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Iodocyclization/base-induced hydrodeiodination reaction of 5-substituted 4-alkenols. The influence of substituent on the stereoselective pathway

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Abstract—The electrophilic iodocyclization reaction of (*Z*)- and (*E*)-5-*n*-alkylsubstituted 4-alken-1-ols followed by base-induced hydrodeiodination reaction stereoselectively gave, respectively, (*Z*)- and (*E*)-alkylidentetrahydrofurans in high yield. Completely different outcomes were observed with (*Z*)- and (*E*)-6,6-dimethylhept-4-en-1-ol: their iodocyclization furnished, respectively, *threo*- and *erythro*-2-(1-iodo-2,2-dimetylpropyl)tetrahydrofuran with high stereoselectivity. The *threo* isomer gave clean formation of 6-*tert*-butyl-3,4-dihydro-2*H*-pyran by base-induced ring expansion, while *erythro* isomer underwent a base-induced ring contraction to 1-cyclopropyl-3,3-dimethylbutan-1-one. Moreover, (*Z*)- and (*E*)-5-cyclopropylpent-4-en-1-ol underwent a 6-*endo*-iodocyclization to *threo*- and *erythro*-2-cyclopropyl-3-iodotetrahydro-2*H*-pyran, respectively, that under the same basic treatment, gave two isomeric 6-cyclopropyldihydro-2*H*-pyrans in a stereoselective fashion.

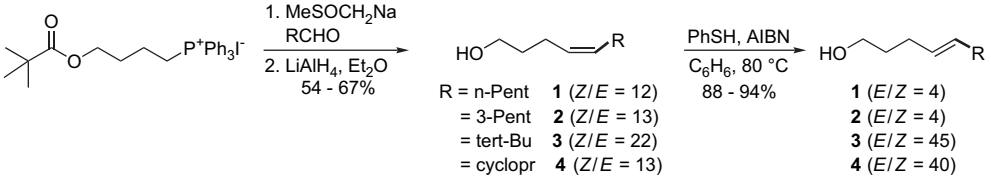
1. Introduction

Cyclic enolethers are of great interest because of their importance in organic chemistry and their role as versatile compounds in synthesis. Recently, they have been utilized for the preparation of 1,2,3,4-tetrahydroquinoline derivatives,[1] substituted indoles,[2] arylated oxacycles[3] and have been used as dienophiles in asymmetric hetero Diels–Alder[4] reactions catalyzed by Cu(II) chiral complexes. The synthesis of cyclic enolethers has attracted the interest of several research groups.[5] Herein, we present some results focused on stereochemical aspects of the preparation of cyclic enolethers by the iodocyclization reaction of 5-substituted 4-alken-1-ols followed by *t*-BuOK induced elimination of hydrogen iodide.

2. Results and discussion

The unsaturated alcohols **1**–**4** were obtained by Wittig olefination with methylsulfynyl carbanion–dimethyl sulfoxide as base-solvent[6a] and successive $LiAlH_4$ reduction of the unsaturated ester intermediates (Scheme 1). This methodology gave *Z*-alkenols with high selectivity (*Z*/*E*=12–22). The treatment with azobisisobutyronitrile–PhSH[6b] allowed their conversion into mixtures in which the (*E*) isomers are greatly predominant (Scheme 1).

Alcohols **1**–**3**, when treated with iodine, underwent a very efficient and clean 5-*exo* cyclization[7] (Scheme 2) that stereoselectively afforded *threo*- (**5t**, **6t**, **7t**) and *erythro*-2-(1-



Scheme 1.

Keywords: β-Iodoethers; Enolethers; 2-Alkylidentetrahydrofurans; Ring expansion.
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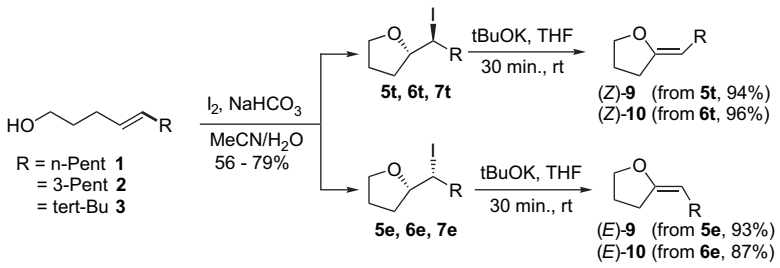
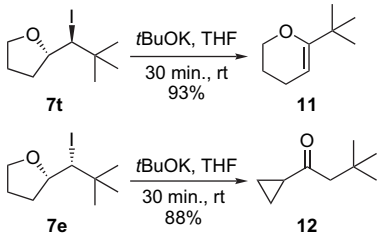


Scheme 2.

iodoalkyl)tetrahydrofurans (**5e**, **6e**, **7e**), respectively, from the *Z*- and *E*-components in the mixture, according to an *anti* addition reaction across the π-bond.[8]

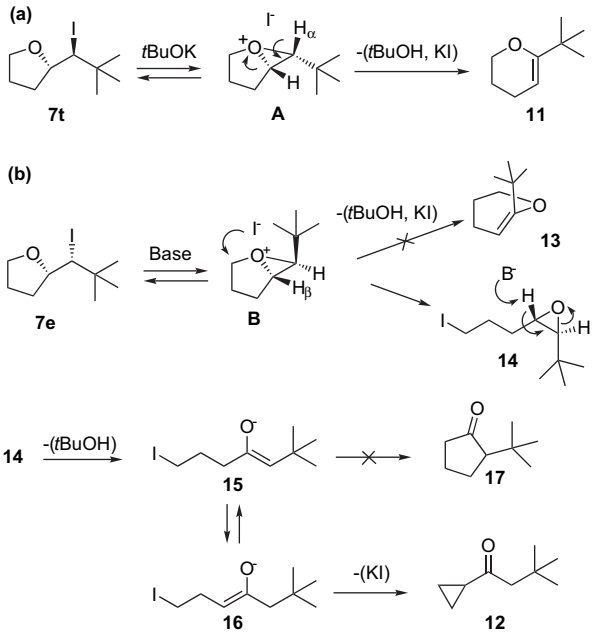
Upon treatment with *t*-BuOK in THF at room temperature, the iodoethers **5t**,**e** and **6t**,**e** underwent a highly and clean stereoselective *anti* hydrogen iodide elimination to give (*Z*)-, (*E*)-**9** and (*Z*)-, (*E*)-**10**, respectively. Therefore, the iodocyclization–hydrodeiodination sequence constitutes a selective and efficient route for the preparation of (*Z*)- and (*E*)-2-alkylidentetrahydrofuran starting from (*Z*)- and (*E*)-alkenols, respectively (Scheme 2). An analogous dehydrohalogenation to enolethers was already observed.[9]

The approach depicted in Scheme 2 resulted as a general route when applied to linear 4-alkenols and also for 4-alkenols with a side chain on C6 but different outcomes were observed with (*Z*)- and (*E*)-6,6-dimethylhept-4-en-1-ol (**3**). Whereas they were efficiently converted into the corresponding *threo*- (**7t**) and *erythro*-2-(1-iodo-2,2-dimethylpropyl)tetrahydrofuran (**7e**) (Scheme 2), the base-induced elimination performed on *threo*- (**7t**) gave 6-*tert*-butyl-3,4-dihydro-2*H*-pyran (**11**) in high yield (93%) by incorporation of the exocyclic halogen-bearing carbon into the ring,[10] while the same reaction performed on the *erythro* isomer (**7e**) furnished the 1-cyclopropyl-3,3-dimetylbutan-1-one (**12**) with similar efficiency (88% yield) (Scheme 3).



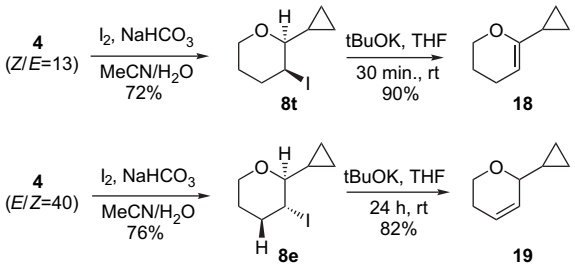
Scheme 3.

The conversion of **7t** into the dihydropyran **11** and **7e** into **12** could occur through the β ethereal-oxygen assisted expulsion of iodide with formation of an oxonium-iodide ion-pair (**7t**→**A** **7e**→**B**, Scheme 4a,b) with concomitant inversion at the carbon. The different evolutions of the two isomeric **A** and **B** forms could be justified by stereoelectronic factors: abstraction of proton H_α or H_β from the oxonium intermediate **A** and **B** (Scheme 4a,b), leads to the enol ether having a *Z* or *E* endocyclic double bond, respectively. Since the incipient six-membered ring cannot accommodate an *E* double bond giving **13** (Scheme 4b), the elimination with ring-contraction process to cyclopropyl ketone takes over. In this case, none of the possible 1,2-elimination products could be detected, and this could be explained by the steric hindrance of the *tert*-butyl group. Scheme 4b depicts the formation of the cyclopropylic ketone **12** from **7e**. In this model, the iodo epoxide **14**,[11] derived from tetrahydrofuran ring-opening by nucleophilic attack of ionic iodide, undergoes a base-induced elimination to enolate **15**.[11a,b] The enolate, due to the steric hindrance of the *tert*-butyl group, isomerizes to enolate **16** that finally cyclizes to give the ketone **12** by intramolecular alkylation.



Scheme 4.

A further different cyclization outcome was observed when (*Z*)- and (*E*)-cyclopropyl alkenols **4** were subjected to the same reaction conditions (Scheme 5). In this case a 6-*endo*



Scheme 5.

iodocyclization occurred, and the *threo*- (**8t**) and *erythro*-2-cyclopropyl-3-iodotetrahydro-2*H*-pyran (**8e**) were isolated from (*Z*)- and (*E*)-**4**, respectively (Scheme 5). We would like to stress that the above iodide promoted electrophilic ring closures were all highly stereoselective as only the *threo* or *erythro* iodoether was obtained from *Z*- or *E*-alkenol, respectively.

Even the tetrahydropyranyl iodides **8t** and **8e** (Scheme 5) underwent *anti* 1,2-elimination to give the unsaturated compounds **18** and **19** with very different reaction times: 30 min for the formation of enolether **18** and 24 h for the generation of allylic ether **19**. In this latter case, the much longer reaction time can be ascribed to both the weaker acidity of the hydrogen involved and to the lower level of substitution on the allylic ether double bond of the final product **19**.

3. Conclusions

In conclusion, the electrophilic iodocyclization of (*Z*)- and (*E*)-5-*n*-alkylsubstituted 4-alken-1-ols followed by base-induced hydrodeiodination reaction stereoselectively gave, respectively, (*Z*)- and (*E*)-alkylidentetrahydrofurans in high yield. However, more bulky or rigid substituents (*tert*-butyl or cyclopropyl) on C5 lead to completely different, although as much effective and stereoselective, reaction pathways of the same two steps synthetic sequence.

4. Experimental

4.1. General

All solvents and reagents were obtained from commercial sources and used without further purification unless otherwise stated. Anhydrous solvents and reagents were obtained as follows: benzene distilled over CaH_2; DMSO distilled at 3 mm of pressure over CaH_2; THF was distilled over sodium benzophenone. ^1H and ^{13}C NMR spectra were recorded at 300 MHz and 75 MHz, respectively. Chemical shifts are in parts per million down-field of TMS. 2D COSY and GHSQC as well DPFGSE-NOE experiments were recorded at 400 MHz. Bulb-to-bulb distillations were done on a Büchi GRK-50 Kugelrohr.

4.1.1. General procedure for the preparation of 5-substituted pent-4-en-1-ols (1–4). To a 2 M solution of $MeS(O)CH_2Na$ (10 mL, 20 mmol) in DMSO[6a] a solution of triphenyl[4-(pivaloyloxy)butyl]phosphonium iodide (20 mmol obtained by reaction of 4-iodobutyl pivalate[12] with Ph_3P in THF) dissolved in of dry DMSO (3 mL) was added under nitrogen cooling with a ice-water bath. The resulting solution ylide was stirred at room temperature for 10 min before the addition of aldehyde (0.8 equiv). The reaction mixture was stirred at room temperature for 1 h, poured into water (50 mL), and extracted with petroleum ether (3×50 mL). The organic solution was dried on Na_2SO_4, the solvent distilled under reduced pressure and the resulting residue chromatographed on silica gel. The pivalic ester obtained was then dissolved in dry Et_2O (10 mL/mmol of ester) and added dropwise to $LiAlH_4$ (1.5 equiv suspended in dry Et_2O) under nitrogen. The reaction mixture was first stirred at room temperature for 1 h then heated at solvent reflux. After 1 h the reaction was cooled at −10 °C and the hydride excess quenched with saturated aqueous solution of NH_4Cl. Warmed to room temperature the reaction mixture was stirred until a gray solid material was separated from the organic phase. After filtration by büchner the solid material was washed with Et_2O. The organic phase was dried on $MgSO_4$, and after solvent evaporation the residue was bulb-to-bulb distilled to give the desire alcohol.

4.1.1.1. Dec-4-en-1-ol (1). Yield 7.35 g, 57%, as a colorless oil of a mixture *Z*/*E*=12; (*Z*)-**1**: ^1H and ^{13}C NMR were identical to those previously reported.[13]

4.1.1.2. 6-Ethyloct-4-en-1-ol (2). Yield 67%, 8.64 g, as a colorless oil of a mixture *Z*/*E*=13; (*Z*)-**2**: ν_{max} (liquid film) 3338 (br), 2959, 2933, 2874, 1458, 1058 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.43 (ddt, *J*=10.9, 7.3, 0.7 Hz, 1H), 5.11–5.01 (m, 1H), 3.65 (t, *J*=6.6 Hz, 2H), 2.20–2.05 (m, 3H), 1.89 (br s, 1H), 1.68–1.58 (m, 2H), 1.50–1.33 (m, 2H), 1.24–1.07 (m, 2H), 0.83 (t, *J*=7.4 Hz, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 135.3, 129.0, 62.6, 40.7, 32.8, 28.2, 24.1, 11.8. Anal. Calcd for $C_{10}H_{20}O$: C, 76.86; H, 12.90; O, 10.24. Found: C, 77.02; H, 12.93.

4.1.1.3. 6,6-Dimethylhept-4-en-1-ol (3). Yield 63%, 7.25 g, as a colorless oil of a mixture *Z*/*E*=22; (*Z*)-**3**: ^1H was identical to that previously reported;[14] ^{13}C NMR (75 MHz, $CDCl_3$) δ 140.4, 128.0, 62.4, 33.14, 33.08, 31.1, 24.7.

4.1.1.4. 5-Cyclopropylpent-4-en-1-ol (4). Yield 54%, 5.32 g, as a colorless oil of a mixture *Z*/*E*=13; (*Z*)-**4**: ν_{max} (liquid film) 3351 (br), 3082, 3005, 2936, 2867, 1418, 1058 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.32 (ddt, *J*=10.7, 7.4, 0.8 Hz, 1H), 4.82–4.73 (m, 1H), 3.69 (t, *J*=6.5 Hz, 2H), 2.27 (dq, *J*=7.4, 1.5 Hz, 2H), 1.73–1.63 (n, 3H), 1.63–1.50 (m, 1H), 0.76–0.69 (m, 2H), 0.35–0.29 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 134.7, 127.3, 62.6, 32.7, 24.0, 9.5, 6.8. Anal. Calcd for $C_8H_{14}O$: C, 76.14; H, 11.18; O, 12.68. Found: C, 76.35; H, 11.21.

4.1.2. General procedure for *Z*/*E* isomerization of 5-substituted pent-4-en-1-ols (1–4).[6b] To a 0.05 M solution of alcohol in dry and degassed benzene warmed at 80 °C and containing thiophenol (0.35 equiv), AIBN (5–10 mol %) was added in two portions in 2 h under nitrogen. The reaction was refluxed for additional two hours, then cooled at room temperature, and washed with 15% water solution of NaOH. After solvent evaporation the residue was filtered on silica gel and bulb-to-bulb distilled to give the isomerized mixture of alcohols.

4.1.2.1. Dec-4-en-1-ol (1). Yield 91%, 3.45 g, as a colorless oil of a mixture *E*/*Z*=4; (*E*)-**1**: ^1H was corresponding to that previously reported;[13a] ^{13}C NMR (75 MHz, $CDCl_3$) δ 131.2, 129.3, 62.4, 32.5, 32.4, 31.4, 29.2, 28.9, 22.5, 14.0.

4.1.2.2. 6-Ethyloct-4-en-1-ol (2). Yield 94%, 3.93 g, as a colorless oil of a mixture *E*/*Z*=4; (*E*)-**2**: ν_{max} (liquid film) 3350 (br), 2961, 2933, 2874, 1456, 1059 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.36 (dt, *J*=15.3, 6.6 Hz, 1H), 5.14 (ddt, *J*=15.3, 8.6, 1.3 Hz, 1H), 3.64 (t, *J*=6.6 Hz, 2H), 2.22 (br s, 1H), 2.14–2.04 (m, 2H), 1.77–1.59 (m,

3H), 1.44–1.31 (m, 2H), 1.27–1.11 (m, 1H), 0.82 (t, J=7.4 Hz, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 135.2, 129.5, 62.3, 46.3, 32.6, 28.9, 27.7, 11.7. Anal. Calcd for $C_{10}H_{20}O$: C, 76.86; H, 12.90; O, 10.24. Found: C, 77.08; H, 12.87.

4.1.2.3. 6,6-Dimethylhept-4-en-1-ol (3). Yield 89%, 4.01 g, as a colorless oil of a mixture E/Z=45; (*E*)-**3** ^{1}H NMR was identical to that previously reported;[14] ^{13}C NMR (75 MHz, $CDCl_3$) δ 142.2, 123.9, 62.3, 32.7, 32.5, 29.7, 28.9.

4.1.2.4. 5-Cyclopropylpent-4-en-1-ol (4). Yield 88%, 2.92 g, as a colorless oil of a mixture E/Z=40; (*E*)-**4**: ν_{max} (liquid film) 3344 (br), 3081, 3005, 2934, 1438, 1057, 1021, 960 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.50 (dt, J=15.2, 6.9 Hz, 1H), 5.00 (ddt, J=15.2, 8.5, 1.4 Hz, 1H), 3.62 (t, J=6.6 Hz, 2H), 2.26 (br s, 1H), 2.06 (dq, J=7.1, 1.4 Hz, 2H), 1.66–1.56 (m, 2H), 1.40–1.28 (m, 1H), 0.68–0.62 (m, 2H), 0.34–0.28 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 134.4, 127.2, 62.3, 32.4, 28.7, 13.4, 6.3. Anal. Calcd for $C_8H_{14}O$: C, 76.14; H, 11.18; O, 12.68. Found: C, 76.31; H, 11.20.

4.1.3. General procedure for the preparation of *threo*- and *erythro*-2-(1-iodoalkyl)tetrahydrofurans (5–8). To a suspension of $NaHCO_3$ (2.5 equiv) in acetonitrile–water (9:1 v/v, 5 mL/mmol of substrate) containing the alcoholic substrate,[15] I_2 (1.7 equiv) was added in four portions during 8 h at room temperature. The reaction mixture was stirred until the substrate disappeared (16–28 h, TLC monitoring). The reaction mixture was poured into Et_2O (5 vol) washed with aqueous 5% $Na_2S_2O_5$, water, and brine. The organic solution was dried on $MgSO_4$, the solvent evaporated under reduced pressure and the crude flash-chromatographed to get the *threo* and *erythro* iodides **5–8**.

4.1.3.1. *threo*-2-(1-Iodohexyl)tetrahydrofuran (5t). Yield 79%, 3.63 g, from **1** (Z/E=12), as a colorless oil: ν_{max} (liquid film) 2955, 2928, 2857, 1459, 1050 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.10 (ddd, J=10.1, 4.7, 3.8 Hz, 1H), 4.00–3.92 (m, 1H), 3.83 (ddd, J=8.0, 7.4, 5.7 Hz, 1H), 3.74 (ddd, J=8.0, 6.3, 4.8 Hz, 1H), 2.13–1.52 (m, 7H), 1.48–1.21 (m, 5H), 0.88 (t, J=6.7 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 82.3, 68.8, 42.6, 36.3, 31.6, 30.8, 29.7, 28.4, 26.2, 14.0. Anal. Calcd for $C_{10}H_{19}IO$: C, 42.57; H, 6.79; I, 44.98; O, 5.67. Found: C, 42.72; H, 6.77.

4.1.3.2. *erythro*-2-(1-Iodohexyl)tetrahydrofuran (5e). Yield 56%, 2.14 g, from **1** (E/Z=4), as a colorless oil: ν_{max} (liquid film) 2955, 2929, 2858, 1459, 1056 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.12 (ddd, J=9.2, 7.1, 4.0 Hz, 1H), 3.99–3.90 (m, 1H), 3.85 (ddd, J=8.2, 7.1, 5.4 Hz, 1H), 3.74 (dd, J=14.1, 7.1 Hz, 1H), 2.21–2.08 (m, 1H), 2.02–1.85 (m, 2H), 1.85–1.66 (m, 3H), 1.66–1.52 (m, 1H), 1.45–1.20 (m, 5H), 0.9 (t, J=6.8 Hz, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 82.2, 68.8, 43.6, 36.4, 32.2, 31.0, 29.1, 25.9, 22.4, 14.0. Anal. Calcd for $C_{10}H_{19}IO$: C, 42.57; H, 6.79; I, 44.98; O, 5.67. Found: C, 42.70; H, 6.81.

4.1.3.3. *threo*-2-(2-Ethyl-1-iodobutyl)tetrahydrofuran (6t). Yield 74%, 4.53 g, from **2** (Z/E=13), as a colorless oil: ν_{max} (liquid film) 2962, 2932, 2873, 1459, 1064 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.22 (dd, J=7.0, 3.1 Hz, 1H), 4.00–3.78 (m, 3H), 2.10–1.88 (m, 3H), 1.67–1.48 (m, 3H), 1.37–1.17 (m, 2H), 0.94 (t, J=7.4 Hz, 3H), 0.87 (t, J=7.4 Hz, 3H), 0.71–0.60 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 81.8, 67.6, 49.9, 45.8, 31.6, 26.2, 26.1, 25.7, 11.6, 11.5. Anal. Calcd for $C_{10}H_{19}IO$: C, 42.57; H, 6.79; I, 44.98; O, 5.67. Found: C, 42.44; H, 6.80.

4.1.3.4. *erythro*-2-(2-Ethyl-1-iodobutyl)tetrahydrofuran (6e). Yield 58%, 2.12 g, from **2** (E/Z=4), as light yellow oil: ν_{max} (liquid film) 2962, 2932, 2874, 1459, 1057 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.21–4.10 (m, 2H), 3.96–3.81 (m, 2H), 2.36–2.22 (m, 1H), 1.97–1.83 (m, 2H), 1.83–1.70 (m, 1H), 1.67–1.49 (m, 2H), 1.23–1.03 (m, 2H), 0.96 (t, J=7.3 Hz, 3H), 0.97–0.92 (m, 1H), 0.88 (t, J=7.3 Hz, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 80.0, 68.9, 50.6, 43.1, 33.9, 26.1, 25.7, 25.4, 11.6, 11.5. Anal. Calcd for $C_{10}H_{19}IO$: C, 42.57; H, 6.79; I, 44.98; O, 5.67. Found: C, 42.73; H, 6.81.

4.1.3.5. *threo*-2-(1-Iodo-2,2-dimethylpropyl)tetrahydrofuran (7t). Yield 75%, 3.82 g, from **3** (Z/E=22), as a colorless oil: ν_{max} (liquid film) 2969, 2868, 1477, 1461, 1088, 1030 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.15 (d, J=1.2 Hz, 1H), 4.05–3.96 (m, 1H), 3.81–3.72 (m, 1H), 3.42–3.35 (m, 1H), 2.06–1.67 (m, 4H), 1.16 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 77.5, 69.1, 62.8, 36.4, 34.4, 29.7, 25.3. Anal. Calcd for $C_9H_{17}IO$: C, 40.31; H, 6.39; I, 47.33; O, 5.97. Found: C, 40.19; H, 6.37.

4.1.3.6. *erythro*-2-(1-Iodo-2,2-dimethylpropyl)tetrahydrofuran (7e). Yield 79%, 4.91 g, from **3** (E/Z=45), as a colorless oil: ν_{max} (liquid film) 2963, 2868, 1477, 1466, 1075, 1056 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.51 (d, J=4.0 Hz, 1H), 3.99–3.90 (m, 1H), 3.78–3.69 (m, 1H), 3.56–3.48 (m, 1H), 2.08–1.74 (m, 4H), 1.14 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 79.3, 67.6, 62.2, 35.0, 33.3, 29.7, 26.6. Anal. Calcd for $C_9H_{17}IO$: C, 40.31; H, 6.39; I, 47.33; O, 5.97. Found: C, 40.21; H, 6.38.

4.1.3.7. *threo*-2-Cyclopropyl-3-iodotrahydro-2*H*-pyran (8t). Yield 72%, 2.85 g, from **4** (Z/E=13), as a colorless oil: ν_{max} (liquid film) 3081, 3008, 2924, 2853, 1460, 1104, 1084 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.55–4.50 (m, 1H), 4.11–4.02 (m, 1H), 3.51–3.39 (m, 1H), 2.33–2.11 (m, 2H), 2.04–1.88 (m, 1H), 1.63 (dd, J=8.0, 1.7 Hz, 1H), 1.48–1.38 (m, 1H), 1.13–1.01 (m, 1H), 0.69–0.60 (m, 1H), 0.57–0.43 (m, 2H), 0.17–0.07 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 84.3, 68.8, 39.2, 34.4, 22.3, 18.8, 3.6, 1.4; this structure was supported also from 2D NMR experiments COSY and GHSQC. Anal. Calcd for $C_8H_{13}IO$: C, 38.12; H, 5.20; I, 50.34; O, 6.35. Found: C, 38.04; H, 5.18.

4.1.3.8. *erythro*-2-Cyclopropyl-3-iodotrahydro-2*H*-pyran (8e). Yield 76%, 4.05 g, from **4** (E/Z=40), as light yellow oil: ν_{max} (liquid film) 3082, 3006, 2941, 2847, 1463, 1105, 1024 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.14–4.02 (m, 2H), 3.45 (ddd, J=13.7, 11.5, 2.3 Hz, 1H), 2.93 (dd, J=9.9, 7.3 Hz, 1H), 2.59–2.49 (m, 1H), 2.17 (ddt, J=12.8, 12.4, 4.3 Hz, 1H), 1.84–1.67 (m, 1H), 1.52–1.43 (m, 1H), 1.07–0.95 (m, 1H), 0.69–0.60 (m, 1H), 0.60–0.47 (m, 2H), 0.41–0.31 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 84.8, 68.4, 38.6, 32.8, 29.7, 16.6, 6.3, 2.1; this structure

was supported also from 2D NMR experiments COSY and GHSQC. Anal. Calcd for $C_8H_{13}IO$: C, 38.12; H, 5.20; I, 50.34; O, 6.35. Found: C, 38.02; H, 5.22.

4.1.4. General procedure for the reactions of iodides 5–8 with *t*-BuOK. *t*-BuOK (1.1 equiv of 1 M solution in THF) was added dropwise to a solution of iodide in dry THF (2 mL/mmol of iodide) at room temperature and under nitrogen. During the addition a white insoluble solid is formed. After 30 min the reaction of iodides **5**, **6**, **7** and **8t** was finished, whereas **8e** needs 24 h (it will be complete in about 1 h if 2.5 equiv of *t*-BuOK is used). The reaction mixture was diluted with petroleum ether (5 vol) and filtered on a short plug of florisil. After solvent evaporation the residue was analyzed without further purification.

4.1.4.1. (*Z*)-2-Hexylidenetetrahydrofuran, (*Z*)-9. Yield 94%, 2.00 g, from **5t** as colorless oil: ^{1}H and ^{13}C NMR were identical to those previously reported.[16]

4.1.4.2. (*E*)-2-Hexylidenetetrahydrofuran, (*E*)-9. Yield 93% 1.23 g, from **5e** as colorless oil: ^{1}H and ^{13}C NMR were identical to those previously reported.[16]

4.1.4.3. (*Z*)-2-(2-Ethylbutylidene)tetrahydrofuran, (*Z*)-10. Yield 96%, 2.46 g, from **6t** as colorless oil: ν_{max} (liquid film) 2962, 2932, 2876, 1712, 1460, 1035 cm^{-1}; ^{1}H NMR (300 MHz, C_6D_6) δ 3.97 (dt, J=9.4, 1.5 Hz, 1H), 3.70–3.65 (m, 2H), 2.69–2.55 (m, 1H), 2.22–2.14 (m, 2H), 1.63–1.48 (m, 2H), 1.45–1.25 (m, 4H), 1.04 (t, J=7.3, 6H); ^{13}C NMR (75 MHz, C_6D_6) δ 156.2, 100.9, 70.6, 40.2, 29.8, 29.7, 25.9, 12.9; this structure was supported also from COSY and DPFGSE-NOE experiments.

4.1.4.4. (*E*)-2-(2-Ethylbutylidene)tetrahydrofuran, (*E*)-10. Yield 87%, 1.08 g, from **6e** as colorless oil: ν_{max} (liquid film) 2957, 2930, 2860, 1718, 1459, 1036 cm^{-1}; ^{1}H NMR (300 MHz, C_6D_6) δ 4.68–4.61 (m, 1H), 3.71–3.64 (m, 2H), 2.21–2.13 (m, 2H), 1.76–1.63 (m, 1H), 1.50–1.38 (m, 4H), 1.28–1.14 (m, 2H), 0.93 (t, J=7.3 Hz, 6H); ^{13}C NMR (75 MHz, C_6D_6) δ 157.4, 100.7, 69.8, 43.3, 30.4, 27.1, 25.8, 12.9; this structure was supported also from COSY and DPFGSE-NOE experiments.

4.1.4.5. 6-*tert*-Butyl-3,4-dihydro-2*H*-pyran (11). Yield 93%, 1.82 g, from **7t** as colorless oil: ^{1}H NMR was corresponding to that previously reported;[17] ^{13}C NMR (75 MHz, $CDCl_3$) δ 153.2, 105.6, 70.8, 31.1, 30.8, 30.1, 24.6.

4.1.4.6. Cyclopropyl-3,3-dimethylbutan-1-one (12).[18] Yield 88%, 2.24 g, from **7e** as colorless oil: ^{1}H NMR (300 MHz, C_6D_6) δ 2.20 (s, 2H), 2.51–2.42 (m, 1H), 1.01–0.96 (m, 2H), 0.98 (s, 9H), 0.50–0.43 (m, 2H); ^{13}C NMR (75 MHz, C_6D_6) 209.2, 57.1, 31.6, 30.6, 22.6, 11.3.

4.1.4.7. 6-Cyclopropyl-3,4-dihydro-2*H*-pyran (18). Yield 90%, 1.24 g, from **8t** as colorless oil: ν_{max} (liquid film) 3301, 2930, 2853, 1677, 1466 cm^{-1}; ^{1}H NMR (300 MHz, C_6D_6) δ 4.55 (t, J=3.8 Hz, 1H), 3.71–3.67 (m, 2H), 1.85–1.79 (m, 2H), 1.50–1.41 (m, 2H), 1.38–1.26 (m, 1H), 0.83–0.77 (m, 2H), 0.46–0.39 (m, 2H); ^{13}C NMR (75 MHz, C_6D_6) δ 155.1, 94.6, 66.8, 23.6, 21.4, 15.3, 4.9.

4.1.4.8. 6-Cyclopropyl-3,6-dihydro-2*H*-pyran (19). Yield 82% 1.61 g, from **8e** as colorless oil: ν_{max} (liquid film) 3009, 2961, 2921, 2854, 1401, 1373 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.90–5.82 (m, 1H), 5.76–5.70 (m, 1H), 4.01 (ddd, J=11.2, 5.6, 2.6 Hz, 1H), 3.64 (ddd, J=11.2, 9.7, 3.9 Hz, 1H), 3.38–3.30 (m, 1H), 2.37–2.23 (m, 1H), 1.98–1.86 (m, 1H), 1.01–0.82 (m, 1H), 0.61–0.45 (m, 2H), 0.42–0.34 (m, 1H), 0.28–0.20 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 129.6, 124.9, 78.5, 63.6, 25.3, 15.5, 3.1, 1.3. Anal. Calcd for $C_8H_{12}O$: C, 77.38; H, 9.74; O, 12.88. Found: C, 77.54; H, 9.77.

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Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2007.09.074.

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