Carbohydrate Research, 191 (1989) 138–143
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

Note

Derivatives of methyl 4-deoxy-4-hydroxyamino-α-D-gluco- and -galacto-pyranosides

JEAN M. J. TRONCHET*†, NICOLETTA BIZZOZERO*, AND MICHEL GEOFFROY**

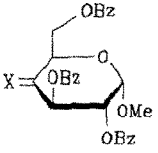
Institute of Pharmaceutical Chemistry, and Institute of Physical Chemistry**, University of Geneva, Sciences II, CH-1211, Geneva 4 (Switzerland)*

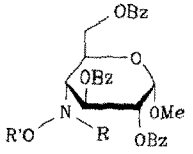
(Received November 28th, 1988; accepted for publication, January 14th, 1989)

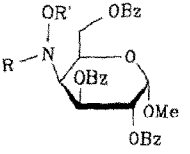
An ideal spin-labelled sugar should resemble very closely its natural congeners, be sufficiently stable, and give e.s.r. spectra offering usable information on the sugar and its environment. Deoxyhydroxyamino sugars approach this goal, but a drawback is their relatively short half-life.

We now describe the preparation and spectral properties of examples of such sugars spin-labelled on C-4. Some of these compounds have been described in a preliminary report[1].

The oxime **2** was obtained in 80% yield from the known[2] keto derivative **1** as an unresolvable 4:1 *E,Z* mixture, acetylation of which gave the *O*-acetylated *E*-oxime **3**. A slightly modified classical procedure[3] using sodium cyanoborohydride was used to reduce **2** to the hydroxyamino stage. Careful control of the pH (optimum value 3) was necessary. The deoxyhydroxyamino sugar derivatives **4** and **5** were obtained (combined yield of 84%) in the ratio 7:9 and isolated by chromatography. Each compound existed in an almost pure $^4C_1$ conformation and the establishment of the configurations by ^{1}H-n.m.r. spectroscopy was straightforward. In the ^{13}C-n.m.r. spectra, the carbon atoms bearing the hydroxyamino group were less deshielded than any of the other carbon atoms of the sugar ring. Their δ values were slightly different (**4**, 61.90; **5**, 61.55).







1 X = O
2 X = NOH
3 X = NOAc

4 R = R' = H
6 R = H, R' = Bz
9 R = H, R' = Ac
10 R = R' = Ac

5 R = R' = H
7 R = H, R' = Bz
8 R = R' = Bz
11 R = H, R' = Ac

†Author for correspondence.

0008-6215/89/$ 03.50

Acylation of **4** and **5** resulted mainly in *O*-acylation, although *N,O*-diacylation occurred in some instances. Thus, benzoylation of **4** gave exclusively **6** (74%), whereas **5** gave **7** (80%) and **8** (15%). In contrast, **4** gave a mixture of the monoacetylated derivative **9** (47%) and the *N,O*-diacetylated **10** (24%), whereas **5** gave exclusively **11** (93%).

The e.s.r. spectra of **4** and **5** showed the same hyperfine coupling with N and *H*-N (both 12 G), but different values were noted for $a_{H\text{-}4}$ (2.1 and 4.7 G, respectively); one extra long-range coupling of 1.2 G with a hydrogen atom was present in the spectrum of **5**. These significant differences in the spectra of **4** and **5** confirmed the sensitivity of e.s.r. to configurational changes[4].

Chemical intuition and examination of molecular models indicated that, in the *gluco* epimer, the equatorial nitroxyl group flanked by two equatorial BzO groups should prefer a conformation where the nitroxyl plane eclipses the H-4 bond ($a_H \sim 0$), whereas, in the *galacto* epimer, the axial nitroxyl should be free to rotate and to adopt other conformations leading to larger a_H coupling constants.

In order to obtain a more precise picture of the phenomenon, the model compounds methyl 2,3,6-tri-*O*-benzoyl-4-*C*-formyl-α-D-gluco- and -galacto-pyranosides, isosteres of **4** and **5**, respectively, were submitted to a molecular mechanics treatment using CHARMm[5] and the visualization and conformational search routines of QUANTA. For the *gluco* epimer, a grid scan indicated a unique almost eclipsed conformation, whereas, for the *galacto* compound, the $E = f(\theta)$ curve showed several minima, the global one corresponding to a dihedral angle (H-4–C-4–C-4′–H-4′) of −145°. Use of other algorithms, such as random sampling and Boltzmann jump, confirmed the previous results. Even though these methods have some limitations associated, for example, with the fact that geometrical constraints have to be applied to some important groups in order to avoid the generation of unnatural bond angles during the energy minimization, they give a reliable qualitative picture and constitute a considerable improvement over the manual manipulation of molecular models.

EXPERIMENTAL

General methods. — See ref. 6. Optical rotations were obtained for solutions in chloroform. Column chromatography was conducted with silica gel (Merck) 70–230 mesh.

*Methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-4-hydroxyimino-α-*D*-xylo-hexopyranoside* (**2**). — A solution of **1** (1.13 g, 2.24 mmol) and hydroxylamine hydrochloride (1.0 g, 14.4 mmol) in ethanol (15 mL) and pyridine (3 mL) was stirred for 2 h at 20°, then extracted with dichloromethane (200 mL). Column chromatography (dichloromethane–ethyl acetate 20:1) of the material in the extract gave **2** (0.93 g, 80%), m.p. 66.8–68.7°, $[\alpha]_D^{24}$ +178° (*c* 1.1); ν_{max}^{KBr} 3400 (OH) and 1700–1740 (C=O) cm^{-1}. ^{1}H-N.m.r. data (200 MHz, $CDCl_3$): *E*-isomer: δ 3.49 (s, 3 H, OMe), 4.71 (dd, 1 H, $J_{6a,6b}$ 12, $J_{5,6a}$ 3 Hz, H-6a), 4.97 (dd, 1 H, $J_{5,6b}$ 6 Hz, H-6b), 5.29 (d, 1 H,

$J_{1,2}$ 3.5 Hz, H-1), 5.37 (dd, 1 H, H-5), 5.64 (dd, 1 H, $J_{2,3}$ 5.5 Hz, H-2), 6.27 (d, 1 H, H-3), 7.25–8.20 (m, 15 H, 3 Ph), and 9.20 (bs, 1 H, NOH); *Z*-isomer: δ 3.52 (s, 3 H, OMe), 4.71 (dd, 1 H, H-6a), 4.95 (dd, 1 H, $J_{5,6b}$ 4, $J_{6a,6b}$ 12 Hz, H-6b), 5.21 (d, 1 H, $J_{1,2}$ 3.5 Hz, H-1), 5.37 (m, 1 H, H-5), 5.65 (dd, 1 H, $J_{2,3}$ 8 Hz, H-2), 6.70 (d, 1 H, H-3), 7.25–8.20 (m, 15 H, 3 Ph), and 8.48 (bs, 1 H, NOH). Mass spectrum: *m/z* 397 (0.3%, [M^+ – BzOH]), 382 (0.2), 368 (0.3), 354 (0.2), 328 (1), 284 (1), 256 (1), 245 (0.8), 231 (0.8), 216 (4), 205 (1), 185 (1), 174 (2), 155 (3), 142 (10), 122 (29), 105 (100), 77 (47), 69 (14), and 57 (25).

Anal. Calc. for $C_{28}H_{25}NO_9$ (519.51): C, 64.74; H, 4.85; N, 2.70. Found: C, 64.55; H, 4.69; N, 2.79.

*Methyl 4-acetoxyimino-2,3,6-tri-O-benzoyl-4-deoxy-α-*D-xylo-*hexopyranoside* (**3**). — A solution of **2** (0.52 g, 1 mmol) in ether (4 mL) and acetic anhydride (0.6 mL, 6 mmol) was kept at 20° for 48 h, then extracted as usual. Column chromatography (hexane–ethyl acetate, 3:2) of the product gave **3** (0.46 g, 82%), m.p. 53.3–54.6°, $[\alpha]_D^{22}$ +134° (*c* 1.1); ν_{max}^{KBr} 1780–1720 (C=O) cm^{-1}. ^{1}H-N.m.r. data (200 MHz, $CDCl_3$): δ 2.18 (s, 3 H, OAc), 3.48 (s, 3 H, OMe), 4.82 (dd, 1 H, $J_{5,6a}$ 4, $J_{6a,6b}$ 12 Hz, H-6a), 4.93 (dd, 1 H, $J_{5,6b}$ 7 Hz, H-6b), 5.30 (m, 2 H, H-1,5), 5.54 (t, 1 H, $J_{1,2} = J_{2,3}$ = 4 Hz, H-2), 6.21 (d, 1 H, H-3), 7.48 and 8.08 (2 m, 15 H, 3 Ph). Mass spectrum: *m/z* 397 (4%, [M^+ – BzOH – CH_2CO]), 338 (1), 275 (1), 244(1), 216(6), 105(100), 77 (22), and 51 (7).

Anal. Calc. for $C_{30}H_{27}NO_{10}$ (561.55): C, 64.17; H, 4.85; N, 2.49. Found: C, 64.27; H, 4.95; N, 2.43.

*Methyl 2,3,6-tri-O-benzoyl-4-deoxy-4-hydroxyamino-α-*D-*glucopyranoside* (**4**). — A solution of **2** (0.78 g, 1.5 mmol) and sodium cyanoborohydride (0.63 g, 10 mmol) in methanol (15 mL) at room temperature was brought to pH 3 (Methyl Orange) with 1:1 6M HCl–methanol. This same mixture was added continually to keep the pH at 3. After completion of the reaction, the mixture was concentrated and extracted (chloroform, 100 mL), and the extract was washed with water (3 × 50 mL), dried (Na_2SO_4), and concentrated. Column chromatography (CH_2Cl_2–AcOEt, 20:1) of the residue gave **5** (0.37 g, 47%) and **4** (0.29 g, 37%), m.p. 128.5–130.6°, $[\alpha]_D^{22}$ +110° (*c* 0.9); ν_{max}^{KBr} 3500 (OH) and 1730 (C=O) cm^{-1}. ^{1}H-N.m.r. data (200 MHz, $CDCl_3$): δ 2.99 (t, 1 H, $J_{3,4} = J_{4,5}$ = 10.5 Hz, H-4), 3.45 (s, 3 H, OMe), 4.66 (m, 2 H, H-5,6a), 4.90 (dd, 1 H, $J_{5,6b}$ 4.5, $J_{6a,6b}$ 13 Hz, H-6b), 5.15 (d, 1 H, $J_{1,2}$ 4 Hz, H-1), 5.35 and 5.68 (2 bs, 2 H, NH and NOH), 5.40 (dd, 1 H, $J_{2,3}$ 10.5 Hz, H-2), 6.05 (t, 1 H, H-3), 7.48 and 8.08 (2 m, 15 H, 3 Ph); ^{13}C (50 MHz, $CDCl_3$): δ 55.40 (OMe), 61.90 (C-4), 63.48 (C-6), 66.41, 67.95, 72.20 (C-2,3,5), 97.16 (C-1), 128.32, 128.40, 129.15, 129.27, 129.57, 129.80, 133.25 (Ar), 165.94, 166.60, and 167.02 (C=O). Mass spectrum: *m/z* 489 (0.7%, [M^+ – MeOH]), 474 (0.1), 397 (0.1), 367 (0.3), 342 (0.2), 313 (0.1), 262 (0.1), 234 (0.2), 214 (3), 201 (1), 191 (1), 176 (0.3), 149 (0.2), 122 (4), 105 (100), 91 (4), 77 (26), and 51 (7).

Anal. Calc. for $C_{28}H_{27}NO_9$ (521.53): C, 64.49; H, 5.22; N, 2.69. Found: C, 64.54; H, 5.24; N, 2.82.

*Methyl 2,3,6-tri-O-benzoyl-4-deoxy-4-hydroxyamino-α-*D-*galactopyranoside*

(**5**). — Obtained as described under **4, 5** had m.p. 165.2–165.8°, $[\alpha]_D^{22}$ +133° (*c* 1); ν_{max}^{KBr} 3450 (OH) and 1720 (C=O) cm^{-1}. ^{1}H-N.m.r. data (200 MHz, $CDCl_3$): δ 3.45 (s, 3 H, OMe), 3.84 (bd, 1 H, $J_{3,4}$ 5, $J_{4,5}$ 1 Hz, H-4), 4.52 (bd, 1 H, H-5), 4.67 (dd, 1 H, $J_{5,6a}$ 3, $J_{6a,6b}$ 12 Hz, H-6a), 4.81 (dd, 1 H, $J_{5,6b}$ 9 Hz, H-6b), 5.25 (d, 1 H, H-1), 5.58 (dd, 1 H, $J_{1,2}$ 3.5, $J_{2,3}$ 11 Hz, H-2), 5.90 (dd, 1 H, H-3), 6.20 (bs, 2 H, NHOH), 7.45 and 8.03 (2 m, 15 H, 3 Ph); ^{13}C (50 MHz, $CDCl_3$): δ 55.14 (OMe), 61.55 (C-4), 65.02 (C-6), 67.86 (C-5), 69.26 (C-2,3), 97.15 (C-1), 128.30, 129.10, 129.22, 129.53, 129.75, 129.92, 132.91, 133.12, 133.26 (Ar), 165.51, 165.83, and 166.24 (C=O). Mass spectrum: *m/z* 489 (0.1%, [M^+ − MeOH]), 432 (0.1), 384 (0.1), 367 (0.3), 338 (0.1), 313 (0.1), 264 (0.1), 245 (0.3), 234 (1), 216 (1), 202 (1), 191 (1), 178 (1), 163 (0.3), 149 (0.1), 122 (6), 105 (100), 96 (1), 85 (4), 77 (29), and 51 (9).

Anal. Calc. for $C_{28}H_{27}NO_9$ (521.53): C, 64.49; H, 5.22; N, 2.69. Found: C, 64.26; H, 5.04; N, 2.88.

*Methyl 2,3,6-tri-*O*-benzoyl-4-benzoyloxyamino-4-deoxy-α-*D*-glucopyranoside* (**6**). — Compound **4** (0.23 g, 0.44 mmol) was treated in the usual manner with benzoyl chloride (0.1 mL, 0.86 mmol) in pyridine (3 mL). Column chromatography (hexane–ethyl acxetate, 7:3) of the product gave **6** (0.20 g, 74%), m.p. 120.5–121.6°, $[\alpha]_D^{22}$ +80° (*c* 1); ν_{max}^{KBr} 3250 (NH) and 1730 (C=O) cm^{-1}. ^{1}H-N.m.r. data (200 MHz, $CDCl_3$): δ 3.39 (s, 3 H, OMe), 3.52 (dt, 1 H, $J_{4,5}$ 10.5, $J_{3,4}$ 10, $J_{4,NH}$ 2 Hz, H-4), 4.41 (dt, 1 H, $J_{5,6a}$ 4, $J_{5,6b}$ 3 Hz, H-5), 4.77 (dd, 1 H, $J_{6a,6b}$ 12.5 Hz, H-6a), 4.81 (dd, 1 H, H-6b), 5.12 (d, 1 H, $J_{1,2}$ 3.5 Hz, H-1), 5.21 (dd, 1 H, $J_{2,3}$ 10 Hz, H-2), 6.09 (t, 1 H, H-3), 7.40 and 7.95 (2 m, 20 H, 5 Ph), and 8.28 (d, 1 H, NH). Mass spectrum: *m/z* 333 (1%), 279 (1), 244 (1), 218 (1), 205 (3), 191 (1), 167 (4), 149 (14), 122 (29), 105 (100), 77 (43), 69 (11), and 57 (21).

Anal. Calc. for $C_{35}H_{31}NO_{10}$ (625.64): C, 67.19; H, 4.99; N, 2.24. Found: C, 67.08; H, 5.16; N, 2.16.

*Methyl 2,3,6-tri-*O*-benzoyl-4-benzyloxyamino-4-deoxy-α-*D*-galactopyranoside* (**7**). — Treatment of **5** (0.56 g, 1 mmol) with benzoyl chloride (0.14 mL, 1.2 mmol) in pyridine (5 mL) gave, after column chromatography (hexane–ethyl acetate, 7:3) of the product, **8** (0.11 g, 15%) and **7** (0.50, 80%), m.p. 62.6–64.4°, $[\alpha]_D^{24}$ +114° (*c* 1.1); ν_{max}^{KBr} 3250 (NH) and 1725 (C=O) cm^{-1}. ^{1}H-N.m.r. data (200 MHz, $CDCl_3$): δ 3.48 (s, 3 H, OMe), 4.02 (bdd, $J_{3,4}$ 5, $J_{4,5}$ 2, $J_{4,NH}$ 1 Hz, H-4), 4.61 (ddd, 1 H, $J_{5,6a}$ 5, $J_{5,6b}$ 8 Hz, H-5), 4.80 (dd, 1 H, $J_{6a,6b}$ 12.5 Hz, H-6a), 4.88 (dd, 1 H, H-6b), 5.35 (d, 1 H, $J_{1,2}$ 3.7 Hz, H-1), 5.70 (dd, 1 H, $J_{2,3}$ 11 Hz, H-2), 6.00 (dd, 1 H, H-3), 7.45 and 8.05 (2 m, 20 H, 4 Ph), and 8.73 (bs, 1 H, NH). Mass spectrum: *m/z* 503 (0.1%, [M^+ − BzOH]), 472 (0.1), 460 (0.1), 382 (0.2), 338 (2), 216 (3), 200 (1), 138 (0.3), 122 (6), 105 (100), 96 (1), and 77 (29).

Anal. Calc. for $C_{35}H_{31}NO_{10}$ (625.64): C, 67.19; H, 4.99; N, 2.24. Found: C, 67.38; H, 5.13; N, 2.37.

*Methyl 2,3,6-tri-*O*-benzoyl-4-(*N*-benzoyloxybenzamido)-4-deoxy-α-*D*-galactopyranoside* (**8**). — Obtained as described under **7, 8** had m.p. 84.5–86.1°, $[\alpha]_D^{22}$ ~ +115° (*c* 0.05); $\nu_{max}^{CCl_4}$ 1730 (C=O) cm^{-1}. ^{1}H-N.m.r. data (200 MHz, $CDCl_3$): δ 3.35 (s, 3 H, OMe), 4.68 (m, 1 H, H-5), 5.00 (m, 3 H, H-1,6,6), 5.40 (bs, 1 H,

H-4), 6.02 (m, 1 H, H-2), 6.21 (dd, 1 H, $J_{3,4}$ 4, $J_{2,3}$ 10 Hz, H-3), 7.45 (m, 15 H, 3 Ph), and 8.02 (m, 10 H, 2 Ph). Mass spectrum: *m/z* 446 (3%), 359 (2), 284 (2), 256 (7), 167 (13), 149 (36), 122 (31), 105 (76), 69 (64), and 55 (100).

Anal. Calc. for $C_{42}H_{35}NO_{11}$ (729.75): C, 69.13; H, 4.83; N, 1.92. Found: C, 68.84; H, 5.11; N, 2.02.

*Methyl 4-acetoxyamino-2,3,6-tri-*O*-benzoyl-4-deoxy-α-*D*-glucopyranoside* (**9**). — Treatment of **4** (180 mg, 0.34 mmol) with acetic anhydride (2 mL) and pyridine (2 mL) gave, after column chromatography (hexane–ethyl acetate, 7:3) of the product, **10** (50 mg, 24%) and **9** (90 mg, 47%), m.p. 120.2–121.4°, $[\alpha]_D^{23}$ +159° (*c* 1); ν_{max}^{KBr} 3250 (NH), 1800 and 1730 (C=O) cm^{-1}. ^{1}H-N.m.r. data (200 MHz, $CDCl_3$): δ 2.10 (s, 3 H, OAc), 3.48 (dt, 1 H, $J_{4,NH}$ 2, $J_{3,4}$ 10, $J_{4,5}$ 10.5 Hz, H-4), 3.50 (s, 3 H, OMe), 4.42 (dt, 1 H, $J_{5,6a}$ 4.5, $J_{5,6b}$ 3 Hz, H-5), 4.78 and 4.83 (m, 2 H, H-6a,6b), 5.20 (d, 1 H, $J_{1,2}$ 4 Hz, H-1), 5.23 (dd, 1 H, $J_{2,3}$ 10 Hz, H-2), 6.07 (t, 1 H, H-3), 7.45 and 8.05 (2 m, 15 H, 3 Ph), and 8.18 (d, 1 H, NH). Mass spectrum: *m/z* 472 (2%, [M^+ − AcOH − $MeO^·$]), 410 (1), 382 (2), 349 (11), 323 (11), 216 (45), 191 (22), 149 (22), 122 (56), 105 (100), 85 (34), and 77 (56).

Anal. Calc. for $C_{30}H_{29}NO_{10}$ (563.57): C, 63.94; H, 5.19; N, 2.49. Found: C, 64.13; H, 5.32; N, 2.58.

*Methyl 4-(*N*-acetoxyacetamido)-2,3,6-tri-*O*-benzoyl-4-deoxy-α-*D*-glucopyranoside* (**10**). — Obtained as described for **9**, **10** had m.p. 84.6–85.6°, $[\alpha]_D^{21}$ +125° (*c* 0.7); ν_{max}^{KBr} 1800 and 1730 (C=O) cm^{-1}. ^{1}H-N.m.r. data (200 MHz, $CDCl_3$): δ 1.86 (s, 3 H, Ac), 2.28 (s, 3 H, Ac), 4.18 (m, 1 H, H-5), 4.63 (dd, 1 H, $J_{6a,6b}$ 12.5, $J_{5,6a}$ 5 Hz, H-6a), 4.81 (bd, 1 H, $J_{5,6b}$ 2 Hz, H-6b), 5.30 (m, 1 H, H-4), 5.20 (m, 2 H, H-1,2), 6.12 (t, 1 H, $J_{2,3} = J_{3,4}$ = 10 Hz, H-3), 7.30 and 8.20 (2 m, 15 H, 3 Ph). Mass spectrum: *m/z* 531 (1%, [M^+ − CH_2CO − MeOH]), 409 (1), 367 (1), 287 (1), 245 (1), 214 (3), 201 (1), 105 (100), 96 (1), 77 (14), and 51 (2).

Anal. Calc. for $C_{32}H_{31}NO_{11}$ (605.60): C, 63.47; H, 5.16; N, 2.31. Found: C, 63.65; H, 5.38; N, 2.22.

*Methyl 4-acetoxyamino-2,3,6-tri-*O*-benzoyl-4-deoxy-α-*D*-galactopyranoside* (**11**). — Treatment of **5** (100 mg, 0.19 mmol) with acetic anhydride (2 mL) and pyridine (2 mL) gave, after column chromatography (dichloromethane–ethyl acetate, 20:1) of the product, **11** (100 mg, 93%), m.p. 62.3–63.5°, $[\alpha]_D^{22}$ +127° (*c* 0.8); ν_{max}^{KBr} 3260 (NH), 1810 and 1740 (C=O) cm^{-1}. ^{1}H-N.m.r. data (200 MHz, $CDCl_3$): δ 1.95 (s, 3 H, OAc), 3.47 (s, 3 H, OMe), 3.88 (m, 1 H, $J_{3,4}$ 4.5, $J_{4,5}$ 1.5, $J_{4,NH}$ 2.5 Hz, H-4), 4.51 (dt, 1 H, $J_{5,6a}$ 7, $J_{5,6b}$ 5 Hz, H-5), 4.66 (dd, 1 H, $J_{6a,6b}$ 11.5 Hz, H-6a), 4.71 (dd, 1 H, H-6b), 5.25 (d, 1 H, $J_{1,2}$ 3.8 Hz, H-1), 5.64 (dd, 1 H, $J_{2,3}$ 11 Hz, H-2), 5.92 (dd, 1 H, H-3), 7.45 and 8.05 (2 m, 15 H, 3 Ph), and 8.37 (bd, 1 H, NH). Mass spectrum: *m/z* 531 (0.3%, [M^+ − MeOH]), 489 (0.1), 409 (0.1), 367 (0.2), 338 (0.3), 305 (0.1), 259 (0.3), 244 (0.8), 216 (0.8), 191 (1), 178 (0.6), 154 (0.5), 122 (6), 105 (100), 96 (0.6), 85 (3), 77 (29), and 51 (1).

Anal. Calc. for $C_{30}H_{29}NO_{10}$ (563.57): C, 63.94; H, 5.19; N, 2.49. Found: C, 63.74; H, 5.03; N, 2.54.

ACKNOWLEDGMENTS

We thank Dr. F. Barbalat for help with the n.m.r. spectral interpretation, and Professor A. Buchs and Dr. F. Gulaçar for the m.s. spectra. The investigation was supported by the Swiss National Science Foundation, Grants 2.671-0.85 and 2000-5.304.

REFERENCES

1 J. M. J. TRONCHET, N. BIZZOZERO, F. BARBALAT-REY, AND M. GEOFFROY, *J. Carbohydr. Chem.*, 6 (1987) 155–160.
2 P. M. COLLINS, P. T. DOGANGES, A. KOLARIKOL, AND W. G. OVEREND, *Carbohydr. Res.*, 11 (1969) 199–206.
3 R. F. BORCH, M. D. BERNSTEIN, AND H. D. DURST, *J. Am. Chem. Soc.*, 93 (1971) 2897–2904.
4 J. M. J. TRONCHET, R. BENHAMZA, N. DOLATSHAHI, M. GEOFFROY, AND H. TÜRLER, *Nucleosides Nucleotides*, 7 (1988) 249–269.
5 B. R. BROOKS, R. E. BRUCCOLERI, B. D. OLAFSON, D. J. STATES, S. SWAMINATHAN, AND M. KARPLUS, *J. Comput. Chem.*, 4 (1983) 187–217.
6 J. M. J. TRONCHET, E. WINTER-MIHALY, J. RUPP, F. BARBALAT-REY, AND M. GEOFFROY, *Carbohydr. Res.*, 136 (1985) 375–390.