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Studies related to carba-pyranoses: a radical decarboxylation approach to monocarba-disaccharides †

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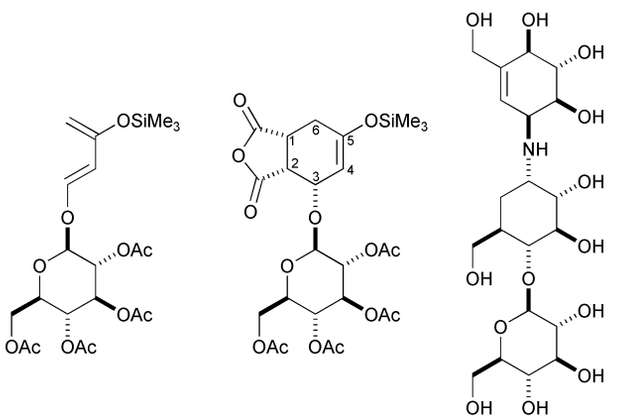
(1⟶1), (1⟶3) and (1⟶4) acetal-linked monocarba-disaccharides have been synthesised from a series of glucosylated γ- and δ-lactonic acids prepared from common intermediate **2**, obtained from the Diels–Alder reaction of maleic anhydride and (*E*)-1-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)-3-(trimethylsiloxy)buta-1,3-diene **1**. Thiohydroxamic ester **14**, prepared from γ-lactonic acid **9**, gave, upon treatment with *tert*-butyl thiol and light, the lactone **15**. Subsequent lithium aluminium hydride reduction and acetylation gave the (1⟶3) acetal-linked monocarbadisaccharides 1,6-di-*O*-acetyl-3-*O*-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl)-2,4-dideoxy-5a-carba-β-L-*threo*-hexopyranose **16**. In a similar manner, protected monocarba-disaccharides **13**, **19**, **30**, and **35** possessing L-*ido*, L-*xylo*, D-*arabino* and L-*ido* configurations of the carba-pyranose ring have been prepared.

Treatment of thiohydroxamic esters **14** and **17** with either *tert*-butyl thiol or trityl thiol, dimethyl sulfide, oxygen and light gave alcohols **20** and **22**. Subsequent lithium aluminium hydride reduction and acetylation gave the monocarbadisaccharides 1,4,6-tri-*O*-acetyl-3-*O*-[2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl]-2-deoxy-5a-carba-β-L-*arabino*-hexopyranose **21** and 1,2,4,6-tetra-*O*-acetyl-3-*O*-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl)-5a-carba-β-L-glucopyranose **23** respectively.

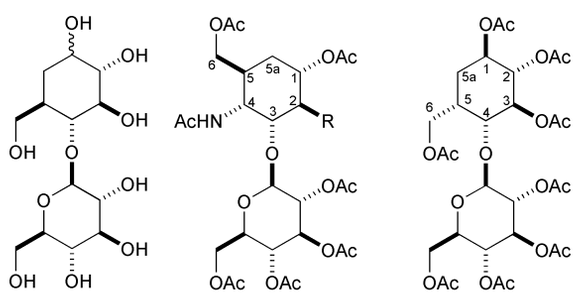
Introduction

Over the past few years, we have shown that anomerically linked glycopyranose units can confer a useful degree of facial reactivity on 1-oxybuta-1,3-dienes in cycloaddition reactions.[2–9] For example, the diene **1** displays good *Re*-face reactivity and undergoes highly *endo*-selective Diels–Alder reactions[2,3,8] with cyclic dienophiles such as maleic anhydride to give cycloadducts exemplified by **2**.



1 **2** **3**

In view of the emerging importance of saccharides in medicinal chemistry,[10,11] we have sought to prepare oligosaccharide-like compounds that incorporate the glycopyranose unit as an integral structural feature. Within this framework, monocarba-disaccharides that feature a pyranose entity glycosidically linked to a carba-pyranose moiety have attracted our attention. Such assemblies, which are found in some aminoglycoside antibiotics, *e.g.* validamycin A **3**,[12] have been the subject of relatively few synthetic endeavours. We planned to use Diels–Alder reactions to construct such monocarba-disaccharides and initially decided to employ the readily available cycloadduct **2**.[2,3] In consequence, any targets would feature a β-D-glucopyranosyl unit. Noting that few acetal-linked monocarba-disaccharides had been synthesised[13–18] (examples include compounds **4** and **5**[16]), we decided to prepare further representatives of this group and have recently reported a strategy where we synthesised the (1⟶3) linked amino-monocarba-disaccharides **6** and **7**.[19]



4 α
5 β

6 R = H
7 R = OAc

13

Central to that and the present work was the finding that adduct **2** could be easily functionalised and manipulated *via* ketone **8** to the γ-lactonic acid **9** and *via* ketone **10** to the γ- and δ-lactonic acids **11** and **12**.[19,20] This provided the means for differentiating the carbonyl groups of the anhydride functionality of **2** and its relatives. Further to this work we have communicated our initial findings where we have synthesised the (1⟶4) linked monocarba-disaccharide **13**.[1] This paper describes this latter finding in full and extensions to that work which culminated in the syntheses of (1⟶1), (1⟶3) and (1⟶4) acetal-linked systems.

Results and discussion

Acetal-linked (1⟶3) monocarba-disaccharides

The strategy employed would require that C-5 and C-6 of cycloadduct **2** would become the C-1 and C-5a centres of the

† A part of this work was reported in preliminary form, see ref. 1.

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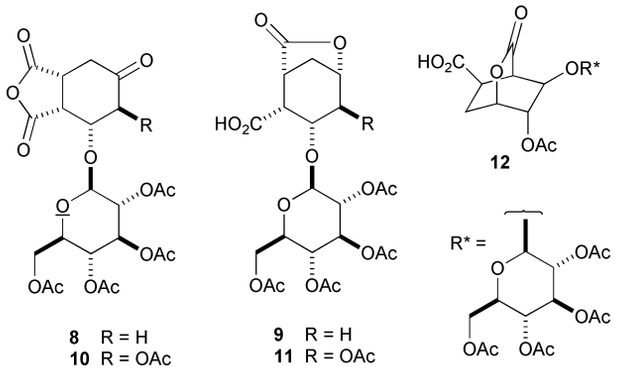


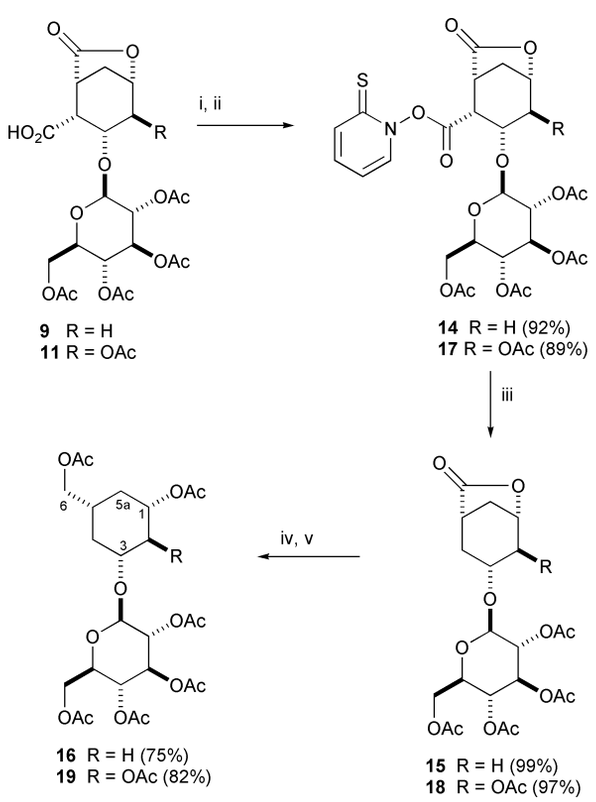
8 R = H
10 R = OAc

9 R = H
11 R = OAc

12

carbapyranose ring system of the (1⟶3)-linked monocarba-disaccharide. This necessitates that the anhydride carbonyl function at C-1 be selectively reduced to a hydroxymethyl group and that at C-2 be replaced by either a hydrogen atom or a hydroxyl group. With respect to the latter issue, it was envisaged that this could be achieved using the radical decarboxylation methodology, developed by Barton and coworkers,[21–24] of the corresponding thiohydroxamic ester derived from lactonic acids **9** and **11**.

To investigate this strategy light sensitive thiohydroxamic ester **14** was synthesised, in 92% yield, from **9** *via* its acid chloride (Scheme 1). Treatment of a dichloromethane solution of **14** and *tert*-butyl thiol, as the hydrogen atom donor, with light from a broad-spectrum tungsten filament lamp, rapidly gave the desired decarboxylated lactone **15** in near quantitative yield. The sequence was continued with the lithium aluminium hydride reduction of **15**, which gave, after subsequent treatment with acetic anhydride and pyridine, the peracetylated (1⟶3) linked 2,4-dideoxy-monocarba-disaccharide **16** in 75% yield. The structure and *threo* stereochemistry of **16** was apparent from an analysis of the ^{1}H NMR spectrum. The pseudo-anomeric proton resonated as an apparent triplet of triplets at δ 4.72 with coupling constants $J_{1,5a\text{-}ax}$ and $J_{1,2ax}$ (12Hz) confirming its axial orientation. Similarly the axial orientations of 3- and 5-H were evident from the apparent quartets assigned to 2-H_{ax} (δ 1.42) and that of 4-H_{ax} (δ 0.98), both with coupling constants J of 12 Hz. The analysis of the coupling constant data was also consistent with the carbocyclic ring adopting a $^1C_4$ chair-like conformation.



9 R = H
11 R = OAc

14 R = H (92%)
17 R = OAc (89%)

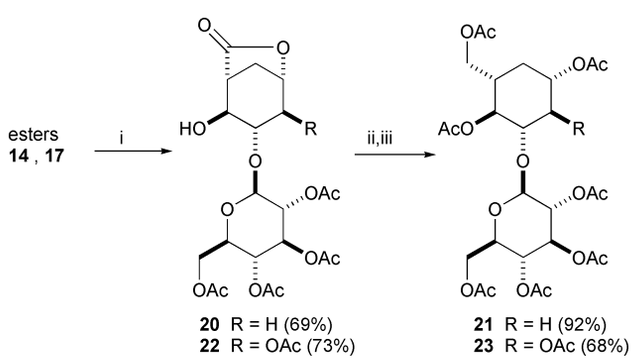
16 R = H (75%)
19 R = OAc (82%)

15 R = H (99%)
18 R = OAc (97%)

Scheme 1 *Reagents and conditions*: i $(COCl)_2$, DMF, CH_2Cl_2; ii, *N*-hydroxypyridinethione, THF; iii, *t*-BuSH, THF, *hv*; iv, $LiAlH_4$, THF, Δ; v, Ac_2O, py.

In a similar manner lactonic acid **11** was converted into thiohydroxamic ester **17** in 89% yield. Light promoted radical decarboxylation in the presence of *tert*-butyl thiol gave lactone **18** in 97% yield. Lithium aluminium hydride reduction and subsequent acetylation gave the protected (1⟶3)-monocarba-disaccharide, 1,2,6-tri-*O*-acetyl-3-*O*-[2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl]-4-deoxy-5a-carba-β-L-*xylo*-hexopyranose **19** (82%). The stereochemistry of **19** was also consistent with the analysis of coupling constant data obtained from its ^{1}H NMR spectrum. 2-H resonated as an apparent triplet at δ 4.95 with $J_{1,2}$ and $J_{2,3}$ both 9.5 Hz indicating axial orientations of 1-, 2- and 3-H. Similarly, the axial orientation of 5-H was confirmed from $J_{4ax,5}$ (12.5 Hz) and $J_{5,5a\text{-}ax}$ (12 Hz).

Barton has reported trapping the radical produced from the decomposition of thiohydroxamic esters with triplet oxygen.[21,24] A hydrogen atom donor is also required to trap the hydroperoxyl radical and continue the propogation cycle. *In situ* reduction of the hydroperoxide results in the formation of an alcohol. Treatment of an oxygen saturated solution of thiohydroxamic ester **14**, *tert*-butyl thiol and dimethyl sulfide gave the desired alcohol **20** and several minor by-products. Separation proved difficult and after repeated column chromatography and a crystallisation **20** was obtained in 43% yield (Scheme 2). The analytical and spectral data were consistent with the proposed structure of **20** with the IR spectrum showing absorptions at 3459 and 1788 cm^{-1} attributed to the hydroxyl and lactone carbonyl stretches respectively. The configuration at the newly functionalised chiral centre (C-2) was tentatively assigned as *S* on the basis that the trapping of the carbon centred radical had occurred from the least hindered face.



20 R = H (69%)
22 R = OAc (73%)

21 R = H (92%)
23 R = OAc (68%)

Scheme 2 *Reagents and conditions*: i, either ^{t}BuSH, Me_2S, O_2, THF, *hv*, or Ph_3CSH, Me_2S, O_2, THF, *hv*; ii, $LiAlH_4$, THF, Δ; iii, Ac_2O, py.

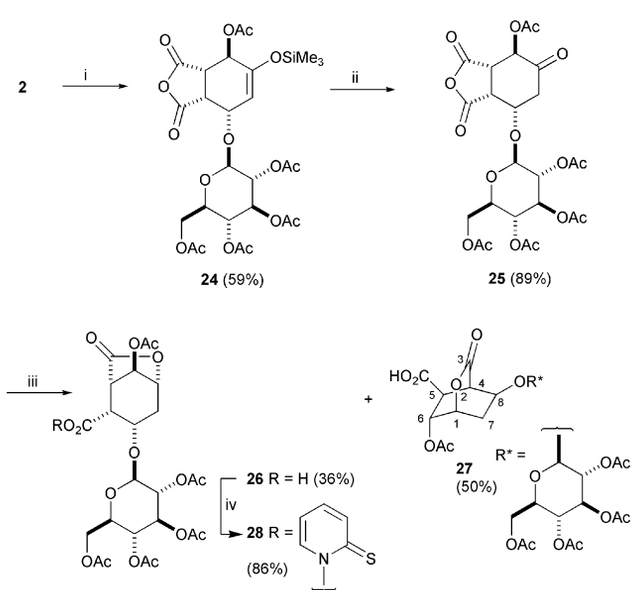
The oxidative decarboxylation protocol was carried out as described by Barton and coworkers[21,24] where oxygen was continuously bubbled through the reaction mixture. The volatility of *tert*-butyl thiol was of concern because the hydrogen atom source was being removed by the gas flow and also because of its very strong odour. The reaction was modified such that trityl thiol was used as the hydrogen atom source (Scheme 2). Reaction of **14** under these conditions resulted in an improvement of the yield of **20** to 69%. Furthermore, ^{1}H NMR spectroscopy showed that **20** was the only carbocyclic product present in the crude reaction product. Lithium aluminium hydride reduction of **20** and subsequent reduction gave the target (1⟶3) linked monocarba-disaccharide **21** in 92% yield. Once again analysis of the coupling constant data clearly showed the L-*arabino* configuration. The proton, 4-H, resonated as a doublet of doublets at δ 4.87 with coupling constants of 9.5 and 10.5 Hz, indicating the axial orientations of 3-, 4- and 5-H. This analysis also confirmed the assignment of the 2*S* configuration of hydroxylactone **20**.

Trapping the carbon centred radical derived from thiohydroxamic ester **17** with oxygen gave hydroxy-lactone **22** in 73% yield (Scheme 2). Lithium aluminium hydride reduction followed by acetylation gave the (1⟶3) linked disaccharide **23** in a 68% yield. The analytical and spectral data again were consistent with the assigned structure of **23** with the analysis of coupling constant data revealing the L-*gluco* stereochemistry of the carba-pyranose ring system.

Acetal linked (1⟶1) monocarba-disaccharides

Our attention turned to the synthesis of (1⟶1) linked systems. It must be noted that compounds **16** and **19** can also be considered as both (1⟶1) and (1⟶3) linked deoxy-sugars depending on the choice of the pseudo-anomeric centre. The synthesis of (1⟶1) linked monocarba-disaccharides necessitates that C-1 and C-2 of cycloadduct **2** become C-5 and C-5a of the target carba-pyranose ring system respectively. Further heteroatom functionalisation at C-6 of **2** is also desirable.

The introduction of an acetoxyl group at C-6 of **2** was achieved by allylic oxidation with lead(IV) acetate in boiling dichloromethane to give acetate **24** in 65% yield (Scheme 3).[25] Hydrolysis of the silylenol ether group of **24** under aqueous acidic conditions proved problematic with hydrolysis of the anhydride moiety also occurring. This was circumvented by treating a chloroform solution of **24** with a small amount of concentrated hydrochloric acid to give the target ketone **25** in 89% yield. Reduction of an acetic acid solution of ketone **25** with sodium cyanoborohydride resulted in concomitant opening of the anhydride to give γ- and δ-lactonic acids **26** and **27** in 36% and 50% yields respectively.

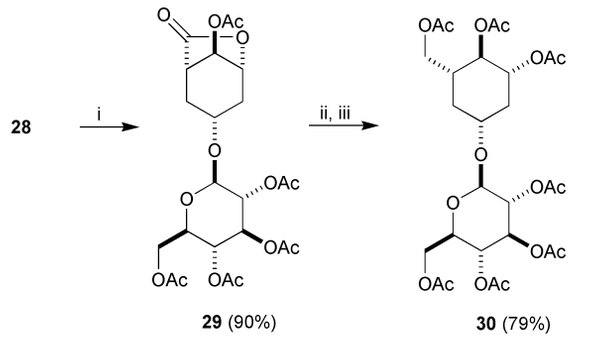


Scheme 3 *Reagents and conditions*: i $Pb(OAc)_4$, CH_2Cl_2, Δ; ii, conc. HCl, $CHCl_3$; iii, $NaBH_3CN$, HOAc; iv, $(COCl)_2$, DMF, CH_2Cl_2 then *N*-hydroxypyridinethione, THF.

Decarboxylation of thiohydroxamic ester **28**, formed from γ-lactonic acid **26** in 86% yield, proceeded smoothly to give lactone **29** in 90% yield (Scheme 4). Subsequent reduction and acetylation gave the (1⟶1) linked peracetylated monocarba-disaccharide **30** possessing the 5a-carba-2-deoxy-D-gluco-pyranosyl ring system.

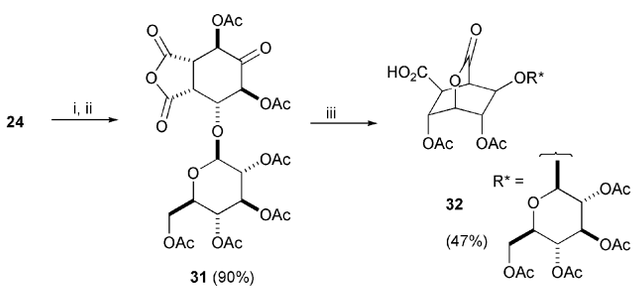
Acetal linked (1⟶4) monocarba-disaccharides

Clearly (1⟶4)-acetal linked monocarba-disaccharides could be accessed from δ-lactonic acids such as **12** *via* decarboxylation and subsequent reduction of the lactone functionality.



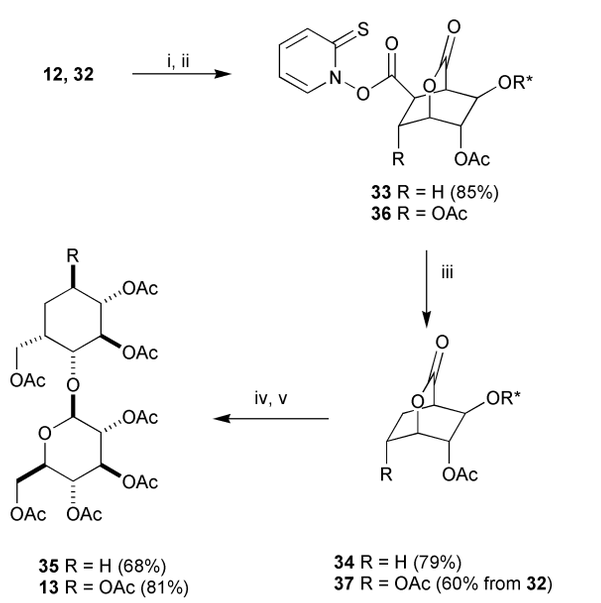
Scheme 4 *Reagents and conditions*: i, Ph_3CSH, CH_2Cl_2, *hν*; ii, $LiAlH_4$, THF, Δ; iii, Ac_2O, py.

A fully substituted δ-lactonic acid was obtained by treatment of the allylic acetate **24** with dimethyldioxirane, which, after acetylation under acidic conditions, gave ketone **31** in 90% yield. Sodium cyanoborohydride reduction of **31** gave the δ-lactonic acid **32** as the sole product albeit in 47% yield (Scheme 5).



Scheme 5 *Reagents and conditions*: i, $(CH_3)_2CO_2$, $(CH_3)_2CO$, CH_2Cl_2; ii, Ac_2O, $HClO_4$; iii, $NaBH_3CN$, HOAc.

Decarboxylation of thiohydroxamic ester **33** derived from **12** gave lactone **34** in 79% yield. Lithium aluminium hydride reduction of **34** and subsequent acetylation gave the protected (1⟶4) acetal-linked 1-deoxy-monocarba-disaccharide **35** (68%, Scheme 6).



Scheme 6 *Reagents and conditions*: i $(COCl)_2$, DMF, CH_2Cl_2; ii, *N*-hydroxypyridinethione, THF; iii, *t*-BuSH, THF, *hν*; iv, $LiAlH_4$, THF, Δ; v, Ac_2O, py.

The thioydroxamic ester **36** derived from acid **32** proved difficult to isolate and was used in the subsequent decarboxylation without purification. Treatment with *tert*-butyl thiol and irradiation with light gave lactone **37** in 60% yield for the

two steps. Reduction and acetylation of **37** gave 1,2,3,6-tetra-*O*-acetyl-4-*O*-[2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl]-5a-carba-α-L-*ido*-hexopyranose **13** (81%). The substitution pattern and stereochemistry about the carbocyclic ring of **13** had been established earlier by an X-ray crystallographic study.[1] In the solid state **13** exits in a $^4C_1$ conformation. On the basis of coupling constant data in deuteriochloroform solution both **13** and **35** are in distorted $^4C_1$ conformations. For both compounds $J_{3,2} = J_{3,4} = 4.5$ Hz: thus, using the modified Karplus equation,[26] $^3J = 12\cos^2\phi$, $\phi(H_3–C_3–C_2–H_2) = \phi(H_3–C_3–C_2–H_2) = 128°$.

In conclusion, we have shown that radical decarboxyation of thiohydroxamic ester derivatives of the Diels–Alder cycloadduct obtained from the reaction dienyl glucoside **1** and maleic anhydride can provide an effective method for the synthesis of acetal-linked monocarba-disaccharides. Dienyl glycosides prepared from other monosaccharides are available[7] and manipulation of their cycloadducts using this methodology would extend the range of monocarba-disaccharides accessible by this approach.

Experimental

Mps were measured on a Gallenkamp capillary melting point apparatus and are uncorrected. Specific optical rotations, given in 10^{-1} deg cm^2 g^{-1}, were measured at ambient temperaure using either a Jasco DIP-370 or a DIP-1000 polarimeter with a cell of path length 1.0 dm. Varian Gemini 200, VXR300 and Inova 500 spectrometers were used to obtain ^{1}H (200, 300 and 500 MHz) and ^{13}C (50 and 75 MHz) NMR spectra. Chemical shifts are reported as parts per million (ppm) using the δ scale. Coupling constants (J) and separations are reported to the nearest 0.5 Hz. IR spectra were recorded on a Perkin-Elmer 1600 series FTIR spectrophotometer. FAB mass spectra were recorded on a Kratos MSORF mass spectrometer; *m*-nitrobenzyl alcohol was used as the matrix and xenon as the ionising gas. Elemental analyses were carried out by Dr. R. G. Cunninghame and associates at the Campbell Microanalytical Laboratory, University of Otago, Dunedin, New Zealand. Thin layer chromatography (TLC) was performed on Merck silica gel DC Alurolle Kieselgel 60F$_{254}$ plates and visualised under a UV lamp and/or with a spray consisting of 5% w/v dodecamolybdophosphoric acid in ethanol with subsequent heating. Flash column chromatography was carried out using Merck Kieselgel 60 (230–400 mesh). All chromatography solvents were reagent grade. THF was distilled from sodium–benzophenone ketyl under nitrogen and dichloromethane was distilled from phosphorus pentoxide. All other solvents and reagents were purified using the methods described by Perrin *et al*.[27]

[(1′*R*,2′*R*,3′*S*,5′*S*)-7′-Oxo-3′-(2″,3″,4″,6″-tetra-*O*-acetyl-β-D-glucopyranosyloxy)-6′-oxabicyclo[3.2.1]octan-2′-carbonyloxy]-2(1*H*)-pyridinethione 14

Dry DMF (2 drops) was added to a solution of oxalyl chloride (0.100 cm^3, 1.15 mmol) and lactonic acid **9** (0.203 g, 0.393 mmol) in dry dichloromethane (30 cm^3) at room temperature. Stirring was continued until the evolution of bubbles ceased. Following the removal of solvent *in vacuo* (<30°), the reaction flask was wrapped with aluminium foil, the residue was dissolved in dry THF (30 cm^3), cooled to 0 °C and the sodium salt of 1-hydroxypyridine-2-thione (0.200 g, 1.34 mmol) was added. The resulting mixture was stirred at 0 °C in the absence of light for 30 min, poured into water (100 cm^3) and extracted with dichloromethane (2 × 50 cm^3). *Workup was performed rapidly under low lighting*. The combined extracts were washed with water (200 cm^3), dried ($MgSO_4$) and the solvent was removed. Crystallisation of the residue from dichloromethane–diethyl ether gave the *title compound* **14** (0.226 g, 92%) as light sensitive, pale green crystals. m.p. 155–156 °C; (Found: C, 51.6; H, 5.2; N, 2.1; S, 5.3. $C_{27}H_{31}O_{14}NS$ requires C, 51.8; H, 5.0; N, 2.2; S, 5.1%); $[\alpha]_D$ −42 (*c* 0.5 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1805 (C=O), 1775 (lactone C=O), 1746 (ester C=O), 1602, 1527; δ_H (300 MHz, $CDCl_3$) 1.87 (1H, d, *J* 11.5 Hz, 8′-H$_\beta$), 1.94, 2.00, 2.02 and 2.10 (each 3H, 4 × s, 4 × OAc) overlapping with 1.94–2.10 (1H, m, 4′-H), 2.58–2.75 (2H, m, 4′- and 8′-H$_\alpha$), 3.30 *br* (1H, d, *J* 5.5 Hz, 1′-H), 3.58 (1H, dd, *J* 4 and 2 Hz, 2′-H), 3.69 (1H, ddd, *J* 9.5, 4 and 3 Hz, 5″-H), 4.14–4.25 (2H, m, 6″-H$_2$), 4.73 (1H, t, *J* 4 and 4 Hz, 3′-H), 4.78 (1H, d, *J* 8 Hz, 1″-H), 4.87 (1H, t, 5 Hz, 5′-H), 4.99–5.18 (3H, m, 2″-, 3″- and 4″-H), 6.75 (1H, td, *J* 7 and 2 Hz, 5-H), 7.24–7.31 (1H, m, 4-H), 7.70 (1H, dd, *J* 9 and 2 Hz, 3-H), 8.00 (1H, dd, *J* 7 and 2 Hz, 6-H); δ_C (75 MHz, $CDCl_3$) 20.5, 20.6, 20.8, 34.9, 36.3, 37.5, 49.1, 61.8, 68.3, 71.1, 72.3, 72.6, 74.2, 75.2, 101.7, 113.0, 134.2, 137.1, 138.4, 155.8, 164.9, 168.7, 169.2, 170.6, 174.5, 175.5; *m/z* (FAB) 626 (MH^+, 34%), 457 (5), 331 ($C_{14}H_{19}O_9^+$, 22), 169 (77), 136 (100).

(1*S*,3*R*,5*S*)-3-(2′,3′,4′,6′-Tetra-*O*-acetyl-β-D-glucopyranosyloxy)-6-oxabicyclo[3.2.1]octan-7-one 15

A solution of *tert*-butyl thiol (5.0 cm^3, 44 mmol) and ester **14** (0.277 g, 0.443 mmol) in dry THF (10 cm^3) at ambient temperature, under an atmosphere of dry nitrogen was irradiated with light from a broad spectrum tungsten filament lamp (150 W) until the yellow solution decolourised (5 min). Evaporation of the solvent *in vacuo* and purification of the residue by silica gel column chromatography [ethyl acetate/hexane (3 : 7) to ethyl acetate, gradient elution] gave the *title compound* **15** (0.208 g, 99%), R_f = 0.5 (EtOAc), as white crystals from dichloromethane–diethyl ether; m.p. 189–191 °C; (Found: C, 53.2; H, 6.1. $C_{21}H_{28}O_{12}$ requires C, 53.4; H, 6.0%); $[\alpha]_D$ −40 (*c* 0.1 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1783 (lactone C=O), 1745 and 1729 (ester C=O); δ_H (300 MHz, $CDCl_3$) 1.74 (1H, d, *J* 11.5, 8-H$_\beta$), 1.85 (1H, ddd, *J* 14.5, 5 and 2.5 Hz, 2-H$_\beta$), 1.93 (1H, ddd, *J* 15, 6 and 1 Hz, 4-H$_\beta$), 1.99, 2.01, 2.08 and 2.13 (each 3H, 4 × s, 4 × OAc), 2.20–2.31 (1H, m, 2-H$_\alpha$), 2.33–2.52 (2H, m, 4- and 8-H$_\alpha$), 2.52–2.57 (1H, m, 1-H), 3.63 (1H, ddd, *J* 9.5, 4.5 and 2.5 Hz, 5′-H), 4.13 (1H, dd, *J* 12.5 and 3 Hz, 6′-H$_a$), 4.22(1H, dd, *J* 12.5 and 4.5 Hz, 6′-H$_b$) overlapping with 4.25 *br* (1H, t, *J* 5.5 Hz, 3-H), 4.59 (1H, d, *J* 8 Hz, 1′-H), 4.81 (1H, *br* t, *J* 5 Hz, 5-H), 4.95 (1H, dd, *J* 9.5 and 8 Hz, 2′-H), 5.07 (1H, t, *J* 9.5 Hz, 4′-H), 5.19 (1H, t, *J* 9.5 Hz, 3′-H); δ_C (50 MHz, $CDCl_3$) 20.7, 20.8, 20.9, 31.7, 34.9, 35.8, 37.3, 62.0, 68.6, 69.6, 70.9, 71.8, 73.0, 76.2, 97.7, 169.4, 169.8, 170.4, 170.7, 177.9; *m/z* 473 (MH^+, 8%), 331 ($C_{14}H_{19}O_9^+$, 38), 169 (45), 154 (100).

1,6-Di-*O*-acetyl-3-*O*-[2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl]-2,4-dideoxy-5a-carba-β-L-*threo*-hexopyranose 16

Lithium aluminium hydride (0.160 g, 4.22 mmol) was carefully added to a solution of lactone **15** (0.116 g, 0.246 mmol) in dry THF (40 cm^3) and the resulting mixture was heated under reflux for 24 h. After cooling, water (1 cm^3) then 1 M sodium hydroxide solution (1 cm^3) was carefully added. The solvents were evaporated, the residue was treated with acetic anhydride (10 cm^3) and pyridine (10 cm^3), and the mixture was stirred for 48 h. Water (100 cm^3) was added and the mixture extracted with dichloromethane (2 × 100 cm^3). The extract was washed with 1 M aqueous hydrochloric acid, water (100 cm^3) and dried ($MgSO_4$). Removal of the solvent and purification of the residue by silica gel column chromatography [ethyl acetate/hexane (3 : 2) as eluent] gave the *title compound* **16** (0.104 g, 75%), R_f = 0.3 (1 : 1 ethyl acetate/hexane), as a white foam; (Found: C, 53.8; H, 6.4. $C_{25}H_{36}O_{14}$ requires C, 53.6; H, 6.5%); $[\alpha]_D$ −18 (*c* 0.5 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 2948, 1738 (ester C=O); δ_H (300 MHz, $CDCl_3$) 0.98 (1H, q, *J* 12 Hz and 4-H$_{ax}$), 1.05 (1H, q, *J* 12 Hz, 5a-H$_{ax}$), 1.42 (1H, q, *J* 12 Hz, 2-H$_{ax}$), 1.61–1.85 (1H, m, 5-H), 2.00, 2.02, 2.03, 2.06 and 2.08 (3, 6, 3, 3 and 3H, 5 × s, 6 × OAc) overlapping with 1.86–2.08 (2H, m, 4- and 5a-H$_{eq}$), 2.33–2.44 (1H, m, 2-H$_{eq}$), 3.59–3.73 (2H, m, 3- and

5′-H), 3.92 and 3.98 (each 1H, overlapping dd and dd, each *J* 11 and 6.5 Hz, 6-H_a and 6-H_b), 4.10 (1H, dd, *J* 12.5 and 2.5 Hz, 6′-H_a), 4.24 (1H, dd, *J* 12.5 and 5.5 Hz, 6′-H_b), 2.75 (1H, d, *J* 8 Hz, 1′-H), 4.72 (1H, tt, *J* 12 and 4.5 Hz, 1-H), 4.94 (1H, dd, *J* 9.5 and 8 Hz, 2′-H), 5.05 (1H, t, *J* 9.5 Hz, 4′-H), 5.19 (1H, t, *J* 9.5 Hz, 3′-H); δ_C (75 MHz, $CDCl_3$) 20.5, 20.6, 20.8, 21.2, 32.0, 33.9, 34.4, 38.8, 62.1, 67.8, 68.4, 69.6, 71.4, 71.7, 72.7, 76.0, 99.8, 169.1, 169.3, 170.2, 170.6, 170.8; *m/z* 561 (MH^+, 5%), 331 ($C_{14}H_{19}O_9^+$, 79), 169 (94), 136 (100).

[(1′*R*,2′*R*,3′*R*,4′*R*,5′*S*)-4′-Acetoxy-7′-oxo-3-(2″,3″,4″,6″-tetra-*O*-acetyl-β-D-glucopyranosyloxy)-6′-oxabicyclo[3.2.1]octane-2′-carbonyloxy]-2(1*H*)-pyridinethione 17

The sodium salt of 1-hydroxypyridine-2-thione (0.340 g, 2.28 mmol) was added to a flask wrapped in aluminium foil containing a solution of acid chloride derived from **11**[19] (0.350 g, 0.590 mmol) in dry THF (30 cm^3) at 0 °C under nitrogen. The resulting mixture was stirred at 0 °C in the absence of light for 30 min. Workup as for the preparation of **14** and crystallisation of the residue from dichloromethane–diethyl ether gave the *title compound* **17** (0.359 g, 89%) as light-sensitive pale green crystals; m.p. 148–149 °C; (Found: C, 50.6; H, 4.8; N, 1.9; S, 4.6. $C_{29}H_{33}O_{16}NS$ requires C, 50.95; H, 4.9; N, 2.05; 4.7%); $[\alpha]_D$ +31 (*c* 0.3 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1818 (C=O), 1790 (γ-lactone C=O), 1747 (ester C=O), 1605 and 1529; δ_H (300 MHz, $CDCl_3$) 1.86, 1.99, 2.02, 2.10 and 2.14 (each 3H, 5 × s, 5 × OAc), 2.27 (1H, d, *J* 12.5 Hz, 8′-H_β), 2.51 (1H, dt, *J* 12 and 6 Hz, 8′-H_α), 3.38 *br* (1H, d, *J* 5.5 Hz, 1′-H), 3.66 (1H, dd, *J* 4.5 and 1.5 Hz, 2′-H), 3.75 (1H, ddd, *J* 9.5, 5 and 2.5 Hz, 5″-H), 4.19 (1H, dd, *J* 12.5 and 5 Hz, 6″-H_a), 4.29 (1H, dd, *J* 12.5 and 2.5 Hz, 6″-H_b), 4.44 *br* (1H, d, *J* 5 Hz, 3′-H), 4.75–4.82 (2H, m, 1″- and 5′-H), 5.02 (1H, dd, *J* 9.5 and 8 Hz, 2″-H), 5.06–5.19 (2H, m, 4″- and 3″-H), 5.64 *br* (1H, d, *J* 4 Hz, 4′-H), 6.73 (1H, td, *J* 7 and 2 Hz, 5-H), 7.23–7.30 (1H, m, 4-H), 7.69 (1H, dd, *J* 8.5 and 1.5 Hz, 3-H), and 7.93 (1H, dd, *J* 7 and 1 Hz, 6-H); *m/z* (FAB) 684 (MH^+, 10%), 331 ($C_{14}H_{19}O_9^+$, 13), 169 (81), 136 (100).

(1*S*,3*R*,4*S*,5*S*) 4-Acetyloxy-3-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)-6-oxabicyclo[3.2.1]octan-7-one 18

A solution of *tert*-butyl thiol (1.50 cm^3, 13.3 mmol) and thionopyridyl ester **17** (0.503 g, 0.736 mmol) in dry tetrahydrofuran (7 cm^3) at ambient temperature under an atmosphere of dry nitrogen, was irradiated with a broad spectrum tungsten filament lamp (150 W) until the yellow solution decolourised (10 min). Workup as described for the preparation of **15** and purification of the residue by silica gel column chromatography [gradient elution; ethyl acetate/hexane (3 : 7) to ethyl acetate] gave after crystallisation from dichloromethane–diethyl ether the *title compound* **18** (0.380 g, 97%), R_f = 0.5 (EtOAc), as white crystals; m.p. 210–212 °C; (Found: C, 52.0; H, 5.8. $C_{23}H_{30}O_{14}$ requires C, 52.1; H, 5.7%); $[\alpha]_D$ −31 (*c* 0.2 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1785 (γ-lactone C=O), 1744 (ester C=O); δ_H (300 MHz, $CDCl_3$) 1.99, 2.01, 2.09, 2.10 (3, 3, 6 and 3H, 4 × s, 5 × OAc) overlapping with 1.99–2.22 (3H, m, 2-H_2 and 8-H_β), 2.24–2.36 (1H, m, 8-H_α), 2.50–2.57 (1H, m, 1-H), 3.66 (1H, ddd, *J* 10, 4.5 and 2.5 Hz, 5′-H), 4.02 *br* (1H, d, *J* 5 Hz, 3-H), 4.15 (1H, dd, *J* 12.5 and 2.5 Hz, 6′-H_a), 4.24 (1H, dd, *J* 12.5 and 4.5 Hz, 6′-H_b), 4.60 (1H, d, *J* 8 Hz, 1′-H), 4.78 *br* (1H, t, *J* 5 Hz, 5-H), 4.96 (1H, dd, *J* 9.5 and 8 Hz, 2′-H), 5.09 (1H, t, *J* 9.5 Hz, 4′-H), 5.19–5.25 (2H, m, 3′- and 4-H); δ_C (50 MHz, $CDCl_3$) 20.6, 20.7, 20.9, 30.0, 31.7, 35.1, 61.8, 68.5, 69.4, 70.9, 71.9, 72.8, 73.6, 75.1, 98.7, 168.9, 169.3, 169.4, 170.3, 170.7, 177.0; *m/z* 553 (MNa^+, 6%), 531 (MH^+, 23), 471 ($MH^+ - CH_3COOH$, 2), 331 ($C_{14}H_{19}O_9^+$, 98), 169 ($MH^+ - 362$, 98), 136 (100).

1,2,6-Tri-*O*-acetyl-3-*O*-[2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl]-4-deoxy-5a-carba-β-L-*xylo*-hexopyranose 19

Lithium aluminium hydride (0.201 g, 5.30 mmol) was carefully added to a solution of **18** (0.380 g, 0.716 mmol) in dry THF (30 cm^3) and the resulting mixture was heated under reflux for 17 h. The workup procedure and subsequent acetylation protocol as described for the preparation of **16** was then employed. Purification of the residue by silica gel column chromatography [ethyl acetate/hexane (7 : 3) as eluent], gave the *title compound* **19** (0.362 g, 82%), R_f = 0.8 (EtOAc), as white crystals after crystallisation from dichloromethane–diethyl ether–hexanes; m.p. 164–166 °C; (Found: C, 52.4; H, 6.3. $C_{27}H_{38}O_{16}$ requires C, 52.4; H, 6.2%); $[\alpha]_D$ −19 (*c* 0.6 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1750 (ester C=O); δ_H (300 MHz, $CDCl_3$) 1.19 (1H, q, *J* 12.5 Hz, 4-H_{ax}) overlapping with 1.25 (1H, q, *J* 12 Hz, 5a-H_{ax}), 1.74–1.91 (1H, m, 5-H), 1.99, 2.01, 2.02, 2.03, 2.06 and 2.08 (3, 3, 6, 3, 3 and 3H, 6 × s, 7 × OAc) overlapping with 1.99–2.14 (2H, m, 4-H_{eq} and 5a-H_{eq}), 3.63–3.73 (2H, m, 5′- and 3-H), 3.93 (1H, dd, *J* 11 and 6.5 Hz, 6-H_a) overlapping with 3.98 (1H, dd, *J* 11 and 6 Hz, 6-H_b), 4.08 (1H, dd, *J* 12.5 and 2 Hz, 6′-H_a), 4.29 (1H, dd, *J* 12.5 and 4.5 Hz, 6′-H_b), 4.55 (1H, d, *J* 8 Hz, 1′-H), 4.78–4.91 (2H, m, 1- and 2′-H), 4.95 (1H, t, *J* 9.5 and 9.5 Hz, 2-H), 5.07 (1H, t, *J* 9.5 Hz, 4′-H) and 5.16 (1H, t, *J* 9.5 Hz, 3′-H); *m/z* 641 (MNa^+, 2%), 619 (MH^+, 2), 331 ($C_{14}H_{19}O_9^+$, 65), 169 (100).

(1*R*,2*S*,3*S*,5*S*)-3-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)-2-hydroxy-6-oxabicyclo[3.2.1]octan-7-one 20

Pyridylthione **14** (0.250 g, 0.48 mmol) and trityl thiol (2.0 g, 7.27 mmol) were dissolved in a mixture of dimethyl sulfide (5 cm^3) and dry THF (10 cm^3) saturated with oxygen initially in the absence of light. The mixture, with a constant stream of oxygen bubbling through, was irradiated with light from broad spectrum tungsten filament lamp (150 W) for 20 min. The solution was flushed with nitrogen, dimethyl sulfide (5 cm^3) added, and the mixture stirred for 2 h. The solution was concentrated under reduced pressure and purification of the residue by silica gel column chromatography [ethyl acetate : hexanes (1 : 1) to ethyl acetate, gradient elution] gave the *title compound* **20** (0.162 g, 69%) as white crystals. R_f = 0.4 (EtOAc); m.p. 189–191 °C (CH_2Cl_2–Et_2O); (Found: C, 51.7; H, 5.7. $C_{21}H_{28}O_{13}$ requires C, 51.6; H, 5.8%); $[\alpha]_D$ −19 (*c* 0.3 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 3459 *br* (O–H), 2939, 1788 (lactone C=O), 1760, 1738 (ester C=O); δ_H (300 MHz, $CDCl_3$) 2.00, 2.02, 2.10 and 2.11 (each 3H, 4 × s, 4 × OAc), 2.02–2.17 (2H, m, 4-H_2), 2.17–2.28 (1H, m, 8-H_a), 2.33 (1H, d, *J* 11.5 Hz, 8-H_b), 2.38–2.44 *br* (1H, s, O-H), 2.73 *br* (1H, t, *J* 4 Hz, 1-H), 3.68 (1H, ddd, *J* 10, 4.5 and 3 Hz, 5′-H), 4.00 *br* (1H, d, *J* 5.5 Hz, 3-H), 4.17(1H, dd, *J* 12.5 and 3 Hz, 6′-H_a) overlapping with 4.10–4.17 (1H, m, 2-H), 4.23 (1H, dd, *J* 12.5 and 4 Hz, 6′-H_b), 4.69 (1H, d, *J* 8 Hz, 1′-H), 4.77–4.83 (1H, m, 5-H), 4.93 (1H, dd, *J* 9.5 and 8 Hz, 2′-H), 5.07 (1H, t, *J* 9.5 Hz, 4′-H), 5.18 (1H, t, *J* 9.5 Hz, 3′-H); δ_C (75 MHz, $CDCl_3$) 20.7, 20.9, 30.3, 32.4, 43.7, 61.9, 67.9, 68.4, 70.8, 72.0, 72.9, 74.9, 76.6, 98.7, 169.4, 169.7, 170.4, 170.9, 175.2; *m/z* 511 (MNa^+, 3%), 489 (MH^+, 7), 331 ($C_{14}H_{19}O_9^+$, 34), 154 (100).

1,4,6-Tri-*O*-acetyl-3-*O*-[2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl]-2-deoxy-5a-carba-β-L-*arabino*-hexopyranose 21

Lithium aluminium hydride (0.171 g, 4.51 mmol) was carefully added to a solution of the lactone **20** (0.146 g, 0.299 mmol) in dry THF (30 cm^3) and the resulting mixture was heated under reflux for 21 h. The workup procedure and subsequent acetylation protocol as described for the preparation of **16** was employed. Purification of the residue by silica gel column chromatography [ethyl acetate : hexanes (3 : 2) as eluent] gave the *title compound* **21** (0.170 g, 92%), R_f = 0.8 (EtOAc), as a white solid. m.p. 180 °C (CH_2Cl_2–Et_2O); (Found: C, 52.5; H, 6.1. $C_{27}H_{38}O_{16}$ requires C, 52.4; H, 6.2%); $[\alpha]_D$ −32 (*c* 0.4 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1732 (ester C=O); δ_H (300 MHz, $CDCl_3$) 1.41 (1H, q, *J* 12.5 Hz, 5a-H_{ax}), 1.64 (1H, q, *J* 12, 2-H_{ax}), 1.76–1.90 (1H, m, 5-H), 1.99, 2.02, 2.04 and 2.10 (3, 3, 9,

6H, 4 × s, 7 × OAc) overlapping with 1.99–2.10 (1H, m, 5a-H_{eq}), 2.30–2.43 (1H, m, 2-H_{eq}), 3.60–3.72 (2H, m, 3- and 5′-H), 3.90 (1H, dd, *J* 11.5 and 3.5 Hz, 6-H_a), 4.00 (1H, dd, *J* 11.5 and 5.5 Hz, 6-H_b), 4.11 (1H, dd, *J* 12.5 and 2.5 Hz, 6′-H_a), 4.26 (1H, dd, *J* 12.5 and 5 Hz, 6′-H_b), 4.61 (1H, d, *J* 8 Hz, 1′-H), 4.78 (1H, tt, *J* 11.5 and 4.5 Hz, 1- H) overlapping with 4.87 (1H, dd, *J* 10.5 and 9.5 Hz, 4-H), 4.95 (1H, dd, *J* 9.5 and 8 Hz, 2′-H), 5.04 (1H, t, *J* 9.5 Hz, 4′-H), and 5.14 (1H, t, *J* 9.5 Hz, 3′-H); δ_C (75 MHz, $CDCl_3$) 20.5, 20.6, 20.8, 21.1, 21.2, 32.7, 37.2, 37.3, 62.0, 63.6, 68.3, 68.5, 71.1, 71.8, 72.9, 74.2, 77.5, 101.1, 169.4, 169.8, 170.3, 170.7, 170.8; *m*/*z* 641 (MNa^+, 8%), 619 (MH^+, 13%), 559 (19), 331 ($C_{14}H_{19}O_9^+$, 58), and 169 ($MH^+ - 450$, 100).

(1*R*,2*S*,3*R*,4*R*,5*S*)-4-Acetyloxy-3-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)-2-hydroxy-6-oxabicyclo[3.2.1]octan-7-one 22

Pyridylthione **17** (0.250 g, 0.37 mmol) and trityl thiol (1.60 g, 5.79 mmol) were dissolved in a mixture of dimethyl sulfide (5 cm^3) and dry THF (10 cm^3) saturated with oxygen initially in the absence of light. The mixture, with a constant stream of oxygen bubbling through, was irradiated with light from a broad spectrum tungsten filament lamp (150 W) for 20 min. The solution was flushed with nitrogen, dimethyl sulfide (5 cm^3) added, and the mixture stirred for 2 h. The solution was concentrated under reduced pressure and purification of the residue by flash chromatography [ethyl acetate : hexanes (1 : 1) as eluent] gave the *title compound* **22** (0.150 g, 73 %), R_f = 0.5 (ethyl acetate), as a white foam; (Found: C, 50.5; H, 5.8. $C_{23}H_{30}O_{15}$ requires C, 50.6; H, 5.5 %); υ_{max} (KBr)/cm^{-1} 3447 (O–H), 1792 (lactone C=O), 1753 (acetate C=O); δ_H (300 MHz, $CDCl_3$) 1.98–2.22 (1H, m, 8-H_{eq}), 2.00, 2.02, 2.07, 2.11 and 2.13 (each 3H, 5 × s, 5 × OAc), 2.37 *br* (1H, d, *J* 4.5 Hz, OH), 2.62 (1H, d, *J* 12.5 Hz, 8-H_{ax}), 2.77 *br* (1H, t, *J* 4.5 Hz, 1-H), 3.70 (1H, ddd, *J* 9.5, 4.5 and 2.5 Hz, 5′-H), 3.90–3.93 (1H, m, 3-H), 4.07–4.13 (1H, m, 2-H), 4.19 (1H, dd, *J* 12.5 and 2.5 Hz, 6′-H_a), 4.26 (1H, dd, *J* 12.5 and 4.5 Hz, 6′-H_b), 4.72 (1H, d, *J* 8 Hz, 1′-H), 4.72–4.77 (1H, m, 5-H), 4.97 (1H, dd, *J* 9.5 and 8 Hz, 2′-H), 5.03–5.06 (1H, m, 4-H), 5.09 (1H, t, *J* 9.5 Hz, 4′-H), 5.19 (1H, t, *J* 9.5 Hz, 3′-H); δ_C (75 MHz, $CDCl_3$) 20.7, 20.8, 20.9, 25.1, 43.3, 61.8, 68.3, 68.7, 70.1, 70.7, 72.3, 72.8, 75.9, 78.4, 99.4, 169.2, 169.4, 169.5, 170.4, 171.0. *m*/*z* 547 (MH^+, 10%), 331 ($C_{14}H_{19}O_9^+$, 50%), 169 (50%), 154 (100%).

1,2,4,6-Tetra-*O*-acetyl-3-*O*-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl)-pseudo-β-L-glucopyranose 23

Lithium aluminium hydride (0.140 g, 3.69 mmol) was added to a solution of alcohol **22** (0.130 g, 0.24 mmol) in dry tetrahydrofuran (10 cm^3) and the mixture heated at reflux for 17 h. Workup and subsequent acetylation as described for the preparation of **16** was employed. Crystallisation of the residue from dichloromethane–diethyl ether gave the *title compound* **23** (0.110 g, 68%), R_f 0.2 (1 : 1 ethyl acetate : hexanes), as white crystals; mp 172–174 °C; (Found: C, 51.3; H, 6.2. $C_{29}H_{40}O_{18}$ requires C, 51.5; H, 6.0%); $[a]_D$ +2.7 (*c* 0.5 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1746 (s, acetate C=O), 1370, 1231, 1039, 560 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 1.50 *br* (1H, q, *J* 12.5 Hz, 5a-H_{ax}), 1.82–2.17 (2H, m, 5-H and 5a-H_{eq}), 1.97, 2.00, 2.01, 2.02, 2.03, 2.05, 2.07, 2.13 (each 3H, 8 × s, 8 × OAc), 3.67 (1H, ddd, *J* 9.5, 4.5 and 2.5 Hz, 5′-H), 3.73 (1H, t, *J* 9.5 Hz, 3-H), 3.90 (1H, dd, *J* 11.5 and 3.5 Hz, 6-H_a), 3.98 (1H, dd, *J* 11.5 and 5 Hz, 6-H_b), 4.04 (1H, dd, *J* 12.5 and 2.5 Hz, 6′-H_a), 4.39 (1H, dd, *J* 12.5 and 4.5 Hz, 6′-H_b), 4.58 (1H, d, *J* 8 Hz, 1′-H), 4.83–4.95 (1H, m, 1-H), 4.90 *br* (1H, t, *J* 9.5 Hz, 2′-H), 4.97–5.08 (3H, m, 2-H, 4-H and 4′-H), 5.10 (1H, t, *J* 9.5 Hz, 3′-H); δ_C (75 MHz, $CDCl_3$) 20.4, 20.6, 20.7, 20.8, 20.9, 21.0, 29.4, 36.7, 61.8, 63.0, 68.1, 70.4, 71.1, 71.8, 72.4, 72.9, 73.1, 79.5, 100.8, 169.3, 169.5, 169.8, 170.4, 170.8; *m*/*z* 699 (MNa^+, 1%), 677 (MH^+, 2%), 331 ($C_{14}H_{19}O_9^+$, 50%), 169 (100%).

(3*S*,4*R*,5*S*,6*R*)-6-Acetoxy-3-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)-1-trimethylsiloxycyclohex-1-ene-4,5-dicarboxylic anhydride 24

A mixture of cycloadduct **2** (5.00 g, 8.52 mmol) and lead tetraacetate (10.0 g, 22.6 mmol) in dry dichloromethane (100 cm^3) was heated to reflux under an inert atmosphere for 1 h. Water (100 cm^3) was added and the mixture cooled to RT. Celite was added, the mixture filtered through a Celite pad, and the filtrate partitioned between dichloromethane and water. The organic layer was washed with saturated sodium hydrogen carbonate solution, dried over anhydrous sodium sulfate, and concentrated under reduced pressure. The brown residue was crystallised from dichloromethane–diethyl ether and recrystallised from the same solvents to give the *title compound* **24** (3.25 g, 59%) as white crystals; mp 140–142 °C; (Found: C, 50.4; H, 5.7. $C_{27}H_{36}O_{16}Si$ requires C, 50.3; H, 5.6%); $[a]_D$ −16 (*c* 0.1 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1780, 1750 (ester C=O), 1650; δ_H (300 MHz, $CDCl_3$) 0.21 (9H, s, $SiMe_3$), 1.98, 2.01, 2.07, and 2.10 (3, 3, 3, and 6H, 4 × s, 5 × OAc), 3.41 (1H, dd, *J* 10.5 and 4.5 Hz, 5-H), 3.54 (1H, dd, *J* 10.5 and 4 Hz, 6-H), 3.66 (1H, ddd, *J* 10, 4.5, and 2.5 Hz, 5′-H), 4.11 (1H, dd, *J* 12.5 and 2.5 Hz, 6′-H_a), 4.18 (1H, dd, *J* 12.5 and 4.5 Hz, 6′-H_b), 4.56 (1H, d, *J* 8 Hz, 1′-), 4.59 (1H, dd, *J* 6.5 and 4.5 Hz, 4-H), 4.88 (1H, dd, *J* 9.5 and 8 Hz, 2′-H), 5.02 (1H, t, *J* 9.5 Hz, 4′-H), 5.15 (1H, t, *J* 9.5 Hz, 3′-H), 5.20 (1H, dd, *J* 7 and 2 Hz, 3-H) and 5.64 (1H, dd, *J* 4 and 2 Hz, 1-H); *m*/*z* 716 ($MSiC_3H_8^+$, 11%), 169 (100).

(3*S*,4*R*,5*S*,6*R*)-6-Acetoxy-3-[(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl)oxy]-1-oxocyclohexane-4,5-dicarboxylic anhydride 25

A solution of the allylic acetate **24** (0.500 g, 0.77 mmol) in chloroform was treated with conc. hydrochloric acid (0.2 cm^3). The mixture was stirred for 1 h at room temperature, washed with water and dried ($MgSO_4$). Removal of the solvent and crystallisation of the residue from dichloromethane–diethyl ether gave the *title compound* **25** (0.398 g, 89%) as white crystals; mp 202–206 °C; (Found: C, 50.2; H, 4.9. $C_{24}H_{28}O_{16}$ requires C 50.4, H 4.9 %); $[a]_D$ −37 (*c* 0.5 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1844 and 1787 (anhydride C=O), 1752 (C=O); δ_H (500 MHz, $CDCl_3$) 1.99, 2.02, 2.09, 2.10 and 2.22 (each 3H, 5 × s, 5 × OAc), 2.56 (1H, dd, *J* 19 and 3 Hz, 2-H_{ax}), 3.09 (1H, dd, *J* 19 and 2.5 Hz, 2-H_{eq}), 3.46 (1H, dd, *J* 11 and 3 Hz, 4-H), 3.60 (1H, dd, *J* 11 and 9.5 Hz, 5-H), 3.69 (1H, ddd, *J* 10, 4.5 and 2.5 Hz, 5′-H), 4.14 (1H, dd, *J* 12.5 and 4.5 Hz, 6′-H_a), 4.18 (1H, dd, *J* 12 and 2.5 Hz, 6′-H_b), 4.63 (1H, d, *J* 8 Hz, 1′-H), 4.66 (1H, q, *J* 3 Hz, 3-H), 4.96 (1H, dd, *J* 9.5 and 8 Hz, 2′-H), 5.04 (1H, t, *J* 9.5 Hz, 4′-H), 5.19 (1H, t, *J* 9.5 Hz, 3′-H), 5.59 (1H, d, *J* 9 Hz, 6-H); *m*/*z* 573 (MH^+, 10%), 513 (MH^+ − AcOH, 4), 331 ($C_{14}H_{19}O_9^+$, 36), 169 (49), 154 (100).

(1*S*,2*R*,3*S*,5*R*,8*R*)-8-Acetoxy-7-oxo-3-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)-6-oxabicyclo[3.2.1]octan-2-carboxylic acid 26

A mixture of sodium cyanoborohydride (1.90 g, 30.2 mmol) and ketone **25** (3.50 g, 6.11 mmol) in glacial acetic acid (100 cm^3) was stirred at room temperature for 18 h. The solution was concentrated under reduced pressure, the residue partitioned between dichloromethane and 1 M hydrochloric acid and the aqueous phase extracted with dichloromethane. The combined organic layers were washed with 1 M hydrochloric acid and dried over anhydrous sodium sulfate. The solution was concentrated under reduced pressure to a white slurry, from which the *title compound* **26** (1.25 g, 2.18 mmol, 36%) crystallised from dichloromethane–diethyl ether as slightly impure (incorrect microanalysis) white crystals; υ_{max} (KBr)/cm^{-1} 3288 (*br* O–H), 1791 (lactone C=O), 1741 (ester C=O), 1720 (acid C=O); δ_H (500 MHz, $CDCl_3$) 1.5–2.3 *br* (1H, s, CO-OH), 1.97–2.18 (1H, m, 4-H_{ax}), 2.00, 2.02, 2.05, 2.10 and 2.14

(each 3H, 5 × s, 5 × OAc), 2.49 *br* (1H, dd, *J* 15.5, 4.0 Hz, 4-H_{eq}), 3.25 *br* (1H, d, *J* 5.5 Hz, 1-H), 3.29 (1H, dd, *J* 4.5 and 2 Hz, 2-H), 3.67 (1H, ddd, *J* 10, 4.5 and 3 Hz, 5′-H), 4.17 (1H, dd, *J* 12.5 and 4.5 Hz, 6′-H_a), 4.21 (1H, dd, *J* 12.5 and 3 Hz, 6′-H_b), 4.52 *br* (1H, t, *J* 4.5 Hz, 3-H), 4.73 (1H, d, *J* 8 Hz, 1′-H), 4.80 *br* (1H, t, *J* 4.5 Hz, 5-H), 4.90 (1H, dd, *J* 9.5 and 8 Hz, 2′-H), 5.07 (1H, t, *J* 9.5 Hz, 4′-H), 5.15 (1H, t, *J* 9.5 Hz, 3′-H), 5.27 *br* (1H, t, *J* 5.5 Hz, 8-H); *m*/*z* 575 (MH^+, 13%), 331 ($C_{14}H_{19}O_9^+$, 62 %), 169 (100%).

The mother liquors were concentrated under reduced pressure to give slightly impure *(1*R*,4*R*,5*S*,6*R*,8*S*) 6-acetoxy-8-(2′,3′,4′,6′-tetra*-O-*acetyl-β-*D*-glucopyranosyloxy)-3-oxo-2-oxabicyclo[2.2.2]octan-3-carboxylic acid* **27** (1.75 g, 50%) as a white foam; υ_{max} (KBr)/cm^{-1} 3467 (COOH), 1753 (C=O); δ_H (500 MHz, $CDCl_3$) *inter alia* 1.99–2.20 (1H, m, 7-H_a), 1.99, 2.03, 2.08, 2.11 and 2.11 (each 3H, 5 × s, 5 × OAc), 2.49 *br* (1H, dd, *J* 16 and 9.5 Hz, 7-H_b), 2.60 (1H, dd, *J* 4.5 and 1.5 Hz, 5-H), 3.31 *br* (1H, dd, *J* 3 and1.5 Hz, 4-H), 3.74 (1H, ddd, *J* 10, 5 and 2.5 Hz, 5′-H), 4.20 (1H, dd, *J* 12.5 and 2 Hz, 6′-H_a), 4.26 (1H, dd, *J* 12.5 and 4 Hz, 6′-H_b), 4.43 (1H, dt, *J* 9 and 3 Hz, 8-H), 4.70 *br* (1H, t, *J* 4 Hz, 1-H), 4.74 (1H, d, *J* 8 Hz, 1′-H), 4.96 (1H, dd, *J* 10 and 8 Hz, 2′-H), 5.10 (1H, t, *J* 9.5 Hz, 4′-H), 5.22 (1H, t, *J* 9.5 Hz, 3′-H), 5.22 *br* (1H, t, *J* 4.5 Hz, 6-H); *m*/*z* 597 (MNa^+, 25%), 575 (MH^+, 10), 331 ($C_{14}H_{19}O_9^+$, 90), 169 (100).

Lactonic acid **26**, upon treatment with ethereal diazomethane, was characterised as its methyl ester, *methyl (1*S*,2*R*,3*S*,5*R*,8*R*)-8-acetoxy-7-oxo-3-(2′,3′,4′,6′-tetra*-O-*acetyl-β-*D*-glucopyranosyloxy)-6-oxabicyclo[3.2.1]octan-2-carboxylate* **26b**. m.p. 239–241 °C (CH_2Cl_2–hexanes); (Found: C, 50.7; H, 5.4. $C_{25}H_{32}O_{16}$ requires C, 51.0;H, 5.5 %); $[\alpha]_D$ −46 (*c* 0.7 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1800 (lactone C=O) and 1750 (ester C=O); δ_H (300 MHz, $CDCl_3$) 1.98, 2.01, 2.05, 2.10 and 2.12 (each 3H, s, 5 × OAc), 2.44 (1H, dd, *J* 16 and 4 Hz, 4-H), 3.22 (1 H, dd, *J* 4 and 2 Hz, 2-H), 3.28 *br* (1H, d, *J* 5.5 Hz, 1-H), 3.61–3.70 (1H, m, 5′-H), 3.81 (3H, s, CO_2Me), 4.12–4.24 (2H, m, 6′-H_2), 4.52 *br* (1H, t, *J* 4 Hz, 3-H), 4.57 (1H, d, *J* 8 Hz, 1′-H), 4.77 (1H, t, *J* 4.5Hz, 5-H), 4.95 (1H, dd, *J* 8 and 9 Hz, 2′-H), 5.05 *br* (1H, t, *J* 9 Hz, 4′-H), 5.12 (1H, t, *J* 9 Hz, 3′-H), 5.25 (1H, t, *J* 5.5 Hz, 8-H); *m*/*z* 611 (MNa^+, 8%), 589 (MH^+, 6), 331 ($C_{14}H_{19}O_9^+$, 90), 169 (100).

Similarly, lactonic acid **27** was characterised as its methyl ester, *methyl (1*R*,4*R*,5*S*,6*R*,8*S) 6-acetoxy-8-(2′,3′,4′,6′-tetra*-O-*acetyl-α-*D*-glucopyranosyloxy)-3-oxo-2-oxabicyclo[2.2.2]octan-3-carboxylate* **27b**. m.p. 153–156 °C (ether); (Found: C, 50.9; H, 5.2. $C_{25}H_{32}O_{16}$ requires C, 51.0; H, 5.5 %); $[\alpha]_D$ −57 (*c* 1.2 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1755 (lactone and ester C=O); δ_H (300 MHz, $CDCl_3$) 1.99, 2.03, 2.08, 2.09 and 2.11 (each 3H, 5 × s, 5 × OAc), 2.47 (1H, ddd, *J* 16, 9 and 1 Hz, H-7), 2.56 (1H, dd, *J* 5 and 1.5 Hz, H-5), 3.16 (1H, dd, *J* 3 and 1.5 Hz, H-4), 3.70 (1H, ddd, *J* 9.5, 4 and 2.5Hz, 5′-H), 3.80 (3H, s, CO_2Me), 4.17 (1H, dd, *J* 12.5 and 2.5 Hz, H-6′), 4.27 (1H, dd, *J* 12.5 and 4 Hz, H-6′), 4.41 (1H, dt, *J* 9 and 3 Hz, H-8), 4.63–4.72 (2H, m, 1′- and 1-H), 4.95 (1H, dd, J 9.5 and 8 Hz, 2′-H), 5.10 (1H, t, *J* 9.5 Hz, 4′-H), 5.21 (1H, t, *J* 9.5 Hz, 3′-H), 5.26–5.29 (1H, m, 6-H); *m*/*z* 589 (MH^+, 5%), 169 (100).

[(1′*S*,2′*R*,3′*S*,5′*R*,8′*R*)-8′-Acetoxy-7′-oxo-3-(2″,3″,4″,6″-tetra-*O*-acetyl-β-D-glucopyranosyloxy)-6′-oxabicyclo[3.2.1]octane-2′-carbonyloxy]-2(1*H*)-pyridinethione 28

Using the procedure described for the preparation of **14**, treatment of **26** (1.00 g, 1.74 mmol) in dry dichloromethane (30 cm^3) with oxalyl chloride (0.50 cm^3, 5.7 mmol) and *N*,*N*-dimethylformamide (0.1 cm^3) and subsequent reaction of the acid chloride in dry THF (30 cm^3) with sodium 1-hydroxypyridine-2-thione (1.00 g, 6.71 mmol) gave the *title compound* **28** (1.02 g, 86%) after crystallisation from dichloromethane–diethyl ether as light-sensitive pale green crystals; mp 160–163 °C; (Found: C, 50.8; H, 4.7; N, 2.1; S 4.7. $C_{29}H_{33}NO_{16}S$ requires C, 51.0; H, 4.9; N, 2.1; S, 4.7%); $[\alpha]_D$ −34 (*c* 0.3 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1824 and 1795 (C=O), 1750 (ester C=O); δ_H (300 MHz, $CDCl_3$) 1.89–2.20 (1H, m, 4′-H_{ax}), 1.94, 2.01, 2.02, 2.11 and 2.19 (each 3H, 5 × s, 5 × OAc), 2.61 (1H, dd, *J* 15.5 and 4 Hz, 4′-H_{eq}), 3.45 *br* (1H, d, *J* 4.5 Hz, 1′-H), 3.69 (1H, ddd, *J* 9.5, 5 and 3 Hz, 5″-H), 3.91 (1H, dd, *J* 4.5 and 2 Hz, 2′-H), 4.17 (1H, dd, *J* 12.5 and 5 Hz, 6″-H_a), 4.23 (1H, dd, *J* 12 and 2.5 Hz, 6″-H_b), 4.71 *br* (1H, t, *J* 4 Hz, 3′-H), 4.78 (1H, d, *J* 8 Hz, 1″-H), 4.86 *br* (1H, t, *J* 4.5 Hz, 5′-H), 5.02 (1H, dd, *J* 9.5 and 8 Hz, 2″-H), 5.06–5.17 (2H, m, 3″- and 4″-H), 5.36 (1H, t, *J* 5.5 Hz, 8′-H), 6.75 (1H, td, *J* 7 and 2 Hz, 5-H), 7.28 (1H, ddd, *J* 8.5, 7 and 1.5 Hz, 4-H), 7.71 (1H, dd, *J* 9 and 2 Hz, 3-H), 7.99 (1H, dd, *J* 7.0, 1.5 Hz, 6-H); δ_C (75 MHz, $CDCl_3$) 20.6, 20.6, 20.7, 20.8, 20.9, 29.6, 38.6, 42.8, 61.7, 68.3, 68.8, 71.1, 72.4, 72.7, 73.2, 74.1, 101.6, 113.1, 134.2, 137.3, 138.3, 165.1, 168.7, 169.1, 169.3, 170.4, 170.6. *m*/*z* 684 (MH^+, 20%), 331 ($C_{14}H_{19}O_9^+$, 19), 136 (100).

(1*S*,3*R*,5*R*,8*R*)-8-Acetoxy-3-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)-6-oxabicyclo[3.2.1]octan-7-one 29

A mixture of thionopyridyl ester **28** (0.500 g, 0.73 mmol) and trityl thiol (4.04 g, 14.5 mmol) in dry dichloromethane (10 cm^3) at 0 °C under an inert atmosphere for 20 min was irradiated with light from a broad spectrum tungsten filament lamp (150 W). Concentration of the orange solution under reduced pressure and purification of the residue by silica gel column chromatography [ethyl acetate : hexanes (1 : 1) as eluent], R_f 0.7 (ethyl acetate), gave the *title compound* **29** (0.350 g, 90%) as a white solid; mp 158–159 °C (CH_2Cl_2–diethyl ether); (Found: C, 51.9; H, 5.9. $C_{23}H_{30}O_{14}$ requires C, 52.1; H 5.7 %); $[\alpha]_D$ −64 (*c* 0.5 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1780 (lactone C=O), 1756 (ester C=O); δ_H (300 MHz, $CDCl_3$) 2.00, 2.02, 2.09, 2.13 and 2.14 (each 3H, 5 × s, 5 × OAc), 2.05–2.17 (3H, m, 2-H_2 and 4-H), 2.28 (1H, dd, *J* 16 and 4.5 Hz, 4-H), 2.72–2.77 (1H, dt, *J* 5.5 and 3 Hz, 1-H), 3.64 (1H, ddd, *J* 9.5, 4.5 and 2.5 Hz, 5′-H), 4.15 (1H, dd, *J* 12.5 and 2.5 Hz, 6′-H_a), 4.21 (1H, dd, *J* 12.5 and 4 Hz, 6′-H_b), 4.21–4.27 (1H, m, 3-H), 4.59 (1H, d, *J* 8 Hz, 1′-H), 4.79 (1H, br t, *J* 4.5 Hz, 5-H), 4.95 (1H, dd, *J* 9.5 and 8 Hz, 2′-H), 5.07 (1H, t, *J* 9.5 Hz, 4′-H), 5.17 (1H, t, *J* 5.5 Hz, 8-H), 5.19 (1H, t, *J* 9.5 Hz, 3′-H); δ_C (75 MHz, $CDCl_3$) 20.7, 20.8, 20.8, 20.9, 25.0, 29.4, 38.0, 61.9, 68.4, 68.5, 69.5, 70.9, 71.9, 72.9, 74.9, 97.6, 169.4, 169.5, 169.8, 170.4, 170.7, 173.6; *m*/*z* 553 (MNa^+, 15%), 531 (MH^+, 7), 331 ($C_{14}H_{19}O_9^+$, 96), 169 (100).

3,4,6-Tri-*O*-acetyl-1-*O*-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl)-2-deoxy-5a-carba-β-D-*arabino*-hexopyranose 30

Treatment of a solution of lactone **29** (0.100 g, 0.19 mmol) in dry THF (10 cm^3) with lithium aluminium hydride (0.100 g, 2.64 mmol) and subsequent acetylation as described for the preparation of compound **16** gave, after crystallisation of the residue from dichloromethane–diethyl ether–hexanes, the *title compound* **30** (0.090 g, 79%) as white crystals; mp 178–181 °C; (Found: C, 52.3; H, 6.3. $C_{27}H_{38}O_{16}$ requires C, 52.4, H 6.2 %); $[\alpha]_D$ −9.1 (*c* 0.5 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1740 (ester C=O); δ_H (300 MHz, $CDCl_3$) 1.41 *br* (1H, q, *J* 12.5 Hz, 5a-H_{ax}), 1.60 (1H, q, *J* 11.5 Hz, 2-H_{ax}), 1.78–1.92 (1H, m, 5-H), 1.95–2.12 (1H, m, 5a-H_{eq}), 2.00, 2.01, 2.03, 2.03, 2.04, 2.06, 2.08 (each 3H, 7 × s, 7 × OAc), 2.40–2.49 (1H, m, 2-H_{eq}), 3.70 (1H, ddd, *J* 9.5, 5 and 2.5 Hz, 5′-H), 3.76 (1H, dt, *J* 11.5 and 4.5 Hz, 1-H), 3.94 (1H, dd, *J* 11.5 and 3.5 Hz, 6-H_a), 4.08 (1H, dd, *J* 11.5 and 5 Hz, 6-H_b), 4.11 (1H, dd, *J* 12.5 and 2.5 Hz, 6′-H_a), 4.23 (1H, dd, *J* 12.5 and 5 Hz, 6′-H_b), 4.59 (1H, d, *J* 8 Hz, 1′-H), 4.79–4.89 (1H, m, 3-H), 4.91 (1H, t, *J* 9.5 Hz, 4-H), 4.93 (1H, dd, *J* 9.5 and 8 Hz, 2′-H), 5.05 (1H, t, *J* 9.5 Hz, 4′-H), 5.19 (1H, t, *J* 9.5 Hz, 3′-H); δ_C (75 MHz, $CDCl_3$) 20.7, 20.7, 20.8, 20.8, 20.9, 21.0, 33.5, 36.8, 37.1, 62.1, 63.6, 68.4, 71.4, 71.9, 72.5, 72.7, 74.7, 100.1, 169.2, 169.4, 170.2, 170.3, 170.7, 170.8; *m*/*z* 641 (MNa^+, 2%), 619 (MH^+, 3), 331 ($C_{14}H_{19}O_9^+$, 97), 169 (100).

[(1′*S*,4′*R*,5′*R*,7′*S*,8′*R*)-7′-Acetoxy-3′-oxo-8′-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)-2′-oxabicyclo[2.2.2]octane-5′-carbonyloxy]-2(1*H*)-pyridinethione 33

Dry DMF (1 drop) was added to a solution of lactonic acid **12**[19] (0.236 g, 0.411 mmol) and oxalyl chloride (0.150 cm^3, 1.72 mmol) in dry THF (15 cm^3) at ambient temperature under a nitrogen atmosphere in a flask wrapped in aluminium foil. After the evolution of bubbles ceased (30 min) the reaction mixture was cooled to 0 °C and the sodium salt of 1-hydroxypyridine-2-thione (0.276 g, 1.85 mmol) was added. The mixture was stirred at 0 °C in the dark for 90 min, under a nitrogen atmosphere, poured into water (100 cm^3), and extracted with dichloromethane (2 × 50 cm^3). Workup as described for the preparation of **14** and crystallisation of the residue from dichloromethane–diethyl ether gave the *title compound* **33** (0.240 g, 85%) as light-sensitive, pale green crystals; m.p. 90–138 °C (decomp.); (Found: C, 50.8; H, 5.2; N, 2.2; S, 4.7. $C_{29}H_{33}O_{16}NS$ requires C, 51.0; H, 4.9; N, 2.1; 4.7%); $[\alpha]_D$ −75 (*c* 0.2 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1798 (C=O), 1747 (ester and lactone C=O), 1605; δ_H (300 MHz, $CDCl_3$) 2.00, 2.04, 2.06, 2.11 and 2.15 (each 3H, 5 × s, 5 × OAc), 2.34 (1H, ddd, *J* 15, 10.5 and 1.5 Hz, 6′-H_β), 2.55 (1H, dddd, *J* 15, 6.5, 3.5 and 1.5 Hz, 6′-H_α), 3.41–3.53 (2H, m, 4′- and 5′-H), 3.74 (1H, ddd, *J* 10, 4 and 2.5 Hz, 5′-H), 4.15–4.23 (2H, m, 8′-H and 6″-H_a), 4.28 (1H, dd, *J* 12.5 and 4.5 Hz, 6″-H_b), 4.72 (1H, d, *J* 8 Hz, 1″-H), 4.80–4.86 (1H, m, 1′-H), 5.00 (1H, dd, *J* 9.5 and 8 Hz, 2″-H), 5.07–5.16 (2H, m, 7′- and 4″-H), 5.21 (1H, t, *J* 9.5 Hz, 3″-H), 6.68 (1H, td, *J* 7 and 2 Hz, 5-H), 7.22–7.28 (1H, m, 4-H), 7.62–7.71 (2H, m, 3- and 6-H); *m*/*z* 684 (MH^+, 20%), 331 ($C_{14}H_{19}O_9^+$, 26), 169 (94), 136 (100).

(1*S*,4*R*,7*R*,8*R*)-7-Acetoxy-8-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)-2-oxabicyclo[2.2.2]octan-3-one 34

A solution of *tert*-butyl thiol (2.5 cm^3, 22 mmol) and thionopyridyl ester **33** (0.343 g, 0.502 mmol) in dry THF (5 cm^3) at ambient temperature under an atmosphere of dry nitrogen, was irradiated with light from a broad spectrum tungsten filament lamp (150 W) until the yellow solution decolourised (10 min). Workup as described for **15** and purification of the residue by silica gel column chromatography [ethyl acetate : hexanes (3 : 7) to ethyl acetate : hexanes (7 : 3), gradient elution] gave the *title compound* **34** (0.211 g, 79%), R_f = 0.6 (EtOAc), as white crystals from dichloromethane–diethyl ether; m.p. 206–208 °C; (Found: C, 52.3; H, 5.9. $C_{23}H_{30}O_{14}$ requires C, 52.1; H, 5.7%); $[\alpha]_D$ −47 (*c* 0.1 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1748 and 1745 (lactone and ester C=O); δ_H (300 MHz, $CDCl_3$) 1.76–1.92 (3H, m, 5-H, and 6-H_2), 2.00, 2.02, 2.06, 2.10 and 2.11 (each 3H, 5 × s, 5 × OAc) overlapping with 2.00–2.11 (1H, m, H-5), 2.87–2.93 (1H, m, 4-H), 3.69 (1H, ddd, *J* 10, 4 and 2.5 Hz, 5′-H), 4.03 *br* (1H, t, *J* 2.5 Hz, 8-H), 4.17 (1H, dd, *J* 12.5 and 2.5 Hz, 6′-H_a), 4.25 (1H, dd, *J* 12.5 and 4 Hz, 6′-H_b), 4.66 (1H, d, *J* 8 Hz, 1′-H), 4.71–4.75 (1H, m, 1-H), 4.95 (1H, dd, *J* 9.5 and 8 Hz, 2′-H), 5.05–5.10 (2H, m, 4′- and 7-H) and 5.20 (1H, t, *J* 9.5 Hz, 3′-H); *m*/*z* 531 (MH^+, 4%), 331 ($C_{14}H_{19}O_9^+$, 32), 169 (67), 136 (100).

2,3,6-Tri-*O*-acetyl-4-*O*-[2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl]-1-deoxy-5a-carba-L-*ido*-hexopyranose 35

Lithium aluminium hydride (0.117 g, 3.08 mmol) was carefully added to a solution of lactone **34** (0.104 g, 0.196 mmol) in dry THF (30 cm^3) and the resulting mixture was heated under reflux for 14 h. Workup and subsequent acetylation as described for the preparation of **16** was employed. Purification of the residue by silica gel column chromatography [ethyl acetate/hexane (7 : 3) as eluent] gave the *title compound* **35** (0.083 g, 68%), R_f = 0.8 (EtOAc), as white crystals from dichloromethane–hexane; m.p. 93–94 °C; (Found: C, 52.15; H, 6.3. $C_{27}H_{38}O_{16}$ requires C, 52.4; H, 6.2%); $[\alpha]_D$ −16 (*c* 0.1 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1745 (ester C=O); δ_H (300 MHz, $CDCl_3$) 1.36–1.48 (1H, m, 5a-H_a), 1.64–1.90 (3H, m, 1-H_2 and 5a-H_b), 1.99, 2.01, 2.05, 2.06, 2.07 and 2.09 (3, 3, 3, 6, 3, and 3H, 6 × s, 7 × OAc) overlapping with 1.99–2.09 (1H, m, 5-H), 3.71–3.78 (2H, m, 4-and 5′-H), 3.91 (1H, dd, *J* 11 and 7 Hz, 6-H_a), 4.01 (1H, dd, *J* 11 and 8 Hz, 6-H_b), 4.08 (1H, dd, *J* 12.5 and 2 Hz, 6′-H_a), 4.29 (1H, dd, *J* 12.5 and 5 Hz, 6′-H_b), 4.57 (1H, d, *J* 8 Hz, 1′-H), 4.83 *br* (1H, q, *J* 4 Hz, 2-H), 4.93 (1H, dd, *J* 9.5 and 8 Hz, 2′-H), 5.03 (1H, t, *J* 9.5 Hz, 4′-H), 5.18 (1H, t, *J* 9.5 Hz, 3′-H), 5.34 *br* (1H, t, *J* 4.5 Hz, 3-H); δ_C (75 MHz, $CDCl_3$) 18.8, 20.6, 20.7, 20.8, 21.0, 21.1, 21.3, 25.1, 35.8, 61.9, 64.4, 68.3, 68.5, 69.0, 71.6, 72.0, 73.1, 78.0, 102.2, 169.5, 170.3, 170.8, 170.9; *m*/*z* 641 (MNa^+, 14%), 619 (MH^+, 17), 559 (8), 331 ($C_{14}H_{19}O_9^+$, 98), 169 (100).

(1*S*,2*R*,3*R*,4*S*,6*R*)-4,6-Diacetoxy-3-[2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl)oxy]-5-oxo-cyclohexane-1,2-dicarboxylic anhydride 31

An excess of freshly prepared dimethyldioxirane in dry acetone (37 cm^3)[28] was added to allylic acetate **24** (1.230 g, 1.91 mmol) and the resulting yellow solution was stirred at ambient temperature for 1 h. The solution was filtered and the filtrate was concentrated *in vacuo* (<30°) leaving an opaque solid, to which was added acetic anhydride (10 cm^3). The mixture was cooled to 0 °C and 70% perchloric acid (7 drops) was added. The mixture was stirred for 20 min at 0 °C, poured into water (60 cm^3) and extracted with dichloromethane (2 × 50 cm^3), dried ($MgSO_4$), and concentrated *in vacuo* (<40°). The residue was crystallised from dichloromethane–diethyl ether to give the *title compound* **31** (1.088 g, 90%) as white crystals; m.p. 164–167 °C; (Found: C, 49.7; H, 4.7. $C_{26}H_{30}O_{18}$ requires C, 49.5; H, 4.8%); $[\alpha]_D$ −59 (*c* 0.3 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1864 and 1796 (anhydride C=O), 1753 (ester and ketone C=O); δ_H (300 MHz, $CDCl_3$) 2.00, 2.02, 2.09, 2.10, 2.15 and 2.24 (each 3H, 6 × s, 6 × OAc), 3.56–3.66 (2H, m, 1- and 2-H), 3.77 (1H, ddd, *J* 10, 5 and 3 Hz, 5′-H), 4.17 (1H, dd, *J* 12.5 and 3 Hz, 6′-H_a) overlapping with 4.22 (1H, dd, *J* 12.5 and 5 Hz, 6′-H_b), 4.46 *br* (1H, t, *J* 2.5 Hz, 3-H), 4.69 (1H, d, *J* 8 Hz, 1′-H), 5.02 (1H, dd, *J* 9.5 and 8 Hz, 2′-H,) overlapping with 5.07 (1H, t, *J* 9.5 Hz, 4′-H), 5.21 (1H, t, *J* 9.5 Hz, 3′-H), 5.58 (1H, d, *J* 2 Hz, 4-H), 5.85 (1H, dd, *J* 7.5 and 1.5 Hz, 6-H); *m*/*z* 631 (MH^+, 10%), 331 ($C_{14}H_{19}O_9^+$, 81), 136 (100).

(1*S*,4*R*,5*S*,6*R*,7*S*,8*R*)-6,7-Diacetoxy-8-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)-3-oxo-2-oxabicyclo[2.2.2]octan-5-carboxylic acid 32

Sodium cyanoborohydride (0.800 g, 12.7 mmol) was added to a solution of ketone **31** (1.60 g, 2.54 mmol) in glacial acetic acid (50 cm^3), and the mixture stirred at RT under a drying tube overnight. The solution was concentrated under reduced pressure, the residue partitioned between dichloromethane and 1 M hydrochloric acid, and the aqueous layer extracted with dichloromethane. The combined organic layers were washed with 1 M hydrochloric acid and dried over anhydrous sodium sulfate. The solution was concentrated under reduced pressure to a white foam, which was dried *in vacuo*. Slow crystallisation from dichloromethane–diethyl ether–hexanes gave the *title compound* **32** (0.760 g, 47%) as white crystals; m.p. 183–185 °C; (Found: C, 49.6; H, 5.0. $C_{26}H_{32}O_{18}$ requires C, 49.4; H, 5.1%); υ_{max} (KBr)/cm^{-1} 3700–2600 *br* (carboxylic O–H), 1781 (lactone C=O), 1749 (ester C=O), 1717 (carboxylic acid C=O), δ_H (300 MHz, $CDCl_3$) 2.00, 2.03, 2.05, 2.08, 2.11 and 2.12 (each 3H, 6 × s, 6 × OAc), 2.85 (1H, dd, *J* 6.5 and 1 Hz, 5-H), 3.34 *br* (1H, d, *J* 2 Hz, 4-H), 3.78 (1H, dt, *J* 10 and 3 Hz, 5′-H), 4.20 (1H, dd, *J* 12.5 and 3 Hz, 6′-H_a), 4.28 (1H, dd, *J* 12.5 and 4 Hz, 6′-H_b), 4.34 (1H, *br* t, *J* 2.5 Hz, 8-H), 4.40–4.75 *br* (1H, s, COOH), 4.85 (1H, d, *J* 8.5 Hz, 1′-H), 4.93–5.02 (2H, m, 1- and 2′-H), 5.12 (1H, t, *J* 9.5 Hz, 4′-H) overlapping with 5.05–5.16 (1H, m, 7-H), 5.23 (1H, t, *J* 9.5 and 9.5 Hz, 3′-H), 5.32 (1H, ddd, *J* 6, 3 and 1.5 Hz, 6-H); *m*/*z* 655 (MNa^+, 2%), 633 (MH^+, 6), 331 ($C_{14}H_{19}O_9^+$, 36), 169 (42), 154 (100).

(1*S*,4*R*,6*R*,7*S*,8*R*)-6,7-Diacetoxy-8-(2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyloxy)-2-oxabicyclo[2.2.2]octan-3-one 37

Oxalyl chloride (0.220 cm^3, 2.52 mmol) and dry DMF (1 drop) was added to a solution of lactonic acid **32** (0.428 g, 0.677 mmol) in dry THF (12 cm^3) under nitrogen in a flask wrapped in aluminium foil. The solution was stirred at RT, and once the evolution of bubbles ceased (50 min), the reaction mixture was cooled to 0 °C and the sodium salt of 1-hydroxypyridine-2-thione (0.437 g, 2.93 mmol) was added. The resulting mixture was stirred at 0 °C under nitrogen for 90 min. After warming to RT *tert*-butyl thiol (15.0 cm^3, 133 mmol) was added and the mixture was irradiated with light from a broad spectrum tungsten filament lamp (150 W) for 15 min. The solvent was removed *in vacuo* and the residue was dissolved in dichloromethane (50 cm^3), washed with water (100 cm^3), dried ($MgSO_4$) and evaporated to dryness. Purification by repeated silica gel column chromatography [ethyl acetate : hexanes (3 : 7) to ethyl acetate : hexane (7 : 3), gradient elution] gave the *title compound* **37** (0.239 g, 60%), R_f = 0.4 (7 : 3 EtOAc/hexane), as a white solid; m.p. 179–185 °C (CH_2Cl_2–diethyl ether–hexanes); (Found: C, 50.8; H, 5.5. $C_{25}H_{32}O_{16}$ requires C, 51.0; H, 5.5%); $[\alpha]_D$ −56 (*c* 0.3 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1785 (lactone C=O), 1749 (ester C=O); δ_H (300 MHz, $CDCl_3$) 1.72 (1H, ddd, *J* 14.5, 5.5 and 2 Hz, 5H_a), 2.00, 2.03, 2.06 and 2.11 (3, 3, 6, and 6H, 4 × s, 6 × OAc), 2.63 (1H, ddd, *J* 14.5, 9.5 and 4.5 Hz, 5-H_b), 2.94 (1H, dt, *J* 5 and 2.5 Hz, 4-H), 3.70 (1H, ddd, *J* 9.5, 4 and 2.5 Hz, 5′-H), 4.14–4.23 (2H, m, 6′-H_a and 8-H), 4.27 (1H, dd, *J* 12.5 and 4 Hz, 6′-H_b), 4.69 (1H, d, *J* 8.5 Hz, 1′-H), 4.92 (1H, t, *J* 3.5 Hz, 1-H) overlapping with 4.96 (1H, dd, *J* 9.5 and 8.5 Hz, 2′-H), 4.97–5.07 (1H, m, 6-H), 5.11 (1H, t, *J* 9.5 Hz, 4′-H) overlapping with 5.08–5.13 (1H, m, 7-H), 5.21 (1H, t, *J* 9.5 Hz, 3′-H); *m*/*z* 589 (MH^+, 7%), 331 ($C_{14}H_{19}O_9^+$, 56), 169 (78) 136(100).

1,2,3,6-Tetra-*O*-acetyl-4-*O*-[2′,3′,4′,6′-tetra-*O*-acetyl-β-D-glucopyranosyl]-5a-carba-α-L-*ido*-hexopyranose 13

Lithium aluminium hydride (0.149 g, 3.93 mmol) was carefully added to a solution of **37** (0.239 g, 0.406 mmol) in dry THF (30 cm^3) and the resulting mixture was heated under reflux for 16 h. The workup procedure and subsequent acetylation protocol as described for the preparation of **16** was employed. Purification of the residue by silica gel column chromatography [ethyl acetate : hexanes (7 : 3) as eluent] gave the *title compound* **13** (0.223 g, 81%), R_f = 0.3 (1 : 1 EtOAc/hexane), as a white solid; m.p. 116–118 °C (EtOAc–diethyl ether); (Found: C, 51.5; H, 5.8. $C_{29}H_{40}O_{18}$ requires C, 51.5; H, 6.0%); $[\alpha]_D$ −26 (*c* 0.4 in CH_2Cl_2); υ_{max} (KBr)/cm^{-1} 1749 (ester C=O); δ_H (300 MHz, $CDCl_3$) 1.57–1.67 (1H, m, 5a-H_a), 1.99, 2.01, 2.04, 2.06, 2.07 and 2.08 (3, 3, 6, 6, 3, 3H, 6 × s, 8 × OAc) overlapping with 1.99–2.08 (1H, m, 5a-H_a), 2.36–2.48 (1H, m, 5-H), 3.74 (1H, ddd, *J* 10, 5 and 2.5 Hz, 5′-H), 3.81 (1H, t, *J* 4.5 Hz, 4-H), 3.96 (1H, dd, *J* 11 and 7 Hz, 6-H_a), 4.02 (1H, dd, *J* 11 and 7.5 Hz, 6-H_b) overlapping with 4.06 (1H, dd, *J* 12.5 and 2 Hz, 6′-H_a), 4.29 (1H, dd, *J* 12.5 and 5 Hz, 6′-H_b), 4.60 (1H, d, *J* 8 Hz, 1′-H), 4.88–4.95 (2H, m, 2- and 2′-H), 5.02 (1H, t, *J* 9.5 Hz, 4′-H) overlapping with 4.98–5.07 (1H, m, 1-H), 5.17 (1H, t, *J* 9.5 Hz, 3′-H), and 5.39 (1H, t, *J* 4.5 Hz, 3-H); *m*/*z* 699 (MNa^+, 1%), 677 (MH^+, 2), 331 ($C_{14}H_{19}O_9^+$, 58), 169 (100).

References

1 N. S. Trotter, D. S. Larsen, R. J. Stoodley and S. Brooker, *Tetrahedron Lett.*, 2000, **41**, 8957.
2 R. C. Gupta, P. A. Harland and R. J. Stoodley, *Tetrahedron*, 1984, **40**, 4657.
3 R. C. Gupta, C. M. Raynor, R. J. Stoodley, A. M. Z. Slawin and D. J. Williams, *J. Chem. Soc., Perkin Trans. 1*, 1988, 1773.
4 R. C. Gupta, D. S. Larsen, R. J. Stoodley, A. M. Z. Slawin and D. J. Williams, *J. Chem. Soc., Perkin Trans. 1*, 1989, 739.
5 D. S. Larsen and R. J. Stoodley, *J. Chem. Soc., Perkin Trans. 1*, 1989, 1841.
6 D. S. Larsen and R. J. Stoodley, *J. Chem. Soc., Perkin Trans. 1*, 1990, 1339.
7 B. Beagley, D. S. Larsen, R. G. Pritchard and R. J. Stoodley, *J. Chem. Soc., Perkin Trans. 1*, 1990, 3113.
8 W. D. Edwards, R. C. Gupta, C. M. Raynor and R. J. Stoodley, *J. Chem. Soc., Perkin Trans. 1*, 1991, 1913.
9 D. S. Larsen and R. J. Stoodley, *Tetrahedron*, 1990, **46**, 4711.
10 *Carbohydrate-based Drug Discovery*, ed. C.-H. Wong, Wiley-VCH, Weinheim, 2003.
11 *Carbohydrates—Synthetic Methods and Applications in Medicinal Chemistry*, ed. H. Ogura, A. Hasegawa and T. Suami, Kodansha, Tokyo and VCH, Weinheim, 1992.
12 *Dictionary of Antibiotics and Related Substances*, ed. B. W. Bycroft, Chapman and Hall, London and New York, 1988.
13 S. Ogawa, Y. Shibata, N. Chida and T. Suami, *Bull. Chem. Soc. Jpn.*, 1983, **56**, 494.
14 S. Ogawa, I. Sugawa and Y. Shibata, *Carbohydr. Res.*, 1991, **211**, 147.
15 S. Ogawa, S. Yokoi, N. Kimura, Y. Shibata and N. Chida, *Carbohydr. Res.*, 1988, **181**, 57.
16 S. Ogawa, I. Sugawa and Y. Shibata, *Carbohydr. Res.*, 1991, **211**, 147.
17 S. Ogawa and K. Nishi, *Carbohydr. Res.*, 1992, **229**, 117.
18 X. Cheng, N. Khan, G. Kumaran and D. R. Mootoo, *Org. Lett.*, 2001, **3**, 1323.
19 D. S. Larsen, R. J. Lins, R. J. Stoodley and N. S. Trotter, *J. Chem. Soc., Perkin Trans. 1*, 2001, 2204.
20 D. S. Larsen, N. S. Trotter and R. J. Stoodley, *Tetrahedron Lett.*, 1993, **34**, 8151.
21 D. H. R. Barton and S. Z. Zard, *Pure Appl. Chem.*, 1986, **58**, 675.
22 D. H. R. Barton, D. Crich and W. B. Motherwell, *J. Chem. Soc., Chem. Commun.*, 1983, 939.
23 D. H. R. Barton, D. Crich and W. B. Motherwell, *Tetrahedron*, 1985, **41**, 3901.
24 D. H. R. Barton, D. Bridon and S. Z. Zard, *J. Chem. Soc., Chem. Commun.*, 1985, 1066.
25 M. M. L. Crilley, D. S. Larsen, R. J. Stoodley and F. Tome, *Tetrahedron Lett.*, 1993, **34**, 3305.
26 L. M. Jackmann and S. Sternhill, *Applications of Nuclear Magnetic Resonance Spectroscopy in Organic Chemistry*, Pergamon, Oxford, 2nd edn., 1969, p. 334.
27 D. D. Perrin, W. L. F. Armarego and D. R. Perrin, *Purification of Laboratory Chemicals*, Permagon Press, UK, 1980.
28 W. Adam and L. Hadjiarapoglou, *Top. Curr. Chem.*, 1993, **164**, 45.