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TETRAHEDRON: *ASYMMETRY*

A novel synthesis of 2-deoxy-L-ribose†

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Abstract

We report a new synthesis of 2-deoxy-L-ribose starting from the commercially available (*R*)-(+)-5-hydroxymethyl-5*H*-furan-2-one. The key step is a 1,4-addition of $(PhMe_2Si)_2Cu(CN)Li_2$ which proceeds with complete diastereoselection.

1. Introduction

The title compound constitutes the central building block for L-enantiomers of both natural and synthetically modified nucleosides, several of which are highly valuable antiviral agents.[1] Thus, L-thymidine (L-T), L-3′-thiacytidine (L-3-TC, 'Lamivudine'), L-5-fluoro-3′-thiacytidine (L-FTC), L-2′,3′-dideoxycytidine (L-ddC) and L-5-fluoro-2′,3′-dideoxycytidine (L-5-FddC) have shown excellent antiviral activities with greatly reduced toxicities in mammalian systems as compared to the corresponding D-nucleosides. Furthermore, L-nucleosides and derivatives thereof, both with the L-ribose or 2-deoxy-L-ribose backbone, are attractive building blocks for the corresponding oligonucleotides useful in 'antisense' therapy for the binding of fragmental D-*m*RNA.[2]

As a great advantage for therapeutic applications and in contrast to the corresponding D-oligodeoxynucleotides (D-DNA) such enantiomeric L-DNA oligomers display considerably enhanced resistance towards the action of nucleases.[3]

In order to develop versatile synthetic strategies towards such molecules and, obvious from the retrosynthetic analysis outlined in Scheme 1, flexible and facile routes to both: (a) structurally variable bases; and (b) L-riboses and derivatives thereof are required.

2. Results and discussion

Several synthetic approaches to 2-deoxy-L-ribose have been published in recent years, practically all of them starting with molecules from the 'chiral pool' such as L-arabinose or L-ascorbic acid.[4]

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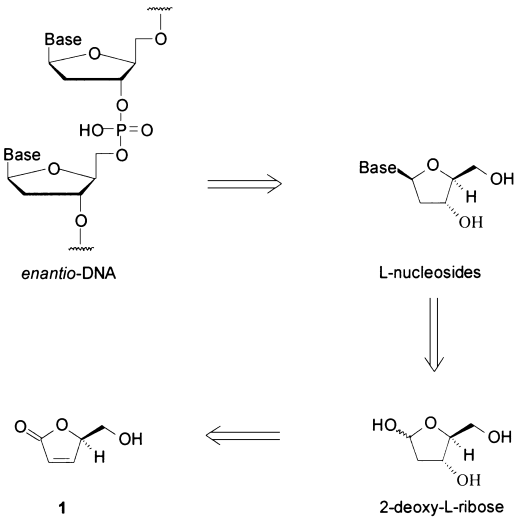
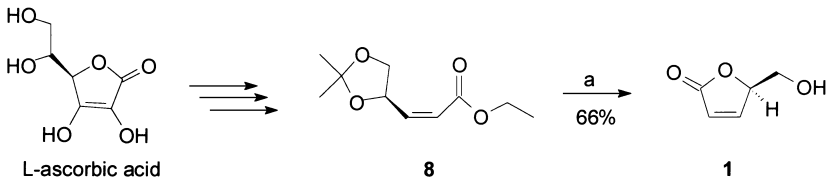


Scheme 1.

Alternatively, the required absolute configuration was introduced by asymmetrisation of an achiral starting material, e.g. by employing the Sharpless epoxidation.[5]

In order to develop a more flexible strategy aimed at the synthesis of L-ribose, 2-deoxy-L-ribose, 2,3-dideoxy-L-ribose and also unnatural derivatives functionalized at the crucial 3′-position in nucleosides, we decided to explore a novel route to such molecules starting from the α,β-unsaturated lactone **1** (Scheme 2).



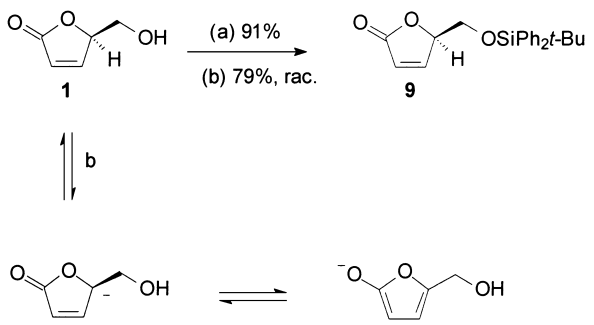
Scheme 2. *Reagents and conditions*: (a) H_2SO_4 (30% sol. in water), MeOH, rt, 2 h

Compound **1** is commercially available but can also be synthesized conveniently from inexpensive L-ascorbic acid via a published procedure[6] (Scheme 2).

Reaction of the key intermediate **8**[6] with catalytic amounts (2%) of H_2SO_4 in MeOH produced **1** in 66% yield (35% overall yield from L-ascorbic acid). For the determination of the enantiomeric purity of **1** via HPLC we decided to convert this material into the corresponding *tert*-butyldiphenylsilyl derivative **9** (Scheme 3).

First attempts along these lines using more standard conditions (Et_3N, DMAP, *t*-$BuPh_2SiCl$)[8] failed. Depending on the employed reaction times various degrees of racemization were observed which we attribute to the transient deprotonation of the allylic proton at C-5 (compare Scheme 3). In contrast, using *t*-$BuPh_2SiCl$ and NH_4NO_3[7] the desired derivative **9** was obtained with excellent yield and free of racemization.

Using *ent*-**9**, prepared from commercially available *ent*-**1** as a reference, the HPLC analysis (column LiChoCART 250-4 (*S*,*S*)-Whelk-5 μm, eluent hexane:isopropanol (97:3), flow rate 1 ml/min, detector UV 254 nm) revealed an enantiomeric purity of >98% (Fig. 1).



Scheme 3. *Reagents and conditions*: (a) *tert*-butyldiphenylsilyl chloride, NH_4NO_3, DMF, rt, 24 h; (b) *tert*-butyldiphenylsilyl chloride, Et_3N, DMAP, dichloromethane, argon, 0°C–rt, 4 h

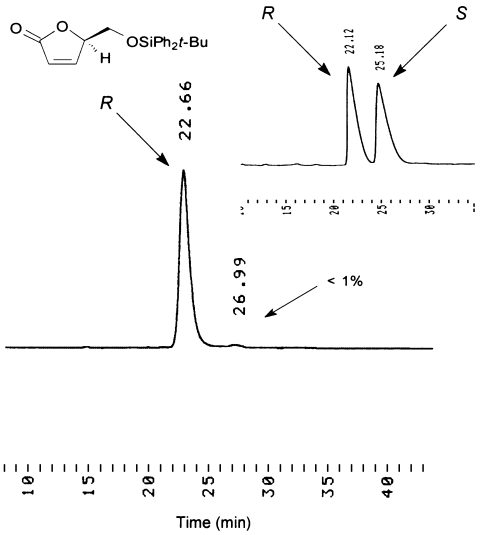


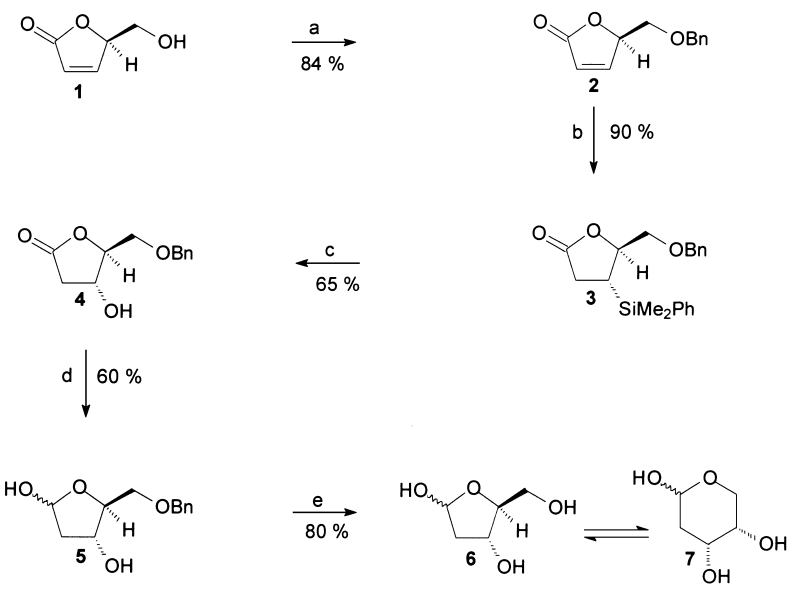
Figure 1. HPLC analysis. Column: LiChroCART 250–4 1.50614. (*S*,*S*)-Whelk 01 (5 μm), eluent: *n*-hexane:isopropanol (97:3); flow rate: 1.0 ml/min

Constituting a 'Michael' system, we felt that nucleophilic 1,4-addition would allow the convenient introduction of various substituents into the 3′-position of nucleosides and this with high diastereoselectivity being directed by the suitably protected 5-hydroxymethyl group in **1**.

While 'soft' nucleophiles (based on sulfur, nitrogen, phosphorus) can successfully be employed for such 1,4-additions, all our initial efforts to introduce derivatives of the 'hard' nucleophile oxygen failed.

Based on previous experiments described by Fleming et al.[9] related to the diastereoselective addition of silyl cuprate reagents to Michael systems, and due to the fact that the silyl functions in the resulting derivatives can be transformed into the corresponding hydroxyl groups[10] with retention of configuration, we report here the successful synthesis of 2-deoxy-L-ribose and related building blocks in enantiomerically pure form (Scheme 4).

(R)-(+)-5-Hydroxymethyl-5*H*-furan-2-one **1** was first converted into the corresponding benzyl ether **2**, thus carrying a protective group which would: (a) be stable under the reaction conditions; (b) direct the entering substituent diastereoselectively to the opposite face; and (c) be easily removable by catalytic hydrogenation. While more classical methods for the introduction of the



Scheme 4. *Reagents and conditions*: (a) $BnOC(=NH)CCl_3$, CF_3SO_3H, dichloromethane:cyclohexane (2:1), rt, 2 h; (b) $(PhMe_2Si)_2Cu(CN)Li_2$, THF, –45°C, 1 h; (c) Br_2, AcOOH, AcOH, rt, 5 h; (d) disiamylborane, THF, rt, 24 h; (e) HCOOH, Pd/C, 10%, MeOH, rt, 1 h

benzyl group (NaH/BnBr, Ag_2O/BnBr)[11] failed, **2** was obtained in 84% yield using benzyl trichloroacetamidate in the presence of CF_3SO_3H. Cuprate addition of $(PhMe_2Si)_2Cu(CN)Li_2$[12] to **2** afforded the corresponding silyl derivative **3** in 90% yield. As to judge from the ^{13}C NMR of **3**, only one diastereoisomer was produced.

Conversion of the silyl derivative **3** into the corresponding hydroxyl derivative **4** was achieved with complete retention of configuration using Br_2 (1 M in AcOH) and AcOOH at rt for 5 h. Compound **4** was obtained in 65% yield. Reduction of the lactone **4** was accomplished with disiamylborane[13] leading to **5** as anomeric mixture ($\alpha:\beta = 70:30$ in $CDCl_3$) in 60% yield. Deprotection of **5** using transfer hydrogenation[14] (HCOOH, Pd/C 10%) resulted in the production of 2-deoxy-L-ribose **6** and **7** in 80% yield as anomeric mixture of the furanoside and pyranoside forms. The spectroscopic data for the isomeric mixture of 2-deoxy-L-ribose (four diastereoisomers) were consistent with those of 2-deoxy-D-ribose.

Using the above outlined strategy towards L-enantiomers of nucleosides we are presently employing enantiomerically pure **5** as well as **6** and **7** as central building blocks.

3. Experimental

3.1. General

Reagents were obtained from commercial suppliers and used without further purification. All glassware and syringes were dried in an oven overnight, allowed to cool and stored under a positive pressure of argon before use. The solvents were dried before use as follows: cyclohexane and dichloromethane over P_2O_5, THF distilled from potassium/benzophenone ketyl, DMF over CaO. CuCN was dried under vacuum (10^{-3} mbar) at 120°C overnight (**CAUTION**: CuCN is very toxic,

handle this substance with protective gloves, do **NOT** dry it over P_2O_5). NH_4NO_3 was dried overnight in a desiccator containing P_2O_5 (**CAUTION**: NH_4NO_3 is a potential explosive, handle with care, do **NOT** heat). Merck silica gel 60 (70–230 mesh) was used for column chromatography. Tlc were run on SiO_2 $60F_{254}$ (Merck), detection with UV and vaniline/H_2SO_4 reagent. ^1H and ^{13}C NMR spectra were measured at 400 MHz (Bruker). Chemical shifts are reported relative to $CDCl_3$ at 7.27 ppm. IR spectra were measured with a Perkin–Elmer Infrared spectrophotometer 1420; the optically rotations with a Perkin–Elmer 241 instrument (thermostated at +20°C, chloroform stabilized with 1% ethanol). Mass spectra were measured with a Variant MAT 311 A (EI, 70 eV) spectrometer. Elemental analyses were carried out with an Elementar Vario EL. The melting points are uncorrected.

3.2. (R)-(+)-5-Hydroxymethyl-5H-furan-2-one **1**

To a stirred solution of 3-(2,2-dimethyl[1,3]dioxolan-4-yl)acrylic acid ethyl ester **8** (M.W. 200.23, 12.2 g, 60.81 mmol) in 30 ml of MeOH, 200 μl of a 30% aqueous solution of H_2SO_4 were added. After 2 h the weakly basic ion exchange resin Amberlite IRA-93 was added portionwise until the pH was adjusted to 6–6.5. The mixture was filtered and the solvent was removed under reduced pressure. The crude product was purified by chromatography on silica gel using AcOEt as eluent. Yield 4.6 g (66%), white crystals, m.p. 43–44°C (from $CHCl_3/Et_2O$). R_f: 0.45 AcOEt. $[\alpha]_D^{20} = +124$ (*c* 1.08, $CHCl_3$, lit.[15] +136.09 (*c* 1.69, H_2O)). ^1H NMR ($CDCl_3$) δ 7.49 (dd, $J = 5.83$ Hz, $J = 1.57$ Hz, 1H), 6.19 (dd, $J = 5.76$ Hz, $J = 2.03$ Hz, 1H), 5.15 (m, 1H), 3,98 (dd, $J = 12.19$ Hz, $J = 3.37$ Hz, 1H), 3.79 (dd, $J = 12.19$ Hz, $J = 4.88$ Hz, 1H), 2.58 (br, 1OH); ^{13}C NMR ($CDCl_3$) δ 173.02, 153.45, 122.97, 83.98, 62.39; IR (KBr, cm^{-1}) 3350, 3085, 2920, 2860, 1735, 1595, 1395, 1325; MS *m*/*z* 85 (100%), 57, 42. Anal. calcd for $C_5H_6O_3$: C, 52.58; H, 5.25. Found: C, 52.30; H, 5.21.

3.3. (R)(+)-5-Benzyloxymethyl-5H-furan-2-one **2**

(*R*)-(+)-5-Hydroxymethyl-5*H*-furan-2-one **1** (M.W. 114.10, 4.0 g, 35.05 mmol) was stirred under argon in a 300 ml mixture of dry dichloromethane:cyclohexane (2:1). The reaction mixture was cooled to 0°C and trichloroacetamidic acid benzyl ester (M.W. 252.53, 7.2 ml, 38.55 mmol, 1.1 equiv.) and trifluoromethanesulfonic acid (M.W. 150.08, 305.6 μL, 3.50 mmol, 0.1 equiv.) were added. After 10 min at 0°C the temperature was increased to rt and the mixture was stirred for an additional 2 h. The mixture was washed with HCl 1N (2×20 ml), water, brine and the organic layer was dried over anhydrous Na_2SO_4. The crude product was purified by chromatography on silica gel using as eluent Et_2O:hexane (2:1). Yield: 6.0 g (84%), oil, R_f: 0.28 Et_2O:hexane (2:1). $[\alpha]_D^{20} = +137$ (*c* 1.31, $CHCl_3$). ^1H NMR ($CDCl_3$) δ 7.50 (dd, $J = 5.67$ Hz, $J = 1.39$ Hz, 1H), 7.38–7.27 (m, 5H), 6.17 (dd, $J = 5.67$ Hz, $J = 1.96$ Hz, 1H), 5.17 (m, 1H), 4.58 (s, 2H), 3.74 (dd, $J = 10.35$ Hz, $J = 5.19$ Hz, 1H), 3.69 (dd, $J = 10.50$ Hz, $J = 5.05$ Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 172.63, 153.80, 137.27, 128.46, 127.93, 127.67, 122.55, 82.13, 13.74, 69.47; IR (film, cm^{-1}) 3070, 3045, 3015, 2890, 2845, 1750, 1590, 1485, 1440, 1355, 1320; MS *m*/*z* 204, 161, 151, 126, 108, 98, 91, 82, 77, 62, 49, 44 (100%), 36. Anal. calcd for $C_{12}H_{12}O_3$: C, 70.51; H, 5.87. Found: C, 69.95; H, 5.76.

3.4. Dimethylphenylsilyl lithium

A solution of phenyldimethylchlorosilane (M.W. 170.72, 7.1 ml, 43.09 mmol) in ca. 40 ml of dry THF was added under argon at 0°C to lithium powder (Aldrich 37 239-0, A.W. 6.94, 897 mg, 129.27 mmol, 3 equiv.). The flask was put into a sonicator for 15 min and the purple solution was

stirred overnight at –5°C. To establish the total amount of base, the solution was titrated with HCl 0.1N (standard solution), using phenolphthalein as indicator (the transformation could be considered quantitative). To our experience, for best results, this reagent must be transferred via cannula.

3.5. (4R,5S)-(–)-5-Benzyloxymethyl-4-(dimethylphenylsilanyl)dihydrofuran-2-one **3**

A suspension of CuCN (M.W. 89.56, 1.9 g, 21.54 mmol, 1.1 equiv.) in 100 ml of dry THF was stirred under argon at –45°C. $Ph(Me)_2SiLi$ from Section 3.4 (see above, 43.09 mmol, 2.2 equiv.) was added via cannula and the mixture was vigorously stirred for 30 min. At –45°C, (*R*)-(+)-5-benzyloxymethyl-5*H*-furan-2-one **2** (M.W. 204.22, 4.0 g, 19.58 mmol) in 15 ml of dry THF was then slowly added via a syringe. The reaction mixture was stirred for 1 h, then quenched at –45°C with a saturated aqueous solution of NH_4Cl. The mixture was filtered, AcOEt (20 ml) was added, and the separated organic phase was washed with water, brine, and then dried over anhydrous Na_2SO_4. Chromatographic separation was carried out on silica gel using as eluent hexane:AcOEt (3:1). Yield 6.0 g (90%), oil, R_f: 0.44 hexane:AcOEt (3:1). $[\alpha]_D^{20} = -22$ (*c* 1.08, $CHCl_3$). ^1H NMR ($CDCl_3$) δ 7.48–7.27 (m, 10H), 4.51 (m, 1H), 4.49 (s, 2H), 3.57 (dd, $J = 11.18$ Hz, $J = 2.49$ Hz, 1H), 3.36 (dd, $J = 11.19$ Hz, $J = 4.68$ Hz, 1H), 2.64 (dd, $J = 17.70$ Hz, $J = 9.96$ Hz, 1H), 2.38 (dd, $J = 17.74$ Hz, $J = 11.06$ Hz, 1H), 1.96 (q, $J = 9.66$ Hz, 1H), 0.37 (s, 3H), 0.35 (s, 3H); ^{13}C NMR ($CDCl_3$) δ 176.87, 137.68, 135.26, 133.70, 129.88, 128.21, 127.75, 127.67, 82.05, 73.45, 71.38, 31.33, 24.07, –4.53, –5.15; IR (film, cm^{-1}) 3045, 3010, 2930, 2890, 2840, 1950, 1875, 1760, 1580, 1485, 1440, 1415, 1350; MS *m*/*z* 340, 325, 280, 271, 262, 241, 219, 191, 165, 156, 136, 117, 105, 91 (100%), 84, 75, 65, 57, 43. Anal. calcd for $C_{20}H_{24}O_3Si$: C, 70.48; H, 7.04. Found: C, 69.78; H, 6.97.

3.6. (4R,5S)-(–)-5-Benzyloxymethyl-4-hydroxydihydrofuran-2-one **4**

To a stirred solution of (4*R*,5*S*)-(–)-5-benzyloxymethyl-4-phenyldimethylsilyldihydrofuran-2-one **3** (M.W. 340.49, 5.0 g, 14.68 mmol) in 100 ml of AcOOH (39% in AcOH), at 0°C, under argon, Br_2 (1 M in AcOH, 7.3 ml, 0.5 equiv.) was added dropwise and the mixture was stirred for 5 h at rt. The solution was diluted with Et_2O (100 ml) and under stirring at 0°C 20 ml of an aqueous solution of $Na_2S_2O_3$ were carefully added. The organic layer was separated, and treated under stirring with 20 ml of a saturated aqueous solution of $NaHCO_3$ followed by an addition of $NaHCO_3$ powder until no further gas evolution was observed. The organic phase was washed again with 20 ml of a saturated aqueous solution of $NaHCO_3$, brine and then dried over anhydrous Na_2SO_4. Chromatographic purification was achieved on silica gel using as eluent hexane:AcOEt (1:1). Yield 2.1 g (65%), oil, R_f: 0.26 hexane:AcOEt (1:1). $[\alpha]_D^{20} = -5$ (*c* 1.38, $CHCl_3$). ^1H NMR ($CDCl_3$) δ 7.38–7.27 (m, 5H), 4.60–4.47 (complex, 4H), 3.70 (dd, $J = 10.70$ Hz, $J = 3.21$ Hz, 1H), 3.66 (dd, $J = 10.73$ Hz, $J = 3.59$ Hz, 1H), 2.93 (dd, $J = 18.05$ Hz, $J = 6.8$ Hz, 1H), 2.45 (dd, $J = 17.96$ Hz, $J = 2.65$ Hz, 1H), 2.09 (br, 1 OH); ^{13}C NMR ($CDCl_3$) δ 175.89, 137.28, 128.53, 127.98, 127.65, 86.26, 73.75, 69.71, 69.41, 38.37; IR (film, cm^{-1}) 3440, 3060, 3030, 2920, 2860, 1770, 1490, 1475, 1450, 1430, 1360; MS *m*/*z* 222, 176, 159, 133, 116, 105, 98, 91 (100%), 83, 77, 70, 65, 57, 51, 43. Anal. calcd for $C_{12}H_{14}O_4$: C, 64.79; H, 6.30. Found: C, 64.21; H, 6.12.

3.7. α,β-(4R,5S)-(–)-5-Benzyloxymethyltetrahydrofuran-2,4-diol **5**

To a stirred solution of 2-methyl-2-butene (M.W. 70.14, 19 ml, 182.23 mmol, 22.5 equiv.) in 20 ml of dry THF, at 0°C, under argon, a 1 M solution of BH_3–THF (45.3 ml, 5.6 equiv.) was added

and the mixture was stirred for 20 min. Then (4*R*,5*S*)-(–)-5-benzyloxymethyl-4-hydroxy-dihydrofuran-2-one **4** (M.W. 222.24, mmol 8.09, 1.8 g) in 10 ml of dry THF was added dropwise. After stirring for 24 h, water (20 ml) was added and the reaction mixture was refluxed for 30 min. Then at 0°C 20 ml of a 30% aqueous solution of H_2O_2 was added dropwise and the pH was adjusted to 8 with NaOH 2N. The mixture was stirred for an additional 10 min. AcOEt (30 ml) was added and the organic layer was separated. The aqueous phase was extracted twice with AcOEt and the collected organic layers were washed with brine and dried over anhydrous Na_2SO_4. The solvents were removed under vacuum (bath temperature max 30°C). Chromatographic purification was carried out on silica gel using as eluent AcOEt:hexane (3:1). Yield 1.1 g (60%), oil, R_f: 0.26 AcOEt:hexane (3:1). $[\alpha]_D^{20} = -32$ (*c* 1.22, $CHCl_3$, 2 h). α:β = 70:30. α-Anomer: ^{1}H NMR ($CDCl_3$) δ 7.37–7.27 (m, 5H), 5.54 (d, $J = 4.78$ Hz, 1H), 4.52 (s, 2H), 4.35 (dt, $J = 4.48$ Hz, $J = 1.50$ Hz, 1H), 4.23 (d, $J = 5.98$ Hz, 1H), 3.50 (dd, $J = 10.18$ Hz, $J = 4.73$ Hz, 1H), 3.45 (br, 2 OH), 3.41 (dd, $J = 10.17$ Hz, $J = 5.09$ Hz, 1H), 2.13 (d, $J = 13.40$ Hz, 1H), 1.98 (d, $J = 13.73$ Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 137.78, 128.37, 127.71, 127.61, 99.24, 85.86, 73.44, 73.33, 70.49, 41.30. β-Anomer: ^{1}H NMR ($CDCl_3$) δ 7.37–7.27 (m, 5H), 5.54 (d, $J = 4.78$ Hz, 1H), 4.57 (d, $J = 6.10$ Hz, 2H), 4.44 (m, 1H), 4.05 (q, $J = 4.06$ Hz, 1H), 3.61 (d, $J = 4.22$ Hz, 2H), 3.45 (br, 2 OH), 2.13 (d, $J = 3.05$ Hz, 1H), 2.11 (d, $J = 5.08$ Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 137.21, 128.51, 127.98, 127.85, 99.03, 84.95, 73.66, 73.10, 71.26, 43.61; IR (film, cm^{-1}) 3350, 3000, 2900, 2840, 1715, 1480, 1440; MS *m*/*z* 206, 115, 107, 91, 71, 59, 45 (100%). Anal. calcd for $C_{12}H_{16}O_4$: C, 64.21; H, 7.13. Found: C, 64.05; H, 7.08.

3.8. 2-Deoxy-L-ribose **6** and **7**

A solution of methanol containing 10% formic acid was degassed under vacuum for 5 min, then 20 ml of this solution were added carefully under argon to 1 g of Pd/C 10%. To this suspension, α,β-(4*R*,5*S*)-(–)-5-benzyloxymethyltetrahydrofuran-2,4-diol **5** (M.W. 224.25, 0.89 mmol, 200 mg), dissolved in 10 ml of the same solution, was added dropwise with stirring. After 1 h the catalyst was filtered off and washed with 5 ml of distilled water. The solvents were removed under vacuum (bath temperature max 30°C). The crude product was purified by column chromatography using as eluent AcOEt:MeOH (9:1). The title compound was isolated as a syrup which was crystallized from AcOEt:MeOH (4:1). Yield 95 mg (80%), white crystals, m.p. 89–90°C (from AcOEt:MeOH, 4:1). R_f: 0.25 AcOEt:MeOH (9:1). $[\alpha]_D^{20} = +52$ (*c* 1.0, H_2O, 24 h); lit.[16a] +52 (*c* 0.5, H_2O); lit.[16b] for 2-deoxy-D-ribose, –51 (*c* 1.3, H_2O); lit.[16c] –52 (*c* 1.05, H_2O). The spectroscopic data were consistent with those of commercially available 2-deoxy-D-ribose.

3.9. (R)-(+)-5-(tert-*Butyldiphenylsilanyloxymethyl*)-5H-*furan-2-one* **9**

To a stirred solution of *(R)*-(+)-5-hydroxymethyl-5*H*-furan-2-one **1** (M.W. 114.10, 50 mg, 0.44 mmol) in 2 ml of dry DMF, under argon, at rt were added NH_4NO_3 (M.W. 80.04, 105.2 mg, 1.31 mmol, 3 equiv.) and *tert*-butyldiphenylsilyl chloride (M.W. 274.87, 145.7 μl, 0.57 mmol, 1.3 equiv.). After 24 h water (10 ml) was added and the mixture was extracted with Et_2O (3×10 ml), the organic layer was dried over anhydrous Na_2SO_4 and the solvent evaporated under reduced pressure. The crude product was purified by chromatography on silica gel using as eluent hexane:AcOEt (4:1). Yield 140 mg (91%), white crystals, m.p. 79–80°C (from pentane/Et_2O). R_f: 0.37 hexane:AcOEt (4:1). $[\alpha]_D^{20} = +76$ (*c* 1.15, $CHCl_3$). ^{1}H NMR ($CDCl_3$) δ 7.62–7.36 (complex, 11H), 6.15 (dd, $J = 5.77$ Hz, $J = 1.76$ Hz, 1H), 5.04 (m, 1H), 3.93 (dd, $J = 10.68$ Hz, $J = 4.57$ Hz,

1H), 3.88 (dd, $J=11.18$ Hz, $J=5.08$ Hz, 1H), 1.02 (s, 9H); ^{13}C NMR ($CDCl_3$) δ 172.82, 153.94, 135.58, 132.79, 130.00, 127.86, 122.71, 83.19, 63.43, 26.70, 19.21; IR (KBr, cm^{-1}) 3090, 3050, 2880, 1960, 1890, 1740, 1595, 1450, 1420, 1380; MS m/z 295, 199 (100%), 181, 135, 77, 55. Anal. calcd for $C_{21}H_{24}O_3Si$: C, 71.48; H, 6.80. Found: C, 70.89; H, 6.45.

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