^1J_{CF}$ = 272.6 Hz); ^{19}F NMR ($CDCl_3$): −116.1 (d, $^3J_{FF}$ = 127.1 Hz, 1F), −149.0 (d, $^3J_{FF}$ = 126.7 Hz, 1F), −63.5(s, 3F); GC–MS, *m/z* (relative intensity): 244 (M^++2, 10), 242 (M^+, 42), 69 (100); HRMS: $C_9H_4F_5{}^{35}Cl$ (calculated: 241.9922; found: 241.9912).

3.13. Synthesis of (Z)-1-chloro-1,2-difluoro-2-(2-thienyl)ethene (**11**)



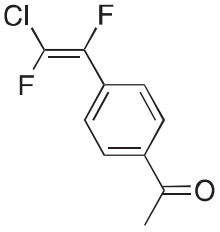
Similar to the procedure described in Section 3.6. 2-Iodothiophene (0.63 g, 3 mmol), DMF (1.5 mL), $Pd(PPh_3)_4$ (0.17 g,

0.15 mmol), and **1** (5.7 mL, 3.6 mmol, 0.63 M) gave after isolation **11** as a yellowish liquid (0.47 g, 2.6 mmol, 87% isolated yield, R_f = 0.65, purity by ^{1}H NMR = 97%); ^{1}H NMR ($CDCl_3$): 7.28 (dd, $^3J_{HH}$ = 3.8 Hz, $^4J_{HF}$ = 1.2 Hz, 1H), 7.08 (m, 1H), 7.43 (m, 1H); ^{13}C NMR ($CDCl_3$): 142.8 (dd, $^1J_{CF}$ = 233.4 Hz, $^2J_{CF}$ = 49.0 Hz), 136.7 (dd, $^1J_{CF}$ = 291.4 Hz, $^2J_{CF}$ = 59.5 Hz), 129.6 (dd, $^2J_{CF}$ = 28.3 Hz, $^3J_{CF}$ = 9.4 Hz), 125.8 (dd, $^3J_{CF}$ = 6.4 Hz, $^4J_{CF}$ = 3.4 Hz), 127.4 (s); ^{19}F NMR ($CDCl_3$): −117.6 (d, $^3J_{FF}$ = 125.2 Hz, 1F), −144.7 (broad d, $^3J_{FF}$ = 125.6 Hz, $^4J_{FH}$ = 1.9 Hz, 1F); GC–MS, *m*/*z* (relative intensity): 182 (M^++2, 43), 180 (M^+, 100), 145 (72); HRMS: $C_6H_3F_2{}^{35}ClS$ (calculated: 179.9612; found: 179.9611).

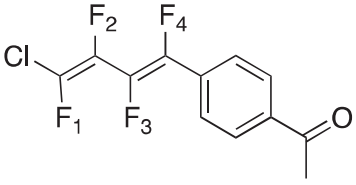


A minor amount (3%) of byproduct, (1*Z*,3*E*)-1-chloro-1,2,3,4-tetrafluoro-4-(2-thienyl)butadiene was detected by ^{19}F NMR ($CDCl_3$): −107.6 (ddd, $^3J_{F(1,2)}$ = 131.9 Hz, $^5J_{FF(1,4)}$ = 26.3 Hz, $^4J_{FF(1,3)}$ = 14.9 Hz, 1F), −154.8 (ddd, $^3J_{FF(2,1)}$ = 131.4 Hz, $^3J_{FF(2,3)}$ = 36.1 Hz, $^4J_{FF(2,4)}$ = 13.7 Hz, 1F), −161.5 (ddddd, $^3J_{FF(3,4)}$ = 127.7 Hz, $^3J_{FF(3,2)}$ = 36.3 Hz, $^4J_{FF(3,1)}$ = 14.4 Hz, $^5J_{FH}$ = 2.0 Hz, 1F), −139.6 (ddd, $^3J_{FF(4,3)}$ = 128.0 Hz, $^5J_{FF(4,1)}$ = 26.4 Hz, $^4J_{FF(4,2)}$ = 13.8 Hz, 1F).

3.14. Synthesis of (Z)-1-chloro-1,2-difluoro-2-(4-acetophenyl)ethene (**12**)

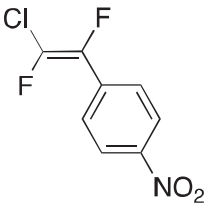


Similar to the procedure described in Section 3.6. 4-Iodoacetophenone (0.49 g, 2 mmol), DMF (2 mL), $Pd(PPh_3)_4$ (0.12 g, 0.1 mmol), and **1** (7.6 mL, 2.6 mmol, 0.34 M) were stirred for 3 h at 95 °C gave after silica gel chromatographic isolation **12** as a yellow solid (0.38 g, 1.8 mmol, 90% isolated yield, mp = 52–53 °C, R_f = 0.05, purity by ^{1}H NMR and ^{19}F NMR = 93%); ^{1}H NMR ($CDCl_3$): 7.67 (broad d, $^3J_{HH}$ = 8.8 Hz, 2H), 8.01 (broad d, $^3J_{HH}$ = 8.8 Hz, 2H), 2.63 (s, 3H); ^{13}C NMR ($CDCl_3$): 144.5 (dd, $^1J_{CF}$ = 235.3 Hz, $^2J_{CF}$ = 42.6 Hz), 140.4 (dd, $^1J_{CF}$ = 296.0 Hz, $^2J_{CF}$ = 59.0 Hz), 132.2 (dd, $^2J_{CF}$ = 23.9 Hz, $^3J_{CF}$ = 7.3 Hz), 125.1 (dd, $^3J_{CF}$ = 8.6 Hz, $^4J_{CF}$ = 6.5 Hz), 128.6 (d, $^4J_{CF}$ = 2.2 Hz), 137.3 (d, $^5J_{CF}$ = 2.2 Hz), 197.1 (s), 26.6 (s); ^{19}F NMR ($CDCl_3$): −114.3 (d, $^3J_{FF}$ = 126.1 Hz, 1F), −148.9 (d, $^3J_{FF}$ = 126.1 Hz, 1F); GC–MS, *m*/*z* (relative intensity): 218 (M^++2, 0.58), 216 (M^+, 2.11), 43 (55), 42(100); HRMS: $C_{10}H_7OF_2{}^{35}Cl$ (calculated: 216.0154; found: 216.0165).

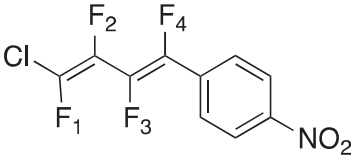


A minor amount (5%) of byproduct, (1*Z*,3*E*)-1-chloro-1,2,3,4-tetrafluoro-4-(4-acetophenyl)butadiene was characterized by HRMS and ^{19}F NMR ($CDCl_3$): −106.1 (ddd, $^3J_{FF(1,2)}$ = 131.2 Hz, $^5J_{FF(1,4)}$ = 28.1 Hz, $^4J_{FF(1,3)}$ = 13.8 Hz, 1F), −155.1 (ddd, $^3J_{FF(2,1)}$ = 131.2 Hz, $^3J_{FF(2,3)}$ = 35.5 Hz, $^4J_{FF(2,4)}$ = 13.1 Hz, 1F), −157.4 (ddd, $^3J_{FF(3,4)}$ = 130.0 Hz, $^3J_{FF(3,2)}$ = 35.4 Hz, $^4J_{FF(3,1)}$ = 13.8 Hz, 1F), −143.2 (ddd, $^3J_{FF(4,3)}$ = 130.0 Hz, $^5J_{FF(4,1)}$ = 28.0 Hz, $^4J_{FF(4,2)}$ = 13.1 Hz, 1F); HRMS: $C_{12}H_7OF_4{}^{35}Cl$ (calculated: 278.0122; found: 278.0124).

3.15. Synthesis of (Z)-1-chloro-1,2-difluoro-2-(4-nitrophenyl)ethene (**13**)

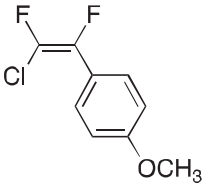


Similar to the procedure described in Section 3.6. 4-Nitroiodobenzene (0.50 g, 2 mmol), DMF (2 mL), $Pd(PPh_3)_4$ (0.12 g, 0.1 mmol), and **1** (7.6 mL, 2.6 mmol, 0.34 M) were stirred for 3 h at 95 °C gave after silica gel chromatographic isolation **13** as a yellow solid (0.42 g, 1.9 mmol, 88% isolated yield, mp = 83–86 °C, R_f = 0.05, purity by ^{1}H NMR = 85%); ^{1}H NMR ($CDCl_3$): 7.76 (dt, $^3J_{HH}$ = 9.0 Hz, $^{3,4}J_{HH}$ = 2.0 Hz, 2H), 8.30 (broad d, $^3J_{HH}$ = 8.8 Hz, 2H); ^{13}C NMR ($CDCl_3$): 143.8 (dd, $^1J_{CF}$ = 235.5 Hz, $^2J_{CF}$ = 42.6 Hz), 141.4 (dd, $^1J_{CF}$ = 297.7 Hz, $^2J_{CF}$ = 58.3 Hz), 133.9 (dd, $^2J_{CF}$ = 24.0 Hz, $^3J_{CF}$ = 7.5 Hz), 125.8 (dd, $^3J_{CF}$ = 8.6 Hz, $^4J_{CF}$ = 6.6 Hz), 124.0 (d, $^4J_{CF}$ = 2.2 Hz), 147.8 (d, $^5J_{CF}$ = 2.6 Hz); ^{19}F NMR ($CDCl_3$): −111.9 (d, $^3J_{FF}$ = 126.3 Hz, 1F), −148.9 (d, $^3J_{FF}$ = 126.3 Hz, 1F); GC–MS, *m*/*z* (relative intensity): 221 (M^++2, 0.11), 219 (M^+, 0.43), 46 (100); HRMS: $C_8H_4F_2{}^{35}ClNO_2$ (calculated: 218.9899; found: 218.9903).



A minor amount (10%) of byproduct, (1*Z*,3*E*)-1-chloro-1,2,3,4-tetrafluoro-4-(4-nitrophenyl)butadiene was detected by HRMS and ^{19}F NMR ($CDCl_3$): −104.8 to −105.4 (m, 1F), −155.0 to −156.0 (m, 2F), −143.1 to −143.7 (m, 1F); HRMS: $C_{10}H_4NO_2F_4{}^{35}Cl$ (calculated: 280.9867; found: 280.9866).

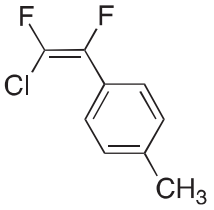
3.16. Synthesis of (E)-1-chloro-1,2-difluoro-2-(4-methoxyphenyl)ethene (**14**)



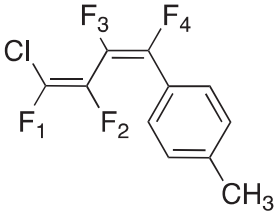
Similar to the procedure described in Section 3.6. 4-Iodoanisole (1.17 g, 5 mmol), DMF (2 mL), $Pd(PPh_3)_4$ (0.3 g, 0.25 mmol), and **2** (10.9 mL, 6 mmol, 0.55 M) were stirred for 5 h at 85 °C. Hexane and ethyl acetate (3:1) was used as an eluent to isolate **14** as a colorless liquid (0.9 g, 4.4 mmol, 85% isolated yield, R_f = 0.3, purity by ^{1}H NMR = 96%); ^{1}H NMR ($CDCl_3$): 7.49 (d, $^3J_{HH}$ = 8.8 Hz, 2H), 6.93 (d, $^3J_{HH}$ = 8.8 Hz, 2H), 3.83 (s, 3H); ^{13}C NMR ($CDCl_3$): 142.6 (dd, $^1J_{CF}$ = 245.4 Hz, $^2J_{CF}$ = 18.9 Hz), 136.1 (dd, $^1J_{CF}$ = 298.3 Hz, $^2J_{CF}$ = 42.5 Hz), 128.6 (dd, $^2J_{CF}$ = 21.0 Hz, $^3J_{CF}$ = 6.7 Hz), 128.6 (dd, $^3J_{CF}$ = 4.9 Hz, $^4J_{CF}$ = 3.5 Hz), 113.9 (s), 160.6 (s), 55.3 (s); ^{19}F NMR

($CDCl_3$): −105.1 (d, $^3J_{FF}$ = 11.1 Hz, 1F), −130.0 (d, $^3J_{FF}$ = 11.1 Hz, 1F); GC–MS, *m/z* (relative intensity): 206 (M^++2, 27), 204 (M^+, 100), 189 (70), 161 (54); HRMS: $C_9H_7OF_2{}^{35}Cl$ (calculated: 204.0153; found: 204.0153).

3.17. Synthesis of (E)-1-chloro-1,2-difluoro-2-(4-methylphenyl) ethene (**15**)

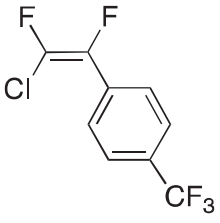


Similar to the procedure described in Section 3.6. 3-Iodotoluene (1.09 g, 5 mmol), DMF (2 mL), $Pd(PPh_3)_4$ (0.3 g, 0.25 mmol), and **2** (10.9 mL, 6 mmol, 0.55 M) gave after silica gel chromatographic isolation **15** as a colorless liquid (0.77 g, 4.1 mmol, 81% isolated yield, R_f = 0.65, purity by ^{1}H NMR = 98%); ^{1}H NMR ($CDCl_3$): 7.51 (broad d, $^3J_{HH}$ = 8.3 Hz, 2H), 7.22 (broad d, $^3J_{HH}$ = 8.0 Hz, 2H), 2.37 (s, 3H); ^{13}C NMR ($CDCl_3$): 142.7 (dd, $^1J_{CF}$ = 245.2 Hz, $^2J_{CF}$ = 18.6 Hz), 136.6 (dd, $^1J_{CF}$ = 298.9 Hz, $^2J_{CF}$ = 42.2 Hz), 124.9 (broad d, $^2J_{CF}$ = 23.0 Hz), 127.1 (dd, $^3J_{CF}$ = 5.4 Hz, $^4J_{CF}$ = 3.7 Hz), 129.1 (s), 140.1 (s), 21.4 (s); ^{19}F NMR ($CDCl_3$): −103.7 (d, $^3J_{FF}$ = 11.3 Hz, 1F), −131.0 (d, $^3J_{FF}$ = 11.6 Hz, 1F); GC–MS, *m/z* (relative intensity): 190 (M^++2, 23), 188 (M^+, 100), 133 (92); HRMS: $C_9H_7F_2{}^{35}Cl$ (calculated: 188.0204; found: 188.0202).



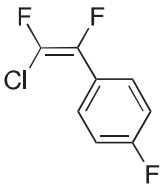
A minor amount (1%) of byproduct, (1*E*,3*Z*)-1-chloro-1,2,3,4-tetrafluoro-4-(4-methylphenyl)butadiene was detected by ^{19}F NMR ($CDCl_3$): −93.4 (broad t, $^3J_{FF(1,2)}$ = $^4J_{FF(1,3)}$ = 5.5 Hz, 1F), −143.6 (ddd, $^3J_{FF(2,3)}$ = 37.7 Hz, $^3J_{FF(2,1)}$ = 4.9 Hz, $^4J_{FF(2,4)}$ = 16.1 Hz, 1F), −136.6 (ddd, $^3J_{FF(3,2)}$ = 38.3 Hz, $^3J_{FF(3,4)}$ = 7.3 Hz, $^4J_{FF(3,1)}$ = 6.8 Hz, 1F), −117.5 (dd, $^4J_{FF(4,2)}$ = 17.1 Hz, $^3J_{FF(4,3)}$ = 7.1 Hz, 1F).

3.18. Synthesis of (E)-1-chloro-1,2-difluoro-2-(4-trifluoromethylphenyl)ethene (**16**)



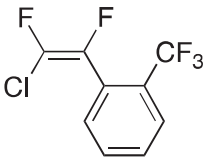
Similar to the procedure described in Section 3.6. 4-Iodobenzotrifluoride (1.36 g, 5 mmol), DMF (2 mL), $Pd(PPh_3)_4$ (0.3 g, 0.25 mmol), and **2** (10.9 mL, 6 mmol, 0.55 M) gave after silica gel chromatographic isolation **16** as a colorless liquid (1.09 g, 4.5 mmol, 84% isolated yield, R_f = 0.35, purity by ^{1}H NMR = 99%); ^{1}H NMR ($CDCl_3$): 7.78 (broad d, $^3J_{HH}$ = 8.5 Hz, 2H), 7.69 (broad d, $^3J_{HH}$ = 8.6 Hz, 2H); ^{13}C NMR ($CDCl_3$): 141.7 (dd, $^1J_{CF}$ = 245.5 Hz, $^2J_{CF}$ = 19.6 Hz), 138.2 (dd, $^1J_{CF}$ = 302.5 Hz, $^2J_{CF}$ = 41.0 Hz), 131.3 (dd, $^2J_{CF}$ = 24.7 Hz, $^3J_{CF}$ = 1.0 Hz), 127.1 (dd, $^3J_{CF}$ = 5.7 Hz, $^4J_{CF}$ = 3.7 Hz), 125.5 (q, $^3J_{CF}$ = 3.9 Hz), 131.6 (q, $^2J_{CF}$ = 33.0 Hz), 123.7 (q, $^1J_{CF}$ = 272.3 Hz); ^{19}F NMR ($CDCl_3$): −98.7 (d, $^3J_{FF}$ = 13.0 Hz, 1F), −133.0 (d, $^3J_{FF}$ = 12.9 Hz, 1F), −63.5 (s, 3F); GC–MS, *m/z* (relative intensity): 244 (M^++2, 33), 242 (M^+, 100), 138 (54), 69 (99); HRMS: $C_9H_4F_5{}^{35}Cl$ (calculated: 241.9922; found: 241.9920).

3.19. Synthesis of (E)-1-chloro-1,2-difluoro-2-(4-fluorophenyl) ethene (**17**)



Similar to the procedure described in Section 3.6. 1-Fluoro-4-iodobenzene (1.11 g, 5 mmol), DMF (2 mL), $Pd(PPh_3)_4$ (0.3 g, 0.25 mmol), and **2** (10.9 mL, 6 mmol, 0.55 M) gave after isolation **17** as a colorless liquid (0.81 g, 4.2 mmol, 84% isolated yield, R_f = 0.65, purity by ^{1}H NMR = 99%); ^{1}H NMR ($CDCl_3$): 7.62 (ddt, $^3J_{HH}$ = 8.9 Hz, $^4J_{HF}$ = 5.2 Hz, $^{4,5}J_{HF}$ = 2.0 Hz, 2H), 7.12 (dd, $^3J_{HF}$ = 8.6 Hz, $^3J_{HF}$ = 8.5 Hz, 2H); ^{13}C NMR ($CDCl_3$): 141.9 (dd, $^1J_{CF}$ = 245.6 Hz, $^2J_{CF}$ = 19.3 Hz), 136.9 (ddd, $^1J_{CF}$ = 299.7 Hz, $^2J_{CF}$ = 41.6 Hz, $^5J_{CF}$ = 1.7 Hz), 123.9 (dd, $^2J_{CF}$ = 23.8 Hz, $^3J_{CF}$ = 3.4 Hz), 129.2 (ddd, $^3J_{CF}$ = 5.4 Hz, $^3J_{CF}$ = 5.1 Hz, $^4J_{CF}$ = 3.5 Hz), 115.7 (d, $^2J_{CF}$ = 22.2 Hz), 163.3 (d, $^1J_{CF}$ = 251.7 Hz); ^{19}F NMR ($CDCl_3$): −102.8 (dd, $^3J_{FF}$ = 11.7 Hz, $^7J_{FF}$ = 3.3 Hz, 1F), −130.5 (d, $^3J_{FF}$ = 12.5 Hz, 1F), −110.2 (dd, 1F); GC–MS, *m/z* (relative intensity): 194 (M^++2, 59), 192 (M^+, 88), 157 (100), 137 (51); HRMS: $C_8H_4F_3{}^{35}Cl$ (calculated: 191.9954; found: 191.9943).

3.20. Synthesis of (E)-1-chloro-1,2-difluoro-2-(2-trifluoromethylphenyl)ethene (**18**)



Similar to the procedure described in Section 3.6. 2-Iodobenzotrifluoride (1.36 g, 5 mmol), DMF (2 mL), $Pd(PPh_3)_4$ (0.3 g, 0.25 mmol), and **2** (8.1 mL, 6 mmol, 0.74 M) were stirred for 24 h at 60 °C. 50% of 2-iodobenzotrifluoride had been converted to **18**. Additional **2** (8.14 mL, 6 mmol, 0.74 M) was added and stirred overnight. **18** was isolated as a colorless liquid (0.83 g, 3.4 mmol, 68% isolated yield, R_f = 0.65, purity by ^{1}H NMR = 98%); ^{1}H NMR ($CDCl_3$): 7.67–7.56 (m, 3H), 7.79(m, 1H); ^{13}C NMR ($CDCl_3$): 139.5 (dd, $^1J_{CF}$ = 254.4 Hz, $^2J_{CF}$ = 20.1 Hz), 138.3 (dd, $^1J_{CF}$ = 302.8 Hz, $^2J_{CF}$ = 40.8 Hz), 125.8 (dd, $^2J_{CF}$ = 22.6 Hz, $^3J_{CF}$ = 2.2 Hz), 130.6 (qd, $^2J_{CF}$ = 31.7 Hz, $^3J_{CF}$ = 3.4 Hz), 127.0 (qd, $^3J_{CF}$ = 4.9 Hz, $^4J_{CF}$ = 1.9 Hz), 131.4 (d, $^5J_{CF}$ = 2.4 Hz), 132.2 (s), 132.9 (d, $^3J_{CF}$ = 2.5 Hz), 123.3 (q, $^1J_{CF}$ = 273.8 Hz); ^{19}F NMR ($CDCl_3$): −103.4 (d, $^3J_{FF}$ = 9.4 Hz, 1F), −117.1 (pentet, $^{3,5}J_{FF}$ = 9.5 Hz, 1F), −61.6 (d, $^5J_{FF}$ = 9.6 Hz, 3F); GC–MS, *m/z* (relative intensity): 244 (M^++2, 48), 242 (M^+, 83), 207 (100), 187 (57), 138 (54); HRMS: $C_9H_4F_5{}^{35}Cl$ (calculated: 241.9922; found: 241.9925).

4. Conclusions

(*Z*)- and (*E*)-2-chloro-1,2-difluoro-1-iodoethene react with the activated zinc to form stable zinc reagents. These zinc reagents react with substituted aryl iodides in a Pd(0) coupling reaction to stereospecifically form the (*E*)- and (*Z*)-1-Chloro-1,2-difluorostyrenes. These styrenes provide potential coupling partners for

additional coupling to prepare unsymmetrical 1,2-difluorostilbenes.

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