Ultrasound Accelerated Coupling Reaction of Grignard Reagents with 1,3-Dioxolanes of α,β-Unsaturated Aldehydes

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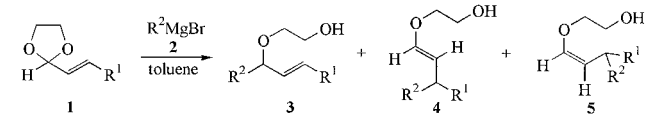
Owing to their stability under basic conditions, acetals are commonly employed as protecting groups for aldehydes and ketones against organometallic nucleophiles.[1,2] Acetals derived from α,β-unsaturated aldehydes are generally more reactive than the saturated ones. An α,β-unsaturated acetal may be cleaved by direct substitution with a nucleophile at the acetal carbon (C1) affording the S_N2 type product or by attack at C3 with concomitant migration of the double bond producing the S_N2' type product. For example, Grignard reagents react with α,β-unsaturated acetals at high temperatures[3] or in the presence of titanium tetrachloride[4] to give mixtures of the S_N2 and S_N2' type products. Depending on the reagent and the reaction conditions, alkyllithiums react with α,β-unsaturated acetals to furnish several types of products.[5] Organolithium reagents add to α,β-ethylenic acetals in the presence of Lewis acid to afford the S_N2' type products exclusively.[6] The use of organocopper and cuprate reagents with Lewis acid generates a mixture of C1- and C3-substituted products.[7] Organoaluminum compounds react with α,β-unsaturated acetals to give either S_N2 or S_N2' type compounds as the major products depending on the reaction conditions.[8]

Scheme 1



1a $R^1 = C_6H_5$ **2a** $R^2 = CH_3$
1b $R^1 = C_3H_7$ **2b** $R^2 = C_2H_5$
1c $R^1 = CH_3$ **2c** $R^2 = n\text{-}C_4H_9$
2d $R^2 = CH_2CH{=}CH_2$

Table 1. Addition of Grignard Reagents to 1,3-Dioxolanes of α,β-Unsaturated Aldehydes at −78 °C

entry	acetal	R^2M	method[a]	recovered SM (%)[b]	yield (%)[b,c]	ratio[b] **3**:**4**+**5**
1	**1a**	**2a**	A	99	1	-:-
2	**1a**	**2a**	B	92	8	>99.9:<0.1
3	**1a**	**2b**	A	91	9	91:9
4	**1a**	**2b**	B	40	54	90:10
5	**1a**	**2d**	A	95	5	83:17
6	**1a**	**2d**	B	93	7	86:14
7	**1b**	**2a**	A	98	2	-:-
8	**1b**	**2a**	B	60	40	>99.9:<0.1
9	**1b**	**2b**	A	84	16	97:3
10	**1b**	**2b**	B	28	72	96:4
11	**1b**	**2d**	A	99	1	-:-
12	**1b**	**2d**	B	69	31	89:11
13	**1c**	**2a**	A	94	6	-:-
14	**1c**	**2a**	B	63	37	>99.9:<0.1
15	**1c**	**2b**	A	78	22	95:5
16	**1c**	**2b**	B	37	63	95:5
17	**1c**	**2d**	A	77	16	81:19
18	**1c**	**2d**	B	55	36	86:14

[a] The reaction was carried out with 3 equiv of the Grignard reagent either under stirring (method A) or under ultrasound irradiation (method B) for 3 h. [b] Determined by GC-MS. [c] Except for starting material and/or product of low boiling point (e.g. entries 13−16), the isolated yields are usually very close to the yields estimated by GC-MS.

The requirement of Lewis acid or elevated temperatures to carry out the coupling of α,β-unsaturated acetals with organometallic reagents is one of the major limitations of the reaction which renders it incompatible with acid- or heat-sensitive functionalities. Because of our successes in the use of sonochemical conditions in accelerating the 1,3-dipolar cycloaddition of nitrile oxides to 1,3-dioxolanes of α,β-unsaturated aldehydes,[9] we decided to investigate the coupling reactions of organometallic nucleophiles with these acetals under sonication. Herein we wish to describe a high-yield substitution reaction of 1,3-dioxolanes of α,β-unsaturated aldehydes with Grignard reagents under mild conditions (Scheme 1).

The reactions of several readily available unsaturated dioxolanes[10] and Grignard reagents were studied under thermal and sonochemical conditions to determine the effect of ultrasound on both the reactivity and the regioselectivity of the reaction. As shown in Table 1, in the absence of Lewis acid, methyl-, ethyl-, and allylmag-

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Table 2. Addition of Grignard Reagents to 1,3-Dioxolanes of α,β-Unsaturated Aldehydes at −60 °C

entry	acetal	R^2M	method[a]	recovered SM (%)[b]	yield (%)[b,c]	ratio[b] **3**:**4**+**5**
1	**1a**	**2a**	A	91	4	-:-
2	**1a**	**2a**	B	1	99 (98)	>99.9:<0.1
3	**1a**	**2b**	A	73	27	89:11
4	**1a**	**2b**	B	0	100 (98)	89:11
5	**1a**	**2d**	A	91	9	81:19
6	**1a**	**2d**	B	38	62 (61)	82:18
7	**1b**	**2a**	A	95	5	-:-
8	**1b**	**2a**	B	0	100 (95)	>99.9:<0.1
9	**1b**	**2b**	A	45	55	96:4
10	**1b**	**2b**	B	0	100 (98)	97:3
11	**1b**	**2d**	A	83	17	84:16
12	**1b**	**2d**	B	0	100 (97)	85:15
13	**1c**	**2a**	A	93	7	-:-
14	**1c**	**2a**	B	4	96 (84)	>99.9:<0.1
15	**1c**	**2b**	A	37	63	90:10
16	**1c**	**2b**	B	0	100 (90)	90:10
17	**1c**	**2d**	A	66	23	82:18
18	**1c**	**2d**	B	0	100 (96)	83:17

[a] The reaction was carried out with 3 equiv of the Grignard reagent either under stirring (method A) or under ultrasound irradiation (method B) for 3 h. [b] Determined by GC-MS. [c] The number in the parentheses is isolated yield.

nesium bromides reacted poorly with these dioxolanes at −78 °C (bath temperature), to give coupling products in low yields. Acceleration and thus improvement of the yields of the coupling reactions could be achieved by ultrasound irradiation. However, only the yield of the reaction of ethylmagnesium bromide could be brought to synthetically useful range at this temperature. Moreover, the reaction of *n*-butyl Grignard reagent with several unsaturated dioxolanes was found to be extremely sluggish at −78 °C even with sonication, resulting in nearly complete recovery of the starting acetals.

Due to the low reactivity of Grignard reagents with 1,3-dioxolanes of α,β-unsaturated aldehydes at −78 °C, the reaction was conducted at −60 °C (Table 2). Although the reaction still proceeded slowly without the assistance of ultrasound, the reaction rate was accelerated dramatically under sonication in the absence of Lewis acid. Excellent yields of the coupling products were realized which rendered the reaction synthetically valuable. Again, ethyl Grignard reagent exhibited the highest reactivity among all the Grignard reagents studied and gave the best results. It is also noteworthy that ultrasound not only enhances the reaction rate but also affords a cleaner reaction as indicated by the ^{1}H NMR spectrum of the crude reaction mixture.

In principle, three types of products could result from the reaction, i.e., the S_N2 type **3**, and the S_N2' types **4** (trans) and **5** (cis). Under the reaction conditions, good to excellent regioselectivities are accomplished, with the S_N2 type products predominanting. These results are far superior to the reported cases.[3] In most cases all three coupling products can be observed except in the case of methyl Grignard where only the 1,2-adduct could be detected. Similar regioselectivities were observed when the reactions were carried out at −60 °C and −78 °C (Table 1 and Table 2). The regioselectivity decreases as the size of the attacking nucleophile increases from methyl to ethyl and to allyl Grignard. The *E*/*Z* ratios of the S_N2' type products are generally in favor of the *E*-isomer.[11,12] The S_N2' products are extremely labile and isomerize readily to the saturated dioxolanes upon standing.[13]

To explore the utility of the reaction, other acetal or ether type protecting groups were treated with the most reactive Grignard, ethylmagnesium bromide, at −78° and −60 °C under sonication for 3 h. Thus, when the dioxolane of cyclohexanecarboxaldehyde and the methoxymethyl (MOM) ethers and the trimethylsilyl (TMS) ethers of 1-nonanol and 1-decanol were reacted with ethylmagnesium bromide, respectively, only the starting materials were recovered intact. Accordingly, saturated dioxolane, MOM ethers, and TMS ethers are stable and can tolerate the reaction conditions. It is noteworthy that nonconjugated dioxolanes and conjugated dioxolanes can be differentiated using this reaction.

Thus ultrasound irradiation has proven to be effective in enhancing the reactivity of organomagnesium reagents toward 1,3-dioxolanes of α,β-unsaturated aldehydes and is an efficient alternative to traditional heating or strongly acidic conditions. Consequently, a practical and synthetically useful reaction, employing Grignard reagents and unsaturated acetals, generating allylic ethers in high yields has been established. Unlike the previously reported procedures which required harsh reaction conditions, the current method requires no Lewis acid catalysis and uses considerably milder reaction conditions.

Experimental Section

Melting points are uncorrected. ^{1}H and ^{13}C NMR spectra ($CDCl_3$ solutions) were measured on a 300 MHz spectrometer. Solvents and reagents were dried prior to use as required. Diethyl ether solutions of methylmagnesium bromoride (3.0 M), ethylmagnesium bromoride (3.0 M), and allylmagnesium bromoride (1.0 M) were purchased from Aldrich. *n*-Butylmagnesium bromoride (2.0 M/THF) was prepared from *n*-butyl bromide and magnesium. Flash chromatography was carried out utilizing silica gel 60, 70−230 mesh ASTM. Medium-pressure liquid chromatography was carried out using Merck Lobar prepacked silica gel columns and a Fluid Metering, Inc. pump. The ratio of the recovered starting material to the S_N2 and S_N2' type products was determined by the GC-MS chromatogram of the crude reaction mixture using a 15 m × 0.22 mm i.d. DB5 capillary column (J&W; 1.0 mm film thickness) and He as carrier gas.

General Procedure. A flat-bottomed, cylindrical, two-necked reaction vessel (7 cm × 2 cm o.d.) containing a solution of the unsaturated acetal (1.0 mmol) in toluene (1.0 mL) was placed in a cold-bath at the temperature specified in the Tables. A titanium microtip (∅ 3 mm)[14] was directly connected to the horn of an ultrasonic processor (Vibracel, Sonic & Materials, 50 W) probe transducer. The microtip was attached to the reaction vessel through a PTFE universal adapter (14/20 joint). A solution of the Grignard reagent (3 equiv) was then added slowly via a syringe to the reaction vessel, and the immersion depth of the microtip was adjusted to achieve maximum acoustic inten-

(11) In most of the cases studied, the amount of the *Z*-products was to little to be isolated and can be barely seen in the GC-MS chromatogram of the crude reaction.

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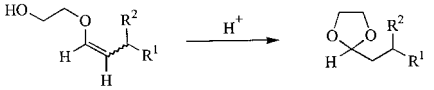
(13) Similar observations have been reported, see refs 5b and 6.



(14) To rule out the possibility of catalysis by the titanium microtip, controlled reactions were performed under the same conditions except the power of the ultrasonic processor was not turned on. The unsaturated dioxolanes were recovered under these reaction conditions.

sity. The reaction was irradiated with the power amplitude adjusted at 100%. After 2 h, the ultrasonic processor was turned off for 15 min to cool it down, and the processor was switched on for another 45 min making the total reaction time 3 h. The reaction was quenched by the addition of saturated aqueous ammonium chloride solution (7 mL) and was extracted with diethyl ether (7 mL × 3). The combined organic layer was washed successively with saturated $NaHCO_3$ (7 mL × 1) and brine (7 mL × 1), dried ($MgSO_4$), and concentrated. The crude reaction mixture was purified by flash column chromatography (hexane/EtOAc) to furnish the desired products.

(1*E*)-1-Phenyl-3-(2-hydroxyethoxy)-1-butene (3aa). Starting with the dioxolane of *trans*-cinnamaldehyde (**1a**), and methylmagnesium bromide (**2a**), the title compound (188 mg, 98%) was obtained after purification. ^{1}H NMR δ 7.42−7.21 (m, 5H), 6.53 (d, J = 16.1 Hz, 1H), 6.11 (dd, J = 16.1, 7.2 Hz, 1H), 4.06 (q′, J = 7.2 Hz, 1H), 3.77−3.44 (m, 4H), 2.23 (br, 1H), 1.36 (d, J = 6.5 Hz, 3H); ^{13}C NMR δ 136.4 (s), 131.3 (d), 128.5 (d), 127.7 (d), 126.4 (d), 77.0 (d), 69.3 (t), 61.9 (t), 21.5 (q); IR (NaCl, neat): 3418 (br), 1662 (m), 750 (s), 696 (s) cm^{-1}; MS: *m*/*z* 192 (3.9%), 177 (9.0%), 147 (17.1%), 131 (93.9%), 115 (84.2%), 91 (52.7%), 77 (43.5%). Anal. Calcd for $C_{12}H_{16}O_2$: C, 74.97; H, 8.39. Found: C, 74.84; H, 8.38.

(1*E*)-3-(2-Hydroxyethoxy)-1-phenyl-1-pentene (3ab). Using the dioxolane of *trans*-cinnamaldehyde (**1a**), and ethylmagnesium bromide (**2b**), the title compound (179 mg, 87%) was obtained after purification. ^{1}H NMR δ 7.42−7.21 (m, 5H), 6.53 (d, J = 16.1 Hz, 1H), 6.06 (dd, J = 16.1, 8.1 Hz, 1H), 3.83−3.41 (m, 5H), 2.06 (br, 1H), 1.83−1.53 (m, 2H), 0.95 (t, J = 7.5 Hz, 3H); ^{13}C NMR δ 136.5 (s), 132.4 (d), 130.2 (d), 128.6 (d), 127.7 (d), 126.4 (d), 82.8 (d), 69.5 (t), 62.0 (t), 28.6 (t), 9.8 (q); IR (NaCl, neat): 3418 (br), 1657 (m), 750 (s), 696 (s) cm^{-1}; MS: *m*/*z* 206 (4.5%), 177 (100%), 145 (41.2%), 133 (87.7%), 115 (85.3%); HRMS calcd for $C_{13}H_{18}O_2$: 206.1307; found: 206.1304. Anal. Calcd for $C_{13}H_{18}O_2$: C, 75.69; H, 8.79. Found: C, 75.54; H, 8.88.

(1*E*)-1-(2-Hydroxyethoxy)-3-phenyl-1-pentene (4ab). The title compound (22 mg, 11%) was obtained after purification. ^{1}H NMR δ 7.36−7.12 (m, 5H), 6.30 (d, J = 12.6 Hz, 1H), 4.98 (dd, J = 12.6, 8.1 Hz, 1H), 3.85−3.72 (m, 4H), 3.04 (q, J = 8.1 Hz, 1H), 1.90 (br, 1H), 1.80−1.60 (m, 2H), 0.86 (t, J = 7.4 Hz, 3H), ^{13}C NMR δ 146.0 (d), 145.9 (s), 128.4 (d), 127.3 (d), 126.0 (d), 109.1 (d), 70.2 (t), 61.4 (t), 46.3 (d), 29.7 (t), 12.1 (q); IR (NaCl, neat): 3418 (br), 1647 (s) 758, 701 (s) cm^{-1}; MS: *m*/*z* 206 (10.0%), 177 (100%), 144 (6.1%), 115 (93.8%), 91 (32.8%), 77 (13.7%). Anal. Calcd for $C_{13}H_{18}O_2$: C, 75.69; H, 8.79. Found: C, 75.81; H, 8.82.

(1*E*)-3-(2-Hydroxyethoxy)-1-phenyl-1-heptene (3ac). Employing the dioxolane of *trans*-cinnamaldehyde (**1a**), and butylmagnesium bromide (**2c**), the title compound (77 mg, 33%) was obtained after purification.[15] ^{1}H NMR δ 7.43−7.21 (m, 5H), 6.52 (d, J = 15.9 Hz, 1H), 6.06 (dd, J = 15.9, 7.4 Hz, 1H), 3.84 (q, J = 7.4 Hz, 1H), 3.77−3.40 (m, 4H), 2.03 (s, 1H), 1.80−1.24 (m, 6H), 0.90 (t, J = 6.9 Hz, 3H); ^{13}C NMR δ 136.5 (s), 132.2 (d), 130.5 (d), 128.6 (d), 127.7 (d), 126.5 (d), 81.5 (d), 69.4 (t), 62.1 (t), 35.5 (t), 27.6 (t), 22.7 (t), 14.0 (q); IR (NaCl, neat): 3421 (br), 1716 (s) cm^{-1}; 750 (s), 696 (s) cm^{-1}; MS: *m*/*z* 234 (5.1%), 189 (3.5%), 177 (100%), 115 (75.7%), 91 (40.1%); HRMS calcd for $C_{15}H_{22}O_2$ 234.1619; found 234.1625. Anal. Calcd for $C_{15}H_{22}O_2$: C, 76.88; H, 9.46. Found: C, 76.54; H, 9.46.

(1*E*)-1-(2-Hydroxyethoxy)-3-phenyl-1-heptene (4ac). The title compound (16 mg, 7%) was obtained after purification.[15] ^{1}H NMR δ 7.35−7.15 (m, 5H), 6.29 (dd, J = 12.6, 0.6 Hz, 1H), 4.97 (dd, J = 12.6, 8.1 Hz, 1H), 3.82−3.70 (m, 4H), 3.12 (q, J = 8.1 Hz, 1H), 1.98 (br, 1H), 1.71−1.60 (m, 2H), 1.36−1.22 (m, 4H), 0.87 (t, J = 6.6 Hz, 3H); ^{13}C NMR δ 145.8 (d), 128.3 (d), 127.2 (d), 125.9 (d), 109.3 (d), 70.1 (t), 61.4 (t), 44.5 (q), 36.6 (t), 29.8 (t), 22.6 (t), 14.0 (q); IR (NaCl, neat): 3429 (br), 1750 (s); 760 (s), 699 (s) cm^{-1}. MS: *m*/*z* 234 (4.4%), 218 (0.4%), 91 (35.2%); HRMS calcd for $C_{15}H_{22}O_2$ 234.1620; found 234.1614.

(1*E*)-3-(2-Hydroxyethoxy)-1-phenyl-1,5-hexadiene (3ad). Beginning with the dioxolane of *trans*-cinnamaldehyde (**1a**), and allylmagnesium bromide (**2d**), the title compound (109 mg, 50%) was obtained after purification. ^{1}H NMR δ 7.42−7.21 (m, 5H), 6.55 (d, J = 15.5 Hz, 1H), 6.09 (dd, J = 15.5, 8.1 Hz, 1H), 5.85 (ddt, J = 17.4, 10.2, 7.2 Hz, 1H), 5.17−5.06 (m, 2H), 3.93 (q, J = 7.2 Hz, 1H), 3.76−3.42 (m, 4H), 2.54−2.32 (m, 2H), 2.02 (s, 1H); ^{13}C NMR δ 136.2 (s), 134.2 (d), 132.3 (d), 129.4 (d), 128.4 (d), 127.6 (d), 126.3 (d), 117.2 (t), 80.6 (d), 69.5 (t), 61.6 (t), 40.1 (t); IR (NaCl, neat): 3419 (br), 1641 (s), 750 (s), 696 (s) cm^{-1}; MS: *m*/*z* 217 (0.1%), 177 (100%), 157 (5.4%), 115 (87.7%), 91 (18.7%), 77 (10.9%); HRMS calcd for $C_{14}H_{18}O_2$: 218.1307; found: 218.1306. Anal. Calcd for $C_{14}H_{18}O_2$: C, 77.03; H, 8.31. Found: C, 77.09; H, 8.33.

(1*E*)-1-(2-Hydroxyethoxy)-3-phenyl-1,5-hexadiene (4ad). The title compound (24 mg, 11%) was obtained after purification. ^{1}H NMR δ 7.34−7.15 (m, 5H), 6.29 (dd, J = 12.6, 0.6 Hz, 1H), 5.71 (ddt, J = 17.1, 10.2, 6.6 Hz, 1H), 5.08−4.93 (m, 3H), 3.83−3.74 (m, 4H), 3.26 (q, J = 7.8 Hz, 1H), 2.52−2.34 (m, 2H), 1.93 (br, 1H); ^{13}C NMR δ 146.3 (d), 144.9 (s), 136.6 (d), 128.4 (d), 127.3 (d), 126.1 (d), 116.2 (t), 108.4 (d), 70.2 (t), 61.4 (t), 44.5 (d), 41.2 (t); MS: *m*/*z* 218 (3.0%), 177 (85.3%), 156 (4.0%), 115 (68.6%), 91 (25.0%). HRMS calcd for $C_{14}H_{18}O_2$ 218.1307; found 218.1314. Anal. Calcd for $C_{14}H_{18}O_2$: C, 77.03; H, 8.31. Found: C, 77.12; H, 8.28.

(3*E*)-2-(2-Hydroxyethoxy)-3-heptene (3ba). Starting with the dioxolane of *trans*-2-hexenal (**1b**), and methylmagnesium bromide (**2a**), the title compound (150 mg, 95%) was obtained after purification. ^{1}H NMR δ 5.60 (dt, J = 15.4, 7.2 Hz, 1H), 5.33 (ddt, J = 15.4, 7.5, 1.2 Hz, 1H), 3.83 (q′, J = 7.5 Hz, 1H), 3.75−3.35 (m, 4H), 2.29 (s, 1H), 2.01 (qd, J = 7.2, 1.2 Hz, 2H), 1.40 (sextet, J = 7.2 Hz, 2H), 1.25 (d, J = 7.5 Hz, 3H), 0.90 (t, J = 7.2 Hz, 3H); ^{13}C NMR δ 133.0 (d), 131.8 (d), 77.0 (d), 69.0 (t), 61.8 (t), 34.1 (t), 22.2 (t), 21.5 (q), 13.5 (q); IR (NaCl, neat): 3404 (br), 1661 (m) cm^{-1}; MS: *m*/*z* 158 (4.6%), 143 (22.4%), 129 (4.7%), 115 (53.4%), 97 (59.0%), 55 (100%) HRMS calcd for $C_9H_{18}O_2$ 158.1307; found 158.1305.

(4*E*)-3-(2-Hydroxyethoxy)-4-octene (3bb). Using the dioxolane of *trans*-2-hexenal (**1b**), and ethylmagnesium bromide (**2b**), the title compound (164 mg, 95%) was obtained after purification. ^{1}H NMR δ 5.60 (dt, J = 15.2, 6.9 Hz, 1H), 5.26 (ddt, J = 15.2, 8.1, 1.4 Hz, 1H), 3.75−3.33 (m, 5H), 2.03 (qd, J = 6.9, 1.4 Hz, 2H), 1.72−1.57 (m, 2H), 1.56−1.35 (m, 2H), 0.90 (t, J = 7.5 Hz, 3H), 0.89 (t, J = 7.5 Hz, 3H); ^{13}C NMR δ 134.2 (d), 130.6 (d), 82.9 (d), 69.0 (t), 62.0 (t), 34.3 (t), 28.5 (t), 22.4 (t), 13.6 (q), 9.9 (q); IR (NaCl, neat): 3421 (br), 1668 (m) cm^{-1}; MS: *m*/*z* 172 (1.1%), 143 (100%), 111 (30.7%), 99 (52.7%); HRMS calcd for $C_{10}H_{20}O_2$ 172.1463; found 172.1460. Anal. Calcd for $C_{10}H_{20}O_2$: C, 69.72; H, 11.70. Found: C, 69.62; H, 11.83.

(1*E*)-3-Ethyl-1-(2-hydroxyethoxy)-1-hexene (4bb). The title compound (5 mg, 3%) was obtained after purification. ^{1}H NMR δ 6.19 (d, J = 12.4 Hz, 1H), 4.51 (dd, J = 12.4, 9.6 Hz, 1H), 3.86−3.71 (m, 4H), 1.96 (t, J = 7.2 Hz, 1H), 1.80−1.65 (m, 6H), 0.86 (t, J = 7.5 Hz, 3H), 0.82 (t, J = 7.2 Hz, 3H); ^{13}C NMR δ 145.6 (d), 109.6 (d), 70.0 (t), 61.5 (t), 39.8 (d), 38.0 (t), 28.7 (t), 20.2 (t), 13.9 (q), 11.5 (q); MS: *m*/*z* 172 (30.2%), 143 (79.7%), 129 (87.3%), 67 (17.0%); HRMS calcd for $C_{10}H_{20}O_2$ 172.1463; found 172.1465.

(4*E*)-6-(2-Hydroxyethoxy)-4-decene (3bc). Employing the dioxolane of *trans*-2-hexenal (**1b**), and butylmagnesium bromide (**2c**), the title compound (86 mg, 43%) was obtained after purification.[15] ^{1}H NMR δ 5.59 (dt, J = 15.6, 7.0 Hz, 1H), 5.27 (ddt, J = 15.6, 8.4, 1.5 Hz, 1H), 3.75−3.32 (m, 5H), 2.14 (s, 1H), 2.03 (q, J = 7.0 Hz, 2H), 1.70−1.21 (m, 8H), 0.90 (t, J = 7.2 Hz, 3H), 0.89 (t, J = 6.6 Hz, 3H); ^{13}C NMR δ 134.0 (d), 130.8 (d), 81.6 (d), 69.0 (t), 62.0 (t), 35.4 (t), 34.2 (t), 27.7 (t), 22.6 (t), 22.3 (t), 14.0 (q), 13.6 (q); IR (NaCl, neat): 3423 (br), 1669 (m) cm^{-1}. MS: *m*/*z* 200 (1.9%), 171 (1.3%), 157 (8.2%), 143 (100%), 139 (11.0%), 81 (14.9%), 57 (85.0%); HRMS calcd for $C_{12}H_{24}O_2$ 200.1776; found 200.1783. Anal. Calcd for $C_{12}H_{24}O_2$: C, 71.95; H, 12.08. Found: C, 71.75; H, 12.12.

(1*E*)-1-(2-Hydroxyethoxy)-3-propyl-1-heptene (4bc). The title compound (6 mg, 3%) was obtained after purification.[15] ^{1}H NMR δ 6.19 (d, J = 12.5 Hz, 1H), 4.52 (dd, J = 12.5, 9.6 Hz, 1H), 3.86−3.74 (m, 4H), 1.99 (s, 1H), 1.88−1.73 (m, 1H), 1.40−1.10 (m, 10H), 0.88 (t, J = 6.9 Hz, 3H), 0.86 (t, J = 6.3 Hz, 3H); ^{13}C NMR δ 145.3 (d), 109.9 (d), 70.1 (t), 61.5 (t), 38.5 (t), 38.1 (d), 35.9 (t), 29.5 (t), 22.8 (t), 20.3 (t), 14.1 (q); IR (NaCl, neat): 3388 (br), 1649 (s) cm^{-1}; MS: *m*/*z* 200 (1.9%), 171 (1.3%), 157 (8.2%), 143 (100%), 139 (11.0%), 81 (14.9%), 57 (85.0%). Anal. Calcd for $C_{12}H_{24}O_2$: C, 71.95; H, 12.08. Found: C, 71.85; H, 12.18.

(15) The reaction was conducted at room temperature for 10 h under sonication.

(5*E*)-4-(2-Hydroxyethoxy)-1,5-nonadiene (3bd). Beginning with the dioxolane of *trans*-2-hexenal (**1b**), and allylmagnesium bromide (**2d**), the title compound (151 mg, 82%) was obtained after purification. ^{1}H NMR δ 5.80 (ddt, J = 15.5, 10.2, 6.9 Hz, 1H), 5.62 (dt, J = 15.5, 7.2 Hz, 1H), 5.31 (ddt, J = 15.5, 8.4, 1.2 Hz, 1H), 5.14−5.02 (m, 2H), 3.75−3.33 (m, 5H), 2.44−2.20 (m, 2H), 2.03 (qd, J = 7.2, 1.2, 2H), 1.68 (s, 1H), 1.41 (sextet, J = 7.2 Hz, 2H), 0.90 (t, J = 7.2 Hz, 3H); ^{13}C NMR δ 134.8 (d), 134.3 (d), 130.1 (d), 116.9 (t), 80.8 (d), 69.1 (t), 61.9 (t), 40.3 (t), 34.2 (t), 22.3 (t), 13.6 (q); IR (NaCl, neat): 3417 (br), 1642 (s) cm^{-1}; MS: *m*/*z* 143 (100%), 123 (4.7%), 99 (30.5%). HRMS calcd for $C_{11}H_{20}O_2$ 184.1463; found 184.1467. Anal. Calcd for $C_{11}H_{20}O_2$: C, 71.70; H, 10.94. Found: C, 71.29; H, 10.73.

(1*E*)-1-(2-Hydroxyethoxy)-3-propyl-1,5-hexadiene (4bd). The title compound (28 mg, 15%) was obtained after purification. ^{1}H NMR δ 6.22 (d, J = 12.8 Hz, 1H), 5.84−5.69 (m, 1H), 5.04−4.95 (m, 2H), 4.57 (dd, J = 12.8, 9.0 Hz, 1H), 3.85−3.74 (m, 4H), 2.17−1.90 (m, 4H), 1.42−1.12 (m, 4H), 0.87 (t, J = 6.9 Hz, 3H); ^{13}C NMR δ 145.6 (d), 137.2 (d), 115.6 (t), 109.0 (d), 70.1 (t), 61.4 (t), 38.1 (d), 40.8 (t), 37.6 (t), 20.2 (t) 14.0 (q); IR (NaCl, neat): 3385 (br), 1652 (s) cm^{-1}; MS: *m*/*z* 184 (0.4%), 143 (100%), 123 (1.0%), 99 (23.7%). HRMS calcd for $C_{11}H_{20}O_2$ 184.1463; found 184.1467. Anal. Calcd for $C_{11}H_{20}O_2$: C, 71.70; H, 10.94. Found: C, 71.46; H, 10.64.

(2*E*)-4-(2-Hydroxyethoxy)-2-pentene (3ca). Starting with the dioxolane of crotonaldehyde (**1c**), and methylmagnesium bromide (**2a**), the title compound (109 mg, 84%) was obtained after purification. ^{1}H NMR δ 5.63 (dq, J = 15.3, 6.6 Hz, 1H), 5.36 (dqd, J = 15.3, 7.2, 1.5 Hz, 1H), 3.83 (q′, J = 7.2 Hz, 1H), 3.75−3.35 (m, 4H), 2.38 (s, 1H), 1.70 (dd, J = 6.6, 1.5 Hz, 3H), 1.24 (d, J = 7.2 Hz, 3H); ^{13}C NMR δ 133.0 (d), 127.6 (d), 76.8 (d), 68.9 (t), 61.8 (t), 21.3 (q), 17.5 (q); IR (NaCl, neat): 3419 (br), 1649 (m) cm^{-1}; MS: *m*/*z* 130 (2.3%), 115 (30.1%), 87 (100%), 69 (88.4%). HRMS calcd for $C_7H_{14}O_2$ 130.0994; found 130.0998.

(2*E*)-4-(2-Hydroxyethoxy)-2-hexene (3cb). Using the dioxolane of crotonaldehyde (**1c**), and ethylmagnesium bromide (**2b**), the title compound (117 mg, 81%) was obtained after purification. ^{1}H NMR δ 5.70−5.55 (m, 1H), 5.29 (dqd, J = 15.3, 6.0, 1.7 Hz, 1H), 3.75−3.33 (m, 5H), 2.02 (br, 1H), 1.72 (dd, J = 3.3, 1.7 Hz, 3H), 1.69−1.40 (m, 2H), 0.89 (t, J = 7.5 Hz, 3H); ^{13}C NMR δ 131.7 (d), 128.8 (d), 82.8 (d), 69.0 (t), 62.0 (t), 28.4 (t), 17.7 (q), 9.8 (q); IR (NaCl, neat): 3418 (br), 1672 (m) cm^{-1}. MS: *m*/*z* 144 (5.3%), 115 (47.8%), 83 (100%); HRMS calcd for $C_8H_{16}O_2$ 144.1150; found 144.1148.

(1*E*)-1-(2-Hydroxyethoxy)-3-methyl-1-pentene (4cb). The title compound (13 mg, 9%) was obtained after purification. ^{1}H NMR δ 6.25 (d, J = 12.6 Hz, 1H), 4.68 (dd, J = 12.6, 8.6 Hz, 1H), 3.87−3.71 (m, 4H), 2.15−1.82 (m, 2H), 1.45−1.10 (m, 2H), 0.98 (d, J = 6.6 Hz, 3H), 0.85 (t, J = 7.2 Hz, 3H). MS: *m*/*z* 144 (9.2%), 115 (80.3%), 83 (27.2%); HRMS calcd for $C_8H_{16}O_2$ 144.1150; found 144.1159.

(2*E*)-4-(2-Hydroxyethoxy)-2-octene (3cc). Using the dioxolane of crotonaldehyde (**1c**), and butylmagnesium bromide (**2c**), the title compound (48 mg, 28%) was obtained after purification.[15] ^{1}H NMR δ 5.61 (dq, J = 15.2, 6.6 Hz, 1H), 5.30 (ddq, J = 15.2, 8.1, 1.5 Hz, 1H), 3.75−3.32 (m, 5H), 2.07 (s, 1H), 1.71 (dd, J = 6.6, 1.5 Hz, 3H), 1.70−1.24 (m, 6H), 0.89 (t, J = 6.6 Hz, 3H); ^{13}C NMR δ 132.0 (d), 128.6 (d), 81.4 (d), 69.0 (t), 62.0 (t), 35.3 (t), 27.7 (t), 22.6 (t), 17.7 (q), 14.0 (q); IR (NaCl, neat): 3412 (br), 1648 (m) cm^{-1}. MS: *m*/*z* 172 (1.0%), 157 (0.2%), 143 (0.5%), 129 (2.5%), 115 (100%), 111 (9.5%), 53 (6.6%); HRMS calcd for $C_{10}H_{20}O_2$ 172.1463; found 172.1468. Anal. Calcd for $C_{10}H_{20}O_2$: C, 69.72; H, 11.70. Found: C, 69.37; H, 11.42.

(1*E*)-1-(2-Hydroxyethoxy)-3-methyl-1-heptene (4cc). The title compound (9 mg, 5%) was obtained after purification.[15] ^{1}H NMR δ 6.24 (d, J = 12.6 Hz, 1H), 4.68 (dd, J = 12.6, 9.0 Hz, 1H), 3.85−3.73 (m, 4H), 2.10−1.90 (m, 2H), 1.35−1.15 (m, 6H), 0.97 (d, J = 6.6 Hz, 3H), 0.88 (t, J = 6.9 Hz, 3H); ^{13}C NMR δ 144.6 (d), 111.5 (d), 70.1 (t), 61.5 (t), 37.6 (t), 32.7 (d), 29.6 (t), 22.7 (t), 22.0 (q), 14.1 (q); IR (NaCl, neat): 3429 (br), 1650 (s) cm^{-1}. MS: *m*/*z* 172 (36.0%), 115 (100%), 111 (11.8%); HRMS calcd for $C_{10}H_{20}O_2$ 172.1463; found 172.1457. Anal. Calcd for $C_{10}H_{20}O_2$: C, 69.72; H, 11.70. Found: C, 69.59; H, 11.61.

(5*E*)-4-(2-Hydroxyethoxy)-1,5-heptadiene (3cd). Employing the dioxolane of crotonaldehyde (**1c**), and allylmagnesium bromide (**2d**), the title compound (125 mg, 80%) was obtained after purification. ^{1}H NMR δ 5.80 (ddt, J = 17.4, 10.2, 6.9 Hz, 1H), 5.65 (dq, J = 15.5, 6.5 Hz, 1H), 5.34 (ddq, J = 15.5, 8.0, 1.7 Hz, 1H), 5.14−5.02 (m, 2H), 3.74−3.30 (m, 5H), 2.45−2.20 (m, 2H), 2.09 (t, J = 5.7 Hz, 1H), 1.70(dd, J = 6.5, 1.7 Hz, 3H); ^{13}C NMR δ 134.7 (d), 131.2 (d), 129.0 (d), 116.8 (t), 80.7 (d), 69.2 (t), 61.8 (t), 40.1 (t), 17.6 (q); IR (NaCl, neat): 3423 (br), 1642 (s) cm^{-1}. MS: *m*/*z* 115 (71.9%), 53 (11.4%). Anal. Calcd for $C_9H_{16}O_2$: C, 69.19; H, 10.32. Found: C, 69.37; H, 10.21.

(1*E*)-1-(2-Hydroxyethoxy)-3-methyl-1,5-hexadiene (4cd). The title compound (25 mg, 16%) was obtained after purification. ^{1}H NMR δ 6.26 (d, J = 12.9 Hz, 1H), 5.84−5.69 (m, 1H), 5.04−4.95 (m, 2H), 4.73 (dd, J = 12.9, 8.4 Hz, 1H), 3.85−3.73 (m, 4H), 2.20−1.95 (m, 4H), 1.00 (d, J = 6.6 Hz, 3H); ^{13}C NMR δ 144.9 (d), 137.1 (d), 115.7 (t), 110.6 (d), 70.1 (t), 61.4 (t), 42.3 (t), 32.7 (d), 21.2 (q). IR (NaCl, neat): 3386 (br), 1651 (s) cm^{-1}, MS: *m*/*z* 156 (0.5%), 115 (60.8%), 53 (8.7%); HRMS calcd for $C_9H_{16}O_2$ 156.1150; found 156.1153. Anal. Calcd for $C_9H_{16}O_2$: C, 69.19; H, 10.32. Found: C, 69.29; H, 10.06.

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Supporting Information Available: ^{1}H and ^{13}C NMR data (6 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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