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Preparation of 4-(Fluorophenyl)but-3-en-2-ols

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Abstract *: 4-(Fluorophenyl)but-3-en-2-ones are reduced to 4-(fluorophenyl)but-3-en-ols by Luche reduction ($NaBH_4$, $CeCl_3$, CH_3OH). 4-(Fluorophenyl)but-3-en-2-ones as substrates have been prepared by solventless Wittig-reaction. 4-(Fluorophenyl)but-3-en-2-ols can be seen as potential starting material for fluorinated styrene derivatives.*

Keywords: *Wittig olefination, Luche reduction, alkenone, alkenol, organofluoro compounds*

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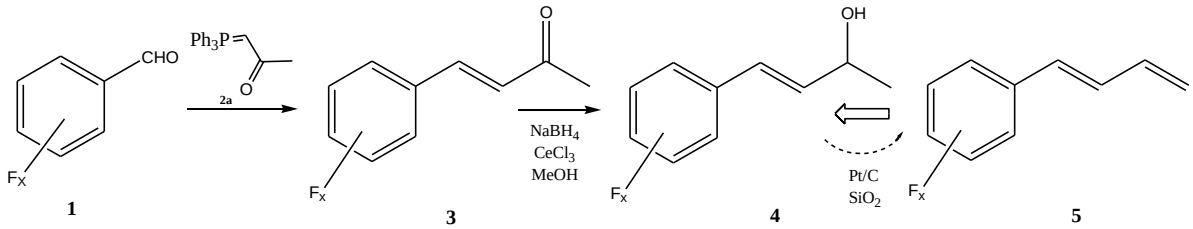
I. Introduction

1-Phenylbutadienes have been investigated as components in co-polymers [1]. In this regard, also 1-(fluorophenyl)buta-1,3-dienes **5** should elicit interest as building blocks in co-polymers [2]. Recently it has been noted that benzylalcohols and cinnamyl alcohols form symmetric ether dimers when heated over Pd/C or Pt/C [3,4]. In the case of ethers stemming from secondary benzyl alcohols, the ethers are very labile and can transform to vinylbenzenes easily [5]. Thus, styrene derivatives have been found to form in acceptable yield by immobilizing the ethers on silica gel and eluting the products with hexane as eluant [5]. In order to investigate whether it is also possible to gain access to 1-(fluorophenyl)buta-1,3-dienes **5** via this synthetic strategy, the author sought an easy entry to 4-(fluorophenyl)alk-3-en-2-ols **4** as starting materials. The present communication describes a facile preparation of 4-(fluorophenyl)alk-3-en-2-ols **4** by Luche reduction [6] of the respective 4-(fluorophenyl)alk-3-en-2-ones **3**, which themselves are prepared by solventless Wittig olefination from commercially available fluorinated benzaldehydes **1** [7].



Scheme 1. 4-(Fluorophenyl)alk-3-en-2-ols as potential precusors of 1-(fluorophenyl)buta-1,3-dienes

II. Experimental

General. – Melting points were measured on a Yanaco microscopic hotstage and are uncorrected. Infrared spectra were measured with JASCO IR-700 and Nippon Denshi JIR-AQ2OM instruments. ^{1}H and ^{13}C NMR spectra were recorded with a JEOL EX-270 spectrometer (^{1}H at 270 MHz, ^{13}C at 67.8 MHz). The chemical shifts are relative to TMS (solvent $CDCl_3$, unless otherwise noted). Mass spectra were measured with a JMS-01-SG-2 spectrometer. Column chromatography was carried out on Wakogel 300. Elemental analysis was carried out at Kyushu University, Hakozaki Campus, Fukuoka, Japan.

Chemicals. – The fluorinated benzaldehydes **1** were acquired commercially (Aldrich). Phosphoranes **2a**, **2b**, and **2c** were synthesized according to literature procedures [8-10]. **2c** was also acquired commercially. The fluorinated 4-phenylbut-3-en-2-ones **3** were prepared by solventless Wittig-reaction. Typical examples for the newly prepared fluorinated phenylalkenones **3** (**3f**, **3i**, **3k**) are given below.

(*E*)-4-(2,5-Difluorophenyl)but-3-en-2-one (**3i**). – To phosphorane **2a** (3.58 g, 11.2 mmol) was added 2,5-difluorobenzaldehyde (**1h**, 1.0 g, 7.0 mmol). The ensuing reaction is exothermic. After the addition, the mixture was heated at 100 °C for 40 min. Direct column chromatography of the cooled mixture on silica gel (hexane/ether/$CHCl_3$ 4:1:1) gave **(*Z*)-3i** (35 mg, 3%) as an oil; IR (neat) *ν* 2972, 2928, 1621, 1585, 1467, 1368, 1313, 1268, 1233, 1199, 1142, 1068, 998, 780, 716 cm^{-1}; ^{1}H-NMR (270 MHz, $CDCl_3$) *ö* 2.23 (3H, s, CH_3), 6.36

(1H, d, ^3J = 12.7 Hz), 6.81 (1H, d, ^3J = 12.7 Hz), 7.01 (2H, m), 7.33 (1H, m); ^{13}C-NMR (67.8 MHz, $CDCl_3$) ö 30.7 (CH_3), 116.6 (dd, J_{CF} = 24.6 Hz, J_{CF} = 8.9 Hz), 117.1 (dd, J_{CF} = 25.1 Hz, J_{CF} = 2.8 Hz), 117.2 (dd, J_{CF} = 24.0 Hz, J_{CF} = 8.9 Hz), 124.4 (dd, J_{CF} = 15.7 Hz, J_{CF} = 8.9 Hz), 131.0 (m), 131.2 (m), 156.2 (J_{CF} = -245 Hz, J_{CF} = 2.2 Hz), 158.1 (dd, J_{CF} = 242 Hz, J_{CF} = 2.2 Hz), 199.3 (CO); MS (EI, 70 eV) *m/z* (%) 182 (M^+, 13), 167 (30), 139 (17), 119 (13). HRMS Found: 182.0539. Calcd. for $C_{10}H_8OF_2$: 182.0543, and **(*E*)-31** [5] (1.17 g, 92%) as colorless plates, mp. 65 °C; IR (KBr) *v* 3066, 1673 (C=O), 1490, 1435, 1365, 1324, 1263, 1233, 1187, 1146, 975, 876, 846, 830, 791, 728, 575, 504, 473, 455 cm^{-1}; ^{1}H-NMR (270 MHz, $CDCl_3$) *ö*2.40 (s, 3H, CH_3), 6.74 (d, 1H, ^3J = 16.5 Hz), 7.06 (m, 2H), 7.25 (m, 1H), 7.61 (d, 1H, ^3J = 16.5 Hz); ^{13}C-NMR (67.8 MHz, $CDCl_3$) *ö* 27.6 (CH_3), 114.3 (dd, J_{CF} = 24.6 Hz, J_{CF} 2.8 Hz), 117.4 (dd, J_{CF} = 25.2 Hz, J_{CF} 8.9 Hz), 118.4 (dd, J_{CF} = 24.6 Hz, J_{CF} = 9.5 Hz), 117.4 (dd, J_{CF} = 25.2 Hz, J_{CF} = 8.9 Hz), 118.4 (dd, J_{CF} = 24.6 Hz, J_{CF} = 9.5 Hz), 123.7 (dd, J_{CF} = 14.6 Hz, J_{CF} = 8.4 Hz), 129.9 (d, J_{CF} = 5.0 Hz), 134.3 (dd, J_{CF} = 2.8 Hz, J_{CF} = 2.8 Hz), 157.4 (dd, J_{CF} – 249 Hz, J_{CF} = 2.2 Hz), 158.7 (dd, J_{CF} = -242 Hz, J_{CF} = 2.2 Hz), 197.9 (CO); MS (EI, 70 eV) *m/z* (%) 182 (M^+, 100), 167 (100), 139 (53), 119 (42). HRMS Found: 182.0546. Calcd. for $C_{10}H_8OF_2$: 182.0543. Found: C, 65.77; H, 4.36%. Calcd. for $C_{10}H_8OF_2$: C, 65.93; H, 4.43%.

(*E*)-4-(2,4-Difluoro)but-3-en-2-one (**3k**). – 2,4-Difluorobenzaldehyde (**1i**, 1.0 g, 7.0 mmol) and **2a** (3.58 g, 11.2 mmol) were reacted at 100 °C for 40 min. Column chromatography on silica gel (hexane/ether/$CHCl_3$ 4:1:1) gave (*E*)-**3k** (1.2 g, 94%) as a colorless oil; IR (neat) ν 2924, 1674 (C=O), 1620, 1500, 1430, 1360, 1255, 1177, 1142, 1090, 968, 910, 851, 808, 729 cm^{-1}; ^{1}H-NMR (270 MHz, $CDCl_3$) *ö* 2.39 (s, 3H, CH_3), 6.73 (d, 1H, ^3J = 16.5 Hz), 6.93 (m, 2H), 7.55 (m, 1H), 7.60 (d, 1H, ^3J = 16.5 Hz); ^{13}C-NMR (67.8 MHz, $CDCl_3$) *ö* 27.5 (CH_3), 104.6 (dd, J_{CF} = 25.8 Hz, J_{CF} = 25.8 Hz), 112.2 (dd, J_{CF} = 21.7 Hz, J_{CF} = 3.3 Hz), 119.0 (dd, J_{CF} = 11.8 Hz, J_{CF} = 3.9 Hz), 128.8 (dd, J_{CF} = 5.0 Hz, J_{CF} = 2.2 Hz), 129.9 (dd, J_{CF} = 9.5 Hz, J_{CF} = 4.5 Hz), 134.6 (dd, J_{CF} = 2.8 Hz, J_{CF} = 1.7 Hz), 161.6 (dd, J_{CF} = -256 Hz, J_{CF} = 12.3 Hz), 164.1 (dd, J_{CF} = -254 Hz, J_{CF} = 12.3 Hz), 190.1 (CO); MS (EI, 70 eV) *m/z* (%) 182 (M^+, 44), 167 (100), 139 (46), 119 (37). HRMS Found: 182.0540. Calcd. for $C_{10}H_8OF_2$: 182.0543. Found: C, 65.78; H, 4.35%. Calcd. for $C_{10}H_8OF_2$: C, 65.93; H, 4.43%.

(*E*)-3-Methyl-4-(3,4,5-trifluorophenyl)but-3-en-2-one (**3f**). – 3,4,5-Trifluorobenzaldehyde (**1c**, 3.0 g, 18.7(5) mmol) and **2b** (9.96 g, 30 mmol) were reacted at 100 °C for 40 min. Column chromatography on silica gel (hexane/ether/$CHCl_3$ 3:1:1) gave **(*E*)-3f** (4.0 g, 94%) as a colorless solid, mp. 73°C; IR (KBr) *v* 1664 (C=O), 1533, 1435, 1395, 1250, 1042, 972, 900, 859, 793, 771, 671, 614 cm^{-1}; ^{1}H-NMR (270 MHz, $CDCl_3$) *ö* 2.03 (d, 3H, ^4J = 1.4 Hz, CH_3), 2.44 (s, 3H, CH_3), 7.04 (m, 2H), 7.32 (bs, 1H); ^{13}C-NMR (67.8 MHz, $CDCl_3$) *ö* 12.7 (CH_3), 25.7 (CH_3), 113.6 (m), 135.8 (m), 139.4 (m), 199.4; MS (EI, 70 eV) *m/z* (%) 214 (M^+, 100), 199 (74), 171 (79), 169 (39), 151 (67), 145 (47). HRMS Found: 214.0603. Calcd. for $C_{11}H_9OF_3$: 214.0605. Found: C, 61.77; H, 4.17%. Calcd. for $C_{11}H_9OF_3$: C, 61.72; H, 4.23%.

(*E*)-4-(3,4,5-Trifluorophenyl)-but-3-en-2-ol (**4b**). – General procedure A: To a solution of **3c** (1.08 g, 5.38 mmol) in MeOH (14 mL) was given at 0 °C $CeCl_3$ (1.30 g, 5.38 mmol). Then, $NaBH_4$ (260 mg, 6.84 mmol) was added, and the resulting solution was stirred for 5 min. Thereafter, water (30 mL) was added, and the mixture was extracted with chloroform (3 X 25 mL). The combined organic phase was dried over anhydrous $MgSO_4$ and concentrated *in vacuo*. The residue was subjected to column chromatography on silica gel (ether/hexane/$CHCl_3$ 1:1:1) to give **4b** (939 mg, 87%) as a colorless oil; IR (neat) ν 3364 (bs, OH), 2976, 2926, 1618, 1530, 1440, 1043, 965, 868, 792 cm^{-1}; ^{1}H NMR (270 MHz, $CDCl_3$) *ö* 1.37 (d, 3H, ^3J = 6.5 Hz, CH_3), 1.65 (bs, 1H, OH), 4.49 (dt, ^3J = 6.5 Hz, ^3J = 5.7 Hz), 6.19 (dd, 1H, ^3J = 15.9 Hz, ^3J = 5.7 Hz), 6.44 (d, 1H, ^3J = 15.9 Hz), 6.96 (t, 2H, ^3J = 7.0 Hz); ^{13}C-NMR (67.8 MHz, $CDCl_3$) *ö* 22.0 (CH_3), 73.2 (CH), 110.2 (m), 127.9 (dd, J_{CF} = 4.5 Hz, J_{CF} = 2.2 Hz), 132.9 (m), 134.5 (d, J_{CF} = 2.2 Hz), 139.2 (J_{CF} = -252 Hz, J_{CF} = 15.1 Hz), 151.4 (m); MS (EI, 70 eV) *m/z* (%) 202 (M^+, 100), 187 (53), 169 (46). 159 (68), 145 (61). HRMS Found: 202.0602. Calcd. for $C_{10}H_9OF_3$: 202.0605.

(*E*)-4-(2,3,4-Trifluorophenyl)-but-3-en-2-ol (**4c**). – **3d** (1.25 g, 6.25 mmol), $CeCl_3$ (1.50 g, 6.25 mmol) and $NaBH_4$ (300 mg, 7.89 mmol) in MeOH (16 mL) were reacted according to general procedure A to provide **4c** (1.11 g, 89%) as a colorless oil; IR (neat) ν 3362 (bs, OH), 2970, 2924, 1608, 1512, 1312, 1144, 1037, 967, 873, 852, 801, 765, 702, 675, cm^{-1}; ^{1}H NMR (270 MHz, $CDCl_3$) *ö* 1.38 (d, 3H, ^3J = 5.9 Hz, CH_3), 1.70 (bs, 1H, OH), 4.51 (m, 1H), 6.32 (dd, 1H, ^3J = 15.9 Hz, ^3J = 5.9 Hz), 6.63 (d, 1H, ^3J = 15.9 Hz), 6.94 (m, 1H), 7.14 (m, 1H); MS (EI, 70 eV) *m/z* (%) 202 (M^+, 100), 187 (67), 169 (40), 159 (36), 145 (75). HRMS Found: 202.0602. Calcd. for $C_{10}H_9OF_3$: 202.0605.

(*E*)-4-(2,3,4,5-Tetrafluorophenyl)-but-3-en-2-ol (**4d**). – **3e** (929 mg, 4.26 mmol), $CeCl_3$ (1.10 g, 4.58 mmol) and $NaBH_4$ (300 mg, 7.89 mmol) in MeOH (16 mL) were reacted according to general procedure A to provide **4d** (872 mg, 93%) as a colorless oil; IR (neat) ν 3310 (bs, OH), 2968, 1524, 1484, 1374, 1302, 1257,

1195, 1144, 1048, 1027, 973, 948, 932 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) *ö* 1.38 (d, 3H, ^3J = 6.2 Hz, CH_3), 1.68 (bs, 1H, OH), 4.52 (m, 1H), 6.31 (dd, 1H, ^3J = 16.2 Hz, ^3J = 5.9 Hz), 6.63 (d, 1H, ^3J = 16.2 Hz), 7.04 (m, 1H); MS (EI, 70 eV) *m/z* (%) 220 (M^+, 100), 205 (78), 163 (76). HRMS Found: 220.0509. Calcd. for $C_{10}H_8OF_4$: 220.0511. Found: C, 54.58; H, 3.64%. Calcd. for $C_{10}H_8F_4O$: C, 54.55; H, 3.66%.

(*E*)-4-(2,3,5-Trifluorophenyl)-but-3-en-2-ol (**4a**). – **3b** (1.40 g, 7.0 mmol), $CeCl_3$ (1.80 g, 7.5 mmol) and $NaBH_4$ (340 mg, 8.94 mmol) in MeOH (20 mL) were reacted according to general procedure A to give **4a** (1.41 g, quant.) as a colorless oil; IR (neat) ν 3382 (bs, OH), 2972, 2928, 1633, 1603, 1490, 1454, 1354, 1204, 1122, 1058, 998, 970, 843, 782 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) *ö* 1.39 (d, 3H, ^3J = 6.5 Hz, CH_3), 1.71 (bd, 1H, ^3J = 4.1 Hz, OH), 4.53 (m, 1H), 6.37 (dd, 1H, ^3J = 16.2 Hz, ^3J = 5.9 Hz), 6.69 (d, 1H, ^3J = 16.2 Hz), 6.81 (m, 1H), 6.93 (m, 1H); MS (EI, 70 eV) *m/z* (%) 202 (M^+, 84), 187 (49), 169 (37), 159 (55). HRMS Found: 202.0605. Calcd. for $C_{10}F_9OF_3$: 202.0605.

(*E*)-4-(2,4-Difluorophenyl)-but-3-en-2-ol (**4g**). – **3h** (800 mg, 4.4 mmol), $CeCl_3$ (1.30 g, 5.4 mmol) and $NaBH_4$ (260 mg, 6.84 mmol) in a solvent mixture of MeOH (10 mL) and diethyl ether (5 mL) were reacted according to general procedure A to give **4g** (730 mg, 91%) as a colorless oil; IR (neat) ν 3348 (bs, OH), 2972, 2878, 1610, 1598, 1502, 1429, 1275, 1140, 1089, 962, 851 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) *ö* 1.38 (d, 3H, ^3J = 6.5 Hz, CH_3), 1.60 (d, 1H, ^3J = 3.9 Hz, OH), 4.50 (m, 1H), 6.28 (dd, 1H, ^3J = 16.2 Hz, ^3J = 6.5 Hz), 6.67 (d, 1H, ^3J = 16.2 Hz), 6.76 – 6.87 (m, 2H), 7.40 (m, 1H); ^{13}C-NMR (67.8 MHz, $CDCl_3$) *ö* 23.4 (CH_3), 69.0 (CH), 104.0 (dd, JCF 25.8 Hz, J_{CF} = 25.8 Hz), 111.4 (dd, J_{CF} – 20.7 Hz, J_{CF} = 2.8 Hz), 128.3 (dd, J_{CF} = 9.5 Hz, J_{CF} = 5.0 Hz), 135.8 (dd, J_{CF} = 4.5 Hz, J_{CF} = 1.7 Hz), 160.4 (dd, J_{CF} = -233 Hz, J_{CF} 12.8 Hz), 162.2 (dd, J_{CF} = -248 Hz, J_{CF} = 12.3 Hz); MS (EI, 70 eV) *m/z* (%) 184 (M^+, 82), 169 (67), 127 (100). HRMS Found: 184.0701. Calcd. for $C_{10}H_{10}OF_2$: 184.0700. Found: C, 64.87; H, 5.49%. Calcd. for $C_{10}H_{10}OF_2$.0.1 H_2O: C, 64.58; H, 5.53%.

(*E*)-4-(2,5-Difluorophenyl)-but-3-en-2-ol (**4h**). – **3k** (2.00 g, 11.0 mmol), $CeCl_3$ (3.40 g, 14.2 mmol) and $NaBH_4$ (650 mg, 17.1 mmol) in MeOH (25 mL) were reacted according to general procedure A to give **4h** (2.02 g, quant.) as a colorless oil; IR (neat) ν 3398 (bs, OH), 2970, 2928, 1621, 1590, 1492, 1431, 1370, 1272, 1235, 1199, 1144, 1059, 970, 871, 809, 730 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) *ö* 1.39 (d, 3H, ^3J = 6.5 Hz, CH_3), 1.64 (d, 1H, ^3J = 3.8 Hz, OH), 4.52 (m, 1H), 6.33 (dd, 1H, ^3J = 15.9 Hz, ^3J = 5.9 Hz), 6.69 (d, 1H, ^3J = 15.9 Hz), 6.84 – 6.93 (m, 1H), 6.95 – 7.02 (m, 1H), 7.14 (m, 1H); ^{13}C-NMR (67.8 MHz, $CDCl_3$) *ö* 23.3 (CH_3), 68.8 (CH), 113.3 (dd, J_{CF} = 24.0 Hz, J_{CF} 3.9 Hz), 115.2 (dd, J_{CF} = 24.6 Hz, J_{CF} = 8.9 Hz), 116.7 (dd, J_{CF} = 25.2 Hz, J_{CF} = 8.3 Hz), 120.8 (dd, J_{CF} = 3.4 Hz, J_{CF}= 2.2 Hz), 125.9 (dd, J_{CF} = 15.1 Hz, J_{CF} = 7.9 Hz), 137.3 (d, J_{CF} = 3.9 Hz), 156.2 (dd, J_{CF} = -245 Hz, J_{CF} = 2.2 Hz), 158.8 (dd, J_{CF} = -241 Hz, J_{CF} = 2.2 Hz); MS (EI, 70 eV) *m/z* (%) 184 (M^+, 100), 169 (57), 151 (27), 141 (43), 127 (52). HRMS Found: 184.0699. Calcd. for $C_{10}H_{10}OF_2$: 184.0700.

(*E*)-4-(3,5-Difluorophenyl)-but-3-en-2-ol (**4f**). – **3i** (1.27 g, 7.0 mmol), $CeCl_3$ (1.80 g, 7.5 mmol) and $NaBH_4$ (305 mg, 8.0 mmol) in MeOH (20 mL) were reacted according to general procedure A to give **4f** (1.08 g, 85%) as a colorless oil; IR (neat) ν 3338 (bs, OH), 2976, 2928, 1622, 1591, 1447, 1317, 1268, 1218, 1119, 1059, 965, 943, 869, 840, 758, 665 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) *ö* 1.37 (d, 3H, ^3J = 6.2 Hz, CH_3), 4.50 (m, 1H), 6.27 (dd, 1H, ^3J = 15.9 Hz, ^3J = 5.9 Hz), 6.50 (d, 1H, ^3J = 15.9 Hz), 6.68 (m, 1H), 6.87 (m, 2H); ^{13}C-NMR (67.8 MHz, $CDCl_3$) *ö* 23.4 (CH_3), 68.4 (CH), 102.7 (t, $^2J_{CF}$ = 25.7 Hz), 109.1 (2C, m), 127.2 (t, J_{CF} = 2.8 Hz), 136.2, 140.2 (t, J_{CF} = 9.6 Hz), 163.2 (2C, dd, J_{CF} = -247 Hz, J_{CF} = 12.8 Hz); MS (EI, 70 eV) *m/z* (%) 184 (M^+, 65), 169 (24), 151 (39), 141 (100), 127 (30). HRMS Found: 184.0701. Calcd. for $C_{10}H_{10}OF_2$: 184.0700. Found: C, 64.78; H, 5.43%. Calcd. for $C_{10}H_{10}OF_2$·0.1H_2O: C, 64.58; H, 5.53%.

(*E*)-4-(2,6-Difluorophenyl)-but-3-en-2-ol (**4i**). – **3L** (2.56 g, 14.1 mmol), $CeCl_3$ (4.30 g, 18.0 mmol) and $NaBH_4$ (900 mg, 23.7 mmol) in MeOH (50 mL) were reacted according to general procedure A to give **4i** (1.25 g, 49%) as a colorless oil; IR (neat) ν 3384 (bs, OH), 2924, 1621, 1586, 1470, 1263, 1233, 1201, 1142, 1061, 999, 944, 780, 715 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) *ö* 1.39 (d, 3H, ^3J = 6.5 Hz, CH_3), 1.66 (bs, 1H, OH), 4.50 (m, 1H), 6.56 (1H, d, ^3J = 16.5 Hz), 6.63 (1H, d, ^3J = 16.5 Hz); ^{13}C-NMR (67.8 MHz, $CDCl_3$) *ö* 23.3, 69.5 (CH), 111.4 (m, 2C), 114.0 (t, J_{CF} = 19.2 Hz), 115.6 (t, J_{CF} = 2.2 Hz), 128.1 (t, J_{CF} = 10.6 Hz), 140.5 (t, J_{CF} = 7.3 Hz), 160.9 (dd, J_{CF} = -250 Hz, J_{CF} = 7.8 Hz); MS (EI, 70 eV) *m/z* 184 (M^+, 100), 169 (96), 141 (53), 127 (78). HRMS Found: 184.0704. Calcd. for $C_{10}H_{10}OF_2$: 184.0700. Found: C, 64.18; H, 5.49%. Calcd. for $C_{10}H_{10}OF_2$.0.2H_2O: C, 63.96; H, 5.58%.

(*E*)-4-(3,4-Difluorophenyl)-but-3-en-2-ol (**4e**). – **3g** (1.28 g, 7.0(5) mmol), $CeCl_3$ (1.70 g, 7.1 mmol) and $NaBH_4$ (340 mg, 8.9(5) mmol) in MeOH (18 mL) were reacted according to general procedure A to give **4e** (1.17 g, 91%) as a colorless oil; IR (neat) ν 3354 (bs, OH), 2920, 1490, 1059, 965, 874, 809 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) *ö* 1.37 (d, 3H, ^3J = 6.5 Hz, CH_3), 1.57 (bs, OH), 4.48 (m, 1H), 6.18 (dd, 1H, ^3J = 15.9 Hz, ^3J = 6.2 Hz), 6.49 (d, 1H, ^3J = 15.9 Hz), 7.06 – 7.22 (m, 3H); ^{13}C-NMR (67.8 MHz, $CDCl_3$) *ö* 23.4 (CH_3), 68.6 (CH),

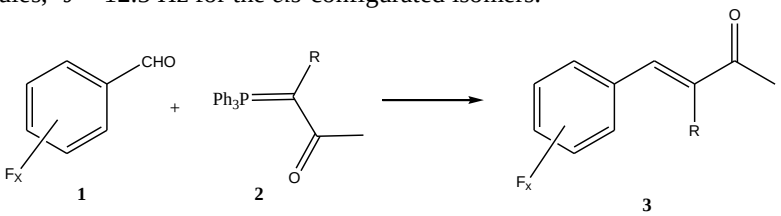
114.8 (d, J_{CF} = 17.3 Hz), 117.3 (d, J_{CF} = 16.8 Hz), 122.6 (dd, J_{CF} = 6.2 Hz, J_{CF} = 3.4 Hz), 127.3, 134.0 (dd, J_{CF} = 5.6 Hz, J_{CF} 3.9 Hz), 134.7 (d, J_{CF} = 2.2 Hz), 149.8 (dd, J_{CF} = -247 Hz, J_{CF} = 11.7 Hz), 150.5 (dd, J_{CF} = -245 Hz, J_{CF} = 10.8 Hz); MS (EI, 70 eV) *m/z* (%) 184 (M^+, 100), 169 (62), 151 (44), 141 (59), 127 (79). HRMS Found: 184.0697. Calcd. for $C_{10}H_{10}OF_2$: 184.0700.

(*E*)-3-(2,3,6-Trifluorophenyl)prop-2-en-1-ol (**6**). – **3n** (1.25 g, 6.72 mmol), $CeCl_3$ (1.73 g, 7.1 mmol) and $NaBH_4$ (285 mg, 7.5 mmol) in MeOH (18 mL) were reacted according to general procedure A to give **6** (600 mg, 48%) as a colorless oil; IR (neat) ν 3336 (bs, OH), 2922, 2860, 1491, 1455, 1244, 1097, 1045, 996, 971, 808 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) *ö*1.55 (t, 1H, ^3J = 5.9 Hz, OH), 4.39 (2H, dd, ^3J = 5.9 Hz, ^3J = 5.3 Hz), 6.64 (d, 1H, ^3J = 16. 2 Hz), 6.70 (dd, 1H, ^3J = 16.2 Hz, ^3J = 5.3 Hz), 6.81 (m, 1H), 6.99 (m, 1H); MS (EI, 70 eV) *m/z* (%) 188 (M^+, 100), 145 (93), 127 (60). HRMS Found: 188.0452. Calcd. for $C_9H_7OF_3$: 188.0449.

3,4,5-Trifluorophenylbutan-2-one (**7**). – A solution of **4b** (225 mg, 1.12(5) mmol) in MeOH/ether (10 mL/5mL) was stirred under a hydrogen atmosphere over Pd/C (25 mg) for 14h at rt. The mixture was filtered, the filter was washe washed with $CHCl_3$ (5 mL), and the organic phase was concentrated *in vacuo*. Column chromatography of the residue on silica gel (hexane/$CHCl_3$/ether 8:1:1) gave **7** (212 mg, 94%) as a colorless oil; IR (neat) ν 2924, 1720 (C=O), 1621, 1528, 1450, 1360, 1235, 1164, 1055, 1028, 865, 830, 782, 705, 653 cm^{-1}; ^1H NMR (270 MHz, $CDCl_3$) *ö* 2.15 (s, 3H, CH_3), 2.72 (m, 2H), 2.85 (m, 2H), 6.79 (m, 2H); ^{13}C-NMR (67.8 MHz, $CDCl_3$) *ö* 28.8 (CH_3), 30.0 (CH_2), 44.2 (CH_2), 112.3 (m), 137.3 (m), 138.2 (m), 151.1 (ddd, J_{CF} = -249 Hz, J_{CF} 9.5 Hz, J_{CF} 4.5 Hz), 206.6 (C_{quat}, CO); MS (EI, 70 eV) *m/z* (%) 202 (M^+, 100), 159 (50), 145 (53). HRMS Found: 202.0607. Calcd. for $C_{11}H_9OF_3$: 202.0605.

III. Results And Discussion

Fluorinated phenylalk-3-en-2-ones (**3a-L**) and 2,3,6-trifluorophenylpropenal **3n** were prepared by solventless Wittig reaction. Phosphoranes **2a**, **2b**, and **2c** are stabilized phosphoranes that are inert to water and air, even at slightly elevated temperatures. Thus, the choice of solvent for Wittig reactions with these phosphoranes is wide, where also solventless Wittig reactions are known [11]. In the present case, the reactions are exothermic, which speaks for the high reactivity of the fluorinated benzaldehydes **1** as phosphoranes **2a** – **2c** are known to be little reactive. The Wittig olefination reactions are run at 100 °C with the help of external heating and are complete after 40 min. The reactions deliver the *E*-alkenes in high selectively. Where *Z*-isomer is formed, it can be separated from the *E*-isomer by column chromatography. *E*- and *Z*-stereochemistry of the molecules could be ascertained by the coupling constant between the two olefinic protons, ^3J = 16 Hz for *trans*-configurated molecules, ^3J = 12.5 Hz for the *cis*-configurated isomers.

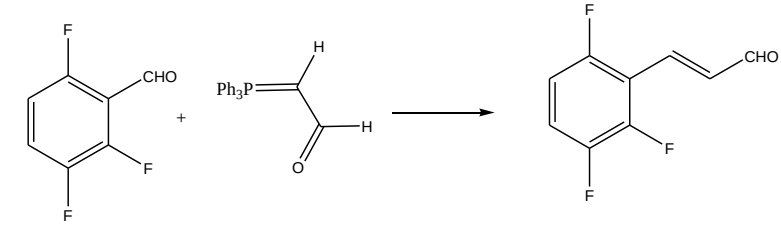


1 **2** **3**

1a: 2,3-F_2
1b: 2,3,5-F_3
1c: 3,4,5-F_3
1d: 2,3,4-F_3
1e: 2,3,4,5-F_4
1c: 3,4,5-F_3
1f: 3,4-F_2
1g: 3,5-F_2
1h: 2,5-F_2
1i: 2,4-F_2
1k: 2,6-F_2

2a: R = H
2a: R = H
2a: R = H
2a: R = H
2a: R = H
2b: R = CH_3
2a: R = H
2a: R = H
2a: R = H
2a: R = H
2a: R = H

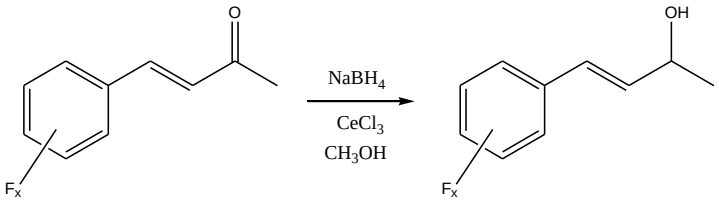
3a: 2,3-F_2, R = H (*E*-isomer: 90%) [7]
3b: 2,3,5-F_3, R = H (*E*-isomer: 90%) [7]
3c: 3,4,5-F_3, R = H (*Z*/*E*-isomer: 7/87%) [7]
3d: 2,3,4-F_3, R = H (Z/E-isomer: 8/87%) [7]
3e: 2,3,4,5-F_4, R = H (Z/E-isomer: 6/80%) [7]
3f: 3,4,5-F_3, R = CH_3 (*E*-isomer: 94%)
3g: 3,4-F_2, R = H (*E*-isomer: 92%) [7]
3h: 3,5-F_2, R = H (Z/E-isomer: 8/86%) [7]
3i: 2,5-F_2, R = H (*Z*/*E*-isomer: 3/93%)
3k: 2,4-F_2, R = H (*E*-isomer: 94%)
3L: 2,6-F_2, R = H (*E*-isomer: quant.) [7]



1L **2c** **3n** (70%) [7]

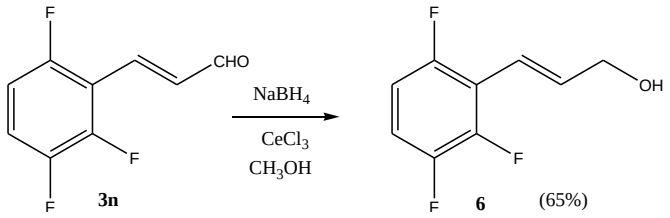
Scheme 2. Solventless Wittig reaction of fluorinated benzaldehydes

There are few papers concerning the reduction of fluoroarylalk-3-en-2-ones **3** to fluoroarylalk-3-en-2-ols **4** and these are limited to monofluorinated arylalkenones. Thus, P. He et al. uses a *N*,*N*-dioxocyclopenta[b]pyrrole-2-carboxamide scandium complex as a chiral Lewis acid; in this case KBH_4 acts as reducing agent and the reaction is run in THF/H_2O [12]. The group of M. P. Watson uses (*S*)-(-)2-butyl-CBS-oxazaborolidine as chiral ligand with catecholborane as reductant [13,14]. There is also one enzymatic reduction known utilizing alcohol dehydrogenase (*Rhodococcus erythropolis*) – NADH [15]. In all three, the reduction of the carbonyl group is stereoselective [16]. Less selective is the reduction of fluorophenylalkenones with Noyori's Ru-TsDPEN complex in the presence of sodium formate in water. Here, predominately the olefinic moiety is reduced. In all the cases above, 4-fluoro- and 3-fluorophenylbut-3-en-2-one were used as substrate, exclusively [12-17].



3b: 2,3,5-F_3, R = H
3c: 3,4,5-F_3, R = H
3d: 2,3,4-F_3, R = H
3e: 2,3,4,5-F_4, R = H
3g: 3,4-F_2, R = H
3i: 2,5-F_2, R = H
3h: 3,5-F_2, R = H
3k: 2,4-F_2, R = H
3L: 2,6-F_2, R = H

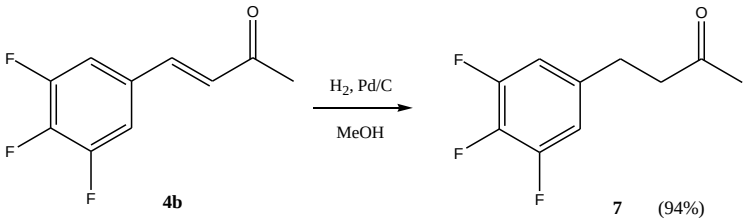
4a: 2,3,5-F_3, R = H (> 99%)
4b: 3,4,5-F_3, R = H (87%)
4c: 2,3,4-F_3, R = H (89%)
4d: 2,3,4,5-F_4, R = H (93%)
4e: 3,4-F_2, R = H (91%)
4f: 3,5-F_2, R = H (85%)
4g: 2,4-F_2, R = H (91%)
4h: 2,5-F_2, R = H (> 99%)
4i: 2,6-F_2, R = H (49%)



3n **6** (65%)

Scheme 3. Luche reduction of fluorophenylbut-3-en-2-ones **3**

In the present case, Luche reduction ($NaBH_4$, $CeCl_3$, MeOH, 0°C [6]) furnished the fluorophenylbut-3-en-2-ols **4** in good yield. As is often with Luche reductions, the reactions were complete in 5 min. Analogously, (*E*)-3-(2,3,6-trifluorophenyl)prop-2-en-1-ol (**6**) was prepared. In none of the reactions was hydrogenation of the olefinic moiety observed. For 3,4,5-trifluorophenylbut-3-en-2-one (**4b**), 3,4,5-trifluorophenylbutan-2-one (**7**) was prepared by hydrogenation (H_2, Pd/C) and used as an indicator of potential hydrogenation of the double bond in the Luche reduction. No hydrogenation product was observed.



4b **7** (94%)

Scheme 4. Preparation of 3,4,5-trifluorophenylbutan-2-one (**7**) as comparative sample in the search for hydrogenated products in the Luche reduction of **3**

IV. Conclusion

A number of fluorinated phenylbut-3-en-2-ols **4** and 2,3,6-trifluorophenylpropenol (**6**) were prepared by Wittig reaction of commercially available fluorinated benzaldehydes **1** and phosphoranes **2a 2b**, and **2c**, followed by Luche reduction. The phenylbut-3-en-2-ols **4** are to be used as starting materials for the preparation of 1-(fluorophenyl)buta-1,3-dienes **5**.

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