New Approach to Sugar Derivatives by Pummerer Reactions of Optically Active Sulphoxide and Sulphide having a 7-Oxabicyclo[2.2.1]heptane Ring System

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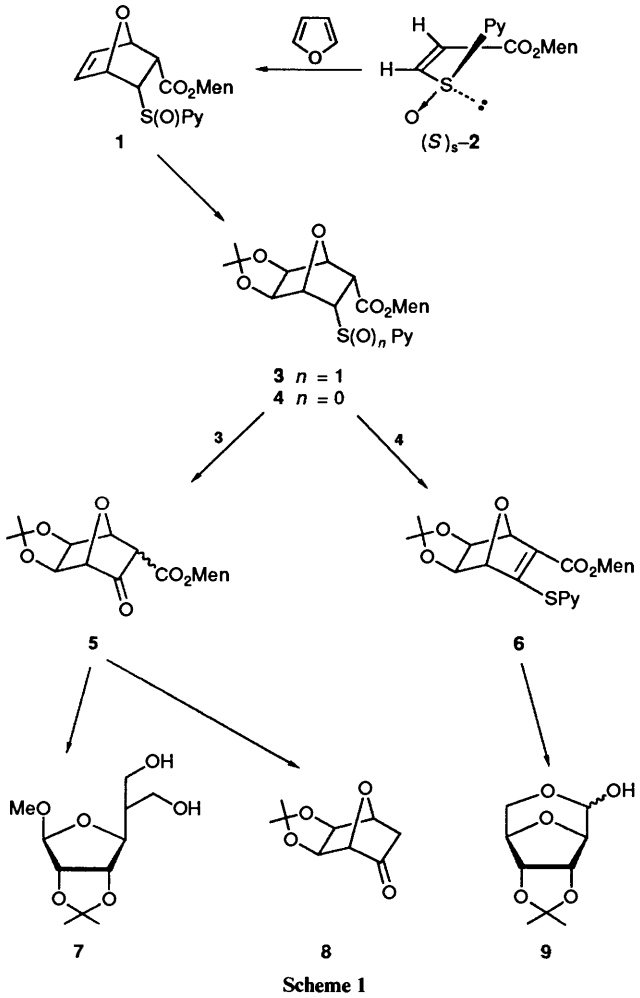
Pummerer reactions of 3-(2-pyridylsulphinyl)-7-oxabicyclo[2.2.1]heptane-2-carboxylate **3** and the corresponding sulphide **4**, which were obtained by an asymmetric Diels–Alder reaction of the $(S)_s$-3-(2-pyridylsulphinyl)acrylate **2** with high diastereoselectivity, gave the β-keto ester **5** and the vinyl sulphide **6** in 62 and 87% yield, respectively. The keto ester **5** was transformed into the C(5)-branched-chain sugar derivative **7** by successive Baeyer–Villiger oxidation and stereoselective cleavage of the resulting lactone **16**. Dealkoxycarbonylation of the keto ester **5** afforded the 7-oxanorbornanone derivative **8**. In addition, upon ozonolysis, the vinyl sulphide **6** was converted into the D-2,5-anhydroallose derivative **9**.

Much attention has recently been focused on optically active 7-oxabicyclo[2.2.1]heptane derivatives. These chirons [1] have been shown to be particularly promising precursors for the synthesis of natural products and/or of products of biological interest.[2,3] We have demonstrated the first asymmetric synthesis of (−)-7-oxabicyclo[2.2.1]hept-5-ene-2-carboxylate **1** by an asymmetric Diels–Alder (D-A) reaction of the $(S)_S$-3-(2-pyridylsulphinyl)-acrylate **2** with furan[4] (Scheme 1). Moreover, we have developed convenient methods for the chiral synthesis of D-showdomycin,[5] the D-2,5-anhydroallose derivative,[5] glyoxalase I inhibitor,[6] shikimates [7] and pseudo-sugars [7] starting with the adduct **1** and its derivatives. In the asymmetric cycloaddition, the chiral sulphinyl group plays an important role in diastereofacial differentiation and activation of the dienophile.[8] However, this functional group was subjected only to β-elimination [5,6] and reductive desulphurization [7] giving olefin and methylene moieties, respectively, in the transformation of the cycloadduct **1** into the target compounds. To make the most of the synthetic versatility of this sulphinyl group, we aimed to use a Pummerer reaction, which is a well-known procedure for the transformation of sulphoxides into carbonyl functions. Although Pummerer reactions of sulphoxide-[9] or sulphide-[10] containing bicyclo[2.2.1]heptanes have been reported, to the best of our knowledge, reactions of the corresponding 7-oxo derivatives have not been described. The Pummerer reaction of the sulphoxide **3** and subsequent hydrolysis may give a β-keto ester **5** which can be transformed into a wide variety of biologically active compounds *via* a C(5)-branched-chain sugar† **7**, a 7-oxanorbornanone derivative **8**‡ (a derivative of 'naked sugars'[2]) and D-2,5-anhydroallose derivative **9**.

Here, we are concerned with Pummerer reactions of the 7-oxabicyclo[2.2.1]heptane sulphoxide **3** and the sulphide **4**, and further reactions of the products **5** and **6** to chiral syntheses of the sugar derivatives **7**, **8** and **9**.



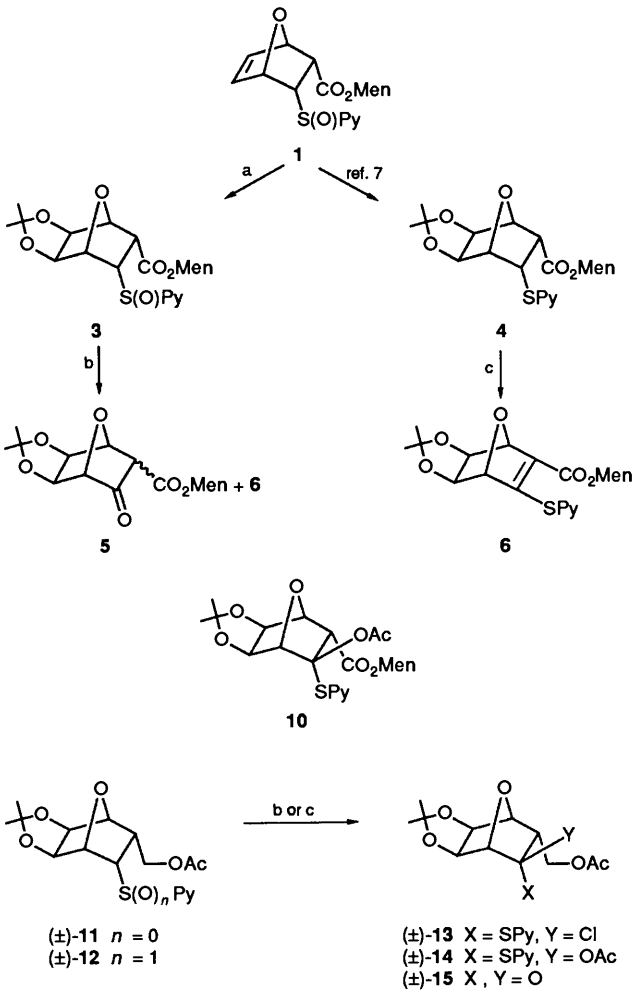
Scheme 1

Results and Discussion

Pummerer Reactions of the Sulphoxide **3** *and the Sulphide* **4**.— Stereoselective *cis* dihydroxylation of the D-A adduct **1** with Me_3NO and a catalytic amount of OsO_4 gave the *exo* diol (Scheme 2). It was transformed into the acetonide **3** on treatment with acetone, 2,2-dimethoxypropane and toluene-*p*-

† Branched-chain sugars have served as the integral part as glycoside component in some antibiotics,[11] and as key intermediates for the preparation of macrolide antibiotics.[12]

‡ Vogel *et al.* have reported the preparation of both enantiomers of **8** by optical resolution.[13] Recently, the same group demonstrated the synthesis of (1*S*)-7-oxabicyclo[2.2.1]hept-5-en-2-one by an asymmetric D-A reaction.[14] The enantiomers of **8** have been shown to be versatile starting materials for the chiral synthesis of D- and L-ribose derivatives,[13] D- and L-hexoses,[2] allonojirimycin [2] and higher-carbon sugars.[15]

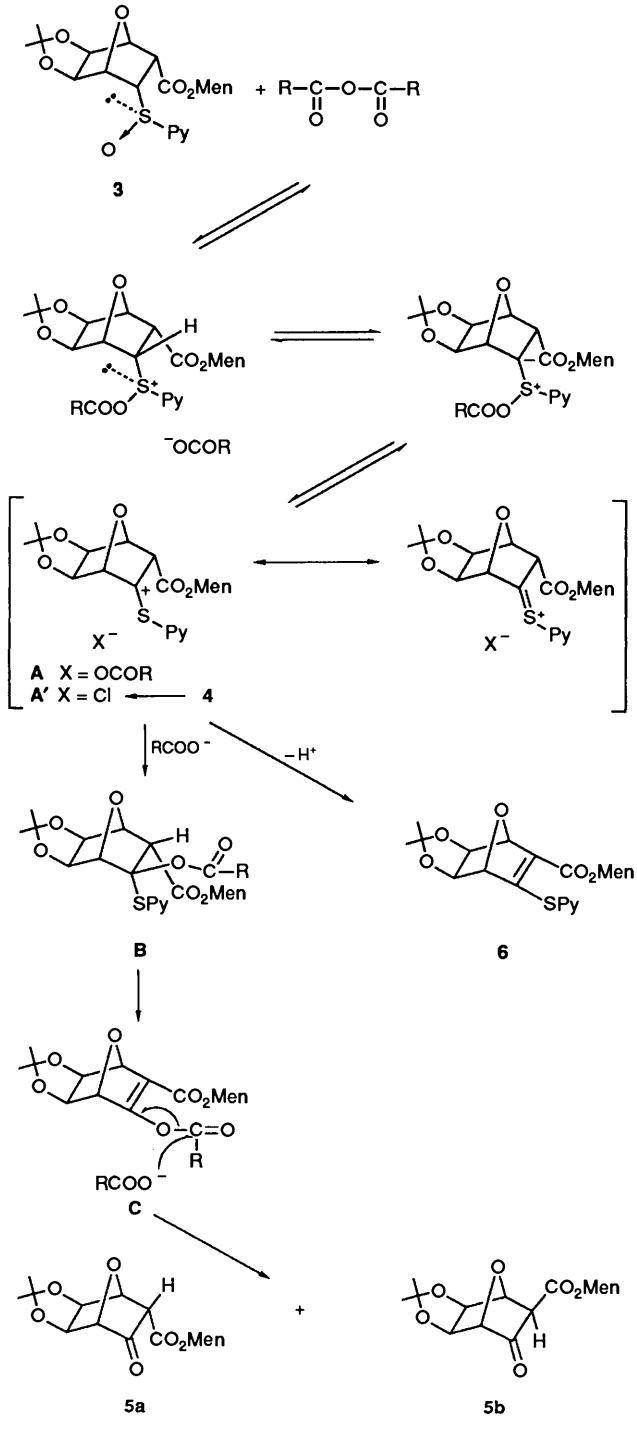


Scheme 2 *Reagents and conditions:* a, Me_3NO, OsO_4, acetone; $Me_2C(OMe)_2$, TSA, acetone; b, TFAA, 0 °C, 0.5 h; c, NCS, CCl_4

sulphonic acid (TsOH) in 83% yield from the D-A adduct **1**. With the *endo* sulphoxide **3**, we examined the conditions for Pummerer reaction. The starting compound **3** was recovered unchanged when the reaction was performed with Ac_2O at room temperature. Under Maignan's conditions [Ac_2O (10 equiv.), trifluoroacetic anhydride (TFAA) (1.5 equiv.), room temp., 2 h],[9] the α-acetoxy sulphide **10** (34%) and the vinyl sulphide **6** (23%) were obtained. Surprisingly, the reaction with TFAA at room temperature gave the desired β-keto ester **5** [1 : 1 at C(2)]* accompanied by the vinyl sulphide **6**. Even under strictly controlled conditions, the product yields varied: 30–48% for the ketone **5** and 23–39% for the sulphide **6**. Because the yield of the ketone **5** from the sulphide **6** was low (<20%) by acid-catalysed hydrolysis (HCl, MeOH or $HgCl_2$, MeCN–H_2O) followed by protection, we examined the reaction conditions to decrease the formation of the sulphide **6**. The yield of the keto ester **5** increased to 62% when the sulphoxide **3** was treated with TFAA at 0 °C for 0.5 h. The vinyl sulphide **6** was still obtained in 12% yield. The structures of **5** and **6** were confirmed by spectral data.

On the other hand, the reaction of the sulphide **4** with *N*-chlorosuccinimide (NCS) gave the vinyl sulphide **6** as an exclusive product in 87% yield. The corresponding α-chloro sulphide was not detected in the reaction mixture. These results were considered to be due to the acidic hydrogen at C(2). To decrease the acidity of this hydrogen, the racemic ester (±)-**4** was converted into the acetoxymethyl sulphide (±)-**11** and the corresponding sulphoxide (±)-**12**. Pummerer reaction of (±)-**11** and (±)-**12** proceeded readily to give the α-chloro or α-acyloxy sulphide (±)-**13** or (±)-**14**. Although hydrolysis of the chloride **13** and the acetate **14** was performed under a variety of conditions, the starting materials were recovered unchanged, no ketone **15** being obtained.

Of the possible paths for formation of the ketone **5** and the vinyl sulphide **6** from the sulphoxide **3**, one may be postulated tentatively in which a carbonium ion **A**, formed (see Scheme 3) by analogy with other Pummerer reactions,[16] picks up the carboxylate anion before losing a proton to give an α-acyloxy



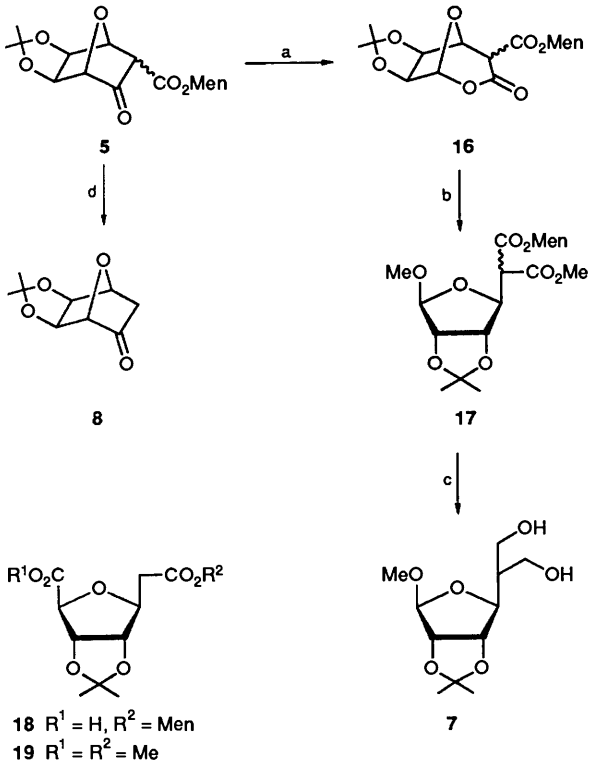
Scheme 3

* The expression '1 : 1 at C(2)' in this text refers to a 1 : 1 epimeric mixture at C(2).

sulphide **B** (a normal Pummerer reaction product). Because of the bicyclic structure of the intermediate **A**, the carboxylate anion may react preferentially from the *exo* face at C(3).[17] The concomitant deprotonation and olefin formation may give the vinyl sulphide **6**.* The ketones **5a** and **5b** may be obtained by further *anti* elimination of the pyridylthio group from **B** and subsequent attack of the carboxylate anion at the carbonyl carbon of the enol ester moiety of **C** followed by protonation.

In the case of the Pummerer reaction of the sulphide **4** with NCS, the carbonium ion **A'** may be formed by analogy with the reaction of the sulphoxide **3** with acid anhydride.[18] The ion **A'** may give the vinyl sulphide **6** under the reaction conditions.

Chiral Synthesis of the C(5)*-Branched-chain Sugar Derivative* **7**, *the 7-Oxanorbornanone Derivative* **8** *and* D-2,5*-Anhydroallose Derivative* **9**.—In order to show some examples of the versatility of the products **5** and **6**, we transformed them into the sugar derivatives **7**, **8** and **9**. Baeyer–Villiger oxidation of the ketone **5** with *m*-chloroperbenzoic acid (mCPBA)[13] gave the lactone **16** [1:2 at C(4)] in 92% yield (Scheme 4). Selective opening of the



Scheme 4 *Reagents and conditions:* a, **m**CPBA, $NaHCO_3$, CH_2Cl_2; b, $Me_2C(OMe)_2$, MsOH, MeOH; c, $LiAlH_4$, Et_2O; d, LiI, DMF, 130 °C

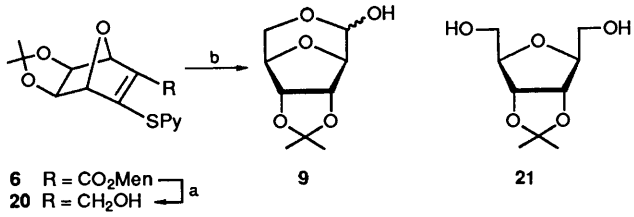
lactone **16** [MeOH, 2,2-dimethoxypropane, methanesulphonic acid (MsOH)][13] gave the L-β-ribofuranose derivative **17** [1:1 at C(5)] in 85% yield. The β-configuration of the methoxy group was confirmed by the 1-H, 2-H coupling constant of the diester **17** compared with that of tetra-*O*-acetyl-β-D-ribofuranose.[19] Reduction of the diester **17** with $LiAlH_4$ afforded the diol **7**, $[\alpha]_D$ +29.6° (*c* 0.44 in $CHCl_3$), in 52% yield, which is a new type of branched-chain sugar.

The simple alkyl esters of **5** had been used previously by Kozikowsky and Ames as key intermediates for the synthesis of (±)-showdomycin.[20] The keto ester **5** may be transformed into D-showdomycin according to their procedure.

* A possibility that *syn* elimination of the acyloxy group of the intermediate **B** may occur to give the vinyl sulphide **6** can not be excluded.

For the synthesis of the 7-oxanorbornanone derivative **8**, we examined dealkoxycarbonylation of the ester **5**. A variety of reagents [$MgCl_2$, dimethyl sulphoxide (DMSO)–H_2O, 160 °C, KOH, PrOH, reflux, 4-dimethylaminopyridine (DMAP),toluene–H_2O,reflux and LiOH,1,2-dimethoxyethane (DME)–H_2O,reflux; CH_2N_2] were used for this purpose; the starting material was recovered in the first two cases; ring fission of the 7-oxanorbornanone framework occurred in the last two cases to afford compounds **18** and **19**, respectively; we were unable to obtain the desired ketone **8**. Finally, Krapcho reaction of the β-keto ester **5** [LiI, dimethylformamide (DMF), 130 °C][21] proceeded smoothly to give the desired ketone **8** (41%). The spectral data of the ketone **8** were identical with those reported in the literature.[13]

Moreover, we examined the transformation of the vinyl sulphide **6** into the D-2,5-anhydroallose derivative **9** (Scheme 5).



Scheme 5 *Reagents and conditions:* a, DIBAL-H, Et_2O; b, O_3, CH_2Cl_2, −78 °C; $NaBH_4$, MeOH; $NaIO_4$, aq. MeOH

Ozonolysis of the vinyl sulphide **6** proceeded with decarboxylation to give the diol **21** (28%) along with the desired compound **9** (12%) after treatment similar to that described in the literature ($NaBH_4$; $NaIO_4$).[5] Anomalous ozonolysis with decarboxylative cleavage was known to take place on 7-oxabicyclo[2.2.1]hept-2-ene-2-carboxylate without any rearrangement.[22] We then examined ozonolysis after reduction [diisobutylaluminium hydride (DIBAL-H)] of the ester **6** to the allyl alcohol **20**. Ozonolysis of compound **20** followed by a similar procedure to that described above gave the desired compound **9** as an anomeric mixture (3:1) in 33% yield exclusively. The spectral data of the synthetic D-2,5-anhydroallose derivative **9** were identical with those of an authentic sample.[5]

Thus, the β-keto ester **5** and the vinyl sulphide **6** were prepared by Pummerer reactions of the sulphoxide **3** and the sulphide **4**, respectively. The key features of these methods are: (1) a simple one-step synthesis of the ketone and the vinyl sulphide from the sulphoxide and the sulphide, respectively; (2) reaction products have an ester group at C(2) which can be transformed into various functional groups. We showed some examples of the versatility of the products **5** and **6** by transformation into the C(5)-branched-chain sugar derivative **7**, the 7-oxanorbornanone derivative **8** and D-2,5-anhydroallose derivative **9**. Investigations with 3-sulphinylbicyclo[2.2.1]-heptane-2-carboxylate are now in progress in our laboratory.

Experimental

M.p.s were measured with a Yanaco melting point apparatus and are uncorrected. Spectroscopic measurements were performed with the following instruments: IR, JASCO A-102; ^1H NMR, JEOL JNM-GX 270 (270 MHz) and Varian XL-200 (200 MHz) for solutions in $CDCl_3$ (unless otherwise stated), with Me_4Si as internal standard; mass, JEOL JMS-D 200; optical rotations, JASCO DIP-140 digital polarimeter. *J* Values are given in Hz. Column chromatography and preparative TLC (PLC) were performed on Kieselgel 60 (Merck, Art. 9385 and Art. 7748, respectively).

(1'R,2'S,5'R)-*Menthyl* (1S,2R,3S,4S,5S,6S)-5,6-(*Isopropylid-*

enedioxy)-3-[(S)$_S$-2-*pyridylsulphinyl*]-7-*oxabicyclo*[2.2.1]*heptane*-2-*carboxylate* **3**.—A mixture of the olefin **1** (200 mg, 0.496 mmol), a 0.0854 mol dm^{-3} solution of OsO_4 in Bu^{t}OH (58 μl, 5 μmol) and trimethylamine *N*-oxide dihydrate (55 mg, 0.50 mmol) in acetone (30 ml) was stirred at room temperature overnight under nitrogen. The reaction mixture was diluted with MeOH (100 ml) and filtered through a Celite pad. Evaporation of the filtrate gave (1′*R*,2′*S*,5′*R*)-menthyl (1*S*,2*R*,3*S*,4*S*,5*S*,6*S*)-5,6-dihydroxy-3-[(*S*)$_S$-2-pyridylsulphinyl]-7-oxabicyclo-[2.2.1]heptane-2-carboxylate (232 mg) as a pale yellow solid. A mixture of the diol (232 mg), 2,2-dimethoxypropane (0.610 ml, 4.96 mmol) and a catalytic amount of TSA in acetone (50 ml) was stirred at 70 °C overnight under nitrogen. After evaporation of the solvent the residue was dissolved in CH_2Cl_2 (50 ml) and the solution was washed with saturated aqueous $NaHCO_3$. The aqueous layer was extracted with CH_2Cl_2 (10 ml × 3) and the combined organic layers were washed with brine, dried ($MgSO_4$) and concentrated. The residue (301 mg) was purified by column chromatography on silica gel [eluent hexane–AcOEt (2:1)] to give the *acetonide* **3** (196 mg, 83%) as a white solid. Crystallisation from hexane–AcOEt gave needles, m.p. 145–148 °C (Found: C, 63.15; H, 7.35; N, 2.8. Calc. for $C_{25}H_{35}NO_6S$: C, 62.89; H, 7.34; N, 2.94%); $[\alpha]_D^{25}$ −84.8° (*c* 0.95, $CHCl_3$); ν_{max}(KBr)/cm^{-1} 1740 (CO), 1570 (C=C) and 1040 (SO); δ_H 0.7–2.0 (18 H, m, 3 × Me, 3 × CH_2, 3 × CH), 2.19 (3 H, s, Me), 2.33 (3 H, s, Me), 3.35 (1 H, dd, *J* 11.8, 5.6, 2-H), 3.75 (1 H, dd, *J* 11.8, 5.6, 3-H), 4.25 (1 H, d, *J* 5.6, 4-H), 4.59 (2 H, d, *J* 5.6, 1-H, 5- or 6-H), 4.65 (1 H, ddd, *J* 10.0, 10.0, 4.8, 1′-H), 5.20 (1 H, d, *J* 5.6, 5- or 6-H), 7.3 (1 H, m, ArH), 7.9 (2 H, m, 2 × ArH) and 8.52 (1 H, m, ArH); *m*/*z* 478 (M^+ + 1), 477 (M^+) and 462 (M^+ − Me).

Pummerer Reaction of the Sulphoxide **3**.—A solution of the sulphoxide **3** (230 mg, 0.480 mmol) in TFAA (1 ml) was stirred at 0 °C for 0.5 h under nitrogen. After evaporation of the solvent, the residue was dissolved in CH_2Cl_2 (10 ml) and the solution was washed with saturated aqueous $NaHCO_3$ at 0 °C. The aqueous layer was extracted with CH_2Cl_2 (5 ml × 3) and the combined extracts were washed with brine, dried ($MgSO_4$) and evaporated. The residue was chromatographed on silica gel [eluent hexane–AcOEt (4:1)] to give (1′R,2′S,5′R)-*menthyl* (1S,4S,5S,6S)-5,6-(*isopropylidenedioxy*)-3-*oxo*-7-*oxabicyclo*-[2.2.1]*heptane*-2-*carboxylate* **5** [a 1:1 epimeric mixture at C(2)] (109 mg, 62%) as a white solid. Crystallisation of the ketone **5** from $CHCl_3$–Et_2O gave needles, m.p. 181–183 °C (Found: C, 65.6; H, 8.2. Calc. for $C_{20}H_{30}O_6S$: C, 65.54; H, 8.26%); ν_{max}($CHCl_3$)/cm^{-1} 1780 (CO) and 1720 (ester CO); δ_H 0.70–2.04 (18 H, m, 3 × Me, 3 × CH_2, 3 × CH), 1.32 (3 H, s, 2 × Me), 1.51 (1.5 H, s, Me), 1.52 (1.5 H, s, Me), 2.82 [0.5 H, s, 2-H (**5b**)], 3.46 [0.5 H, dd, *J* 6.1, 0.7, 2-H (**5a**)], 4.37 [0.5 H, d, *J* 1.0, 4-H (**5a**)], 4.40 [0.5 H, br s, 4-H (**5b**)], 4.51, 4.53, 4.55, 5.02 (2 H, each d, *J* 5.4, 5- and 6-H), 4.66–4.79 (1 H, m, 1′-H), 4.95 [0.5 H, dd, *J* 6.1, 1.2, 1-H (**5a**)] and 5.06 [0.5 H, br s, 1-H (**5b**)]; *m*/*z* 367 (M^+ + 1), 366 (M^+) and 351 (M^+ − Me).

Further elution with the same solvent mixture gave (1′R,2′S,5′R)-*menthyl* (1S,4S,5S,6S)-5,6-(*isopropylidenedioxy*)-3-(2-*pyridylthio*)-7-*oxabicyclo*[2.2.1]*hept*-2-*ene*-2-*carboxylate* **6** (27 mg, 12%) as a yellow oil (Found: M^+, 459.2046. $C_{25}H_{33}NO_5S$ requires *M*, 459.2015); $[\alpha]_D^{26}$ −62.3° (*c* 2.30, $CHCl_3$); ν_{max}(neat)/cm^{-1} 1680 (CO) and 1560 (C=C); δ_H 0.76–2.10 (18 H, m, 3 × Me, 3 × CH_2, 3 × CH), 1.35 (3 H, s, Me), 1.49 (3 H, s, Me), 4.47 and 4.77 (2 H, each d, *J* 5.4, 5- and 6-H), 4.77 (1 H, ddd, *J* 10.7, 10.7, 5.4, 1′-H), 5.04 and 5.10 (2 H, each d, *J* 1.2, 1- and 4-H), 7.24 (1 H, m, ArH), 7.48 (1 H, m, ArH), 7.67 (1 H, m, ArH) and 8.63 (1 H, m, ArH); *m*/*z* 459 (M^+), 444 (M^+ − Me) and 401 (M^+ − Me_2CO).

(1′R,2′S,5′R)-*Menthyl* (1S,4S,5S,6S)-5,6-(*Isopropylidenedioxy*)-3-(2-*pyridylthio*)-7-*oxabicyclo*[2.2.1]*hept*-2-*ene*-2-*carboxylate* **6**.—A mixture of the sulphide **4**[7] (30 mg, 0.065 mmol) and NCS (17 mg, 0.13 mmol) in dry CCl_4 (6 ml) was refluxed for 3 h under nitrogen. The reaction mixture was filtered and the filtrate was concentrated to give an oil (43 mg). Purification of this by column chromatography [eluent hexane–AcOEt (3:1)] afforded the vinyl sulphide **6** (26 mg, 87%) as an oil, which was identical (m.p., IR, NMR and TLC) with the sample prepared from the sulphoxide **3** (*vide supra*).

(1S,4S,5S,6S)-5,6-(*Isopropylidenedioxy*)-7-*oxabicyclo*[2.2.1]-*heptan*-2-*one* **8**.—A mixture of the keto ester **5** (30 mg, 0.082 mmol), dry DMF (0.5 ml) and LiI·$2H_2O$ (139 mg, 0.82 mmol) was heated at 130 °C for 2.5 h under nitrogen. After cooling, the reaction mixture was partitioned with Et_2O (2 ml × 3) and water (0.3 ml). The combined extracts were washed with brine, dried ($MgSO_4$) and concentrated to give a brown oil (489 mg). This oil was passed through a short column of silica gel [eluent hexane–AcOEt (2:1)] to afford a pale brown oil (23 mg). Purification of this oil by PLC [hexane–AcOEt (2:1)] gave the ketone **8** (6.2 mg, 41%) as scales, m.p. 123 °C (from hexane) (lit.,[13] m.p. 128–128.5 °C) (Found: M^+, 184.0738. $C_9H_{12}O_4$ requires *M*, 184.0736); $[\alpha]_D^{27}$ −131.9° (*c* 0.62, $CHCl_3$) {lit.,[13] $[\alpha]_D^{25}$ −133° (*c* 0.79, $CHCl_3$)}; ν_{max}($CHCl_3$)/cm^{-1} 1775 (CO); δ_H 1.33 (3 H, s, Me), 1.52 (3 H, s, Me), 1.86 (1 H, d, *J* 17.8, *endo*-3-H), 2.43 (1 H, ddd, *J* 17.8, 6.5, 1.1, *exo*-3-H), 4.29 (1 H, s, 1-H), 4.48 and 4.53 (2 H, each d, *J* 5.6, 5- and 6-H) and 4.82 (1 H, dd, *J* 6.3, 0.7, 4-H); *m*/*z* 184 (M^+) and 169 (M^+ − Me).

(1′R,2′S,5′R)-*Menthyl* (1R,5S,6S,7S)-6,7-(*Isopropylidenedioxy*)-3-*oxo*-2,8-*dioxabicyclo*[3.2.1]*octan*-4-*carboxylate* **16**.—mCPBA (80% purity; 44 mg, 0.21 mmol) and $NaHCO_3$ (23 mg, 0.27 mmol) were added to a solution of the keto ester **5** (50 mg, 0.14 mmol) in dry CH_2Cl_2 (15 ml) at 0 °C and the reaction mixture was stirred at room temperature overnight under nitrogen. The reaction was quenched with water (3 ml) and the mixture was washed with saturated aqueous $NaHCO_3$. The aqueous layer was extracted with CH_2Cl_2 (6 ml × 3) and the combined extracts were washed with brine, dried ($MgSO_4$) and evaporated to give an oil (79 mg). Purification of this by column chromatography [eluent hexane–AcOEt (4:1)] gave the oily *lactone* **16** (48 mg, 92%) as an epimeric mixture (4-*endo* ester **16a**/4-*exo* ester **16b**, 1:2) (Found: M^+, 367.1742. $C_{19}H_{27}O_7$ requires *M*, 367.1755); ν_{max}($CHCl_3$)/cm^{-1} 1750–1710 (CO); δ_H 0.71–2.07 (18 H, s, 3 × Me, 3 × CH_2, 3 × CH), 1.32 [2 H, s, Me (**16b**)], 1.33 [1 H, s, Me (**16a**)], 1.48 (3 H, s, Me), 3.44 [0.67 H, s, 4-H (**16b**)], 3.92 [0.33 H, d, *J* 8.6, 4-H (**16a**)], 4.60 [0.67 H, br s, 5-H (**16b**)], 4.68 [0.33 H, d, *J* 5.6, 6- or 7-H (**16a**)], 4.79 [0.33 H, d, *J* 9.0, 5-H (**16a**)], 4.83 [0.67 H, d, *J* 5.6, 6- or 7-H (**16b**)], 4.86–4.96 (1 H, m, 1′-H), 5.09 [0.33 H, d, *J* 5.6, 6- or 7-H (**16a**)], 5.18 [0.67 H, d, *J* 5.6, 6- or 7-H (**16b**)], 5.33 [0.33 H, br s, 1-H (**16a**)] and 5.80 [0.67 H, d, *J* 0.7, 1-H (**16b**)]; *m*/*z* 383 (M^+ + 1), 367 (M^+ − Me) and 323 (M^+ − Me − CO_2).

(1′R,2′S,5′R)-*Menthyl* (*Methyl* 5-*Deoxy*-2,3-O-*isopropylidene*-5-*methoxycarbonyl*-β-L-*ribohexofuranosid*)*uronate* **17**.—MsOH (12.2 μl, 0.189 mmol) was added dropwise to a mixture of the lactone **16** (48 mg, 0.13 mmol), dry MeOH (2 ml) and 2,2-dimethoxypropane (0.155 ml, 1.26 mmol) at 0 °C. After 2 days at room temperature under nitrogen, the reaction was quenched with AcONa (*ca.* 15 mg) and the solvent was evaporated. $CHCl_3$ (6 ml) and water (1 ml) were added to the residue at 0 °C and the pH of the mixture was adjusted to 7–8 with saturated aqueous $NaHCO_3$. The aqueous layer was extracted with $CHCl_3$ (5 ml × 3) and the combined extracts were washed with brine, dried ($MgSO_4$) and evaporated to give a pale brown oil (59 mg). Purification of this by column chromatography [eluent hexane–AcOEt (5:1)] afforded the *diester* **17** [a 1:1 epimeric

mixture at C(5)] (46 mg, 85%) as an oil (Found: M^+, 428.2359. $C_{22}H_{36}O_8$ requires M, 428.2409); $\nu_{max}(CHCl_3)/cm^{-1}$ 1745 and 1725 (CO); m/z 428 (M^+), 413 (M^+ − Me) and 397 (M^+ − OMe).

For the *epimer* I: δ_H 0.71–2.05 (18 H, m, 3 × Me, 3 × CH_2, 3 × CH), 1.31 (3 H, s, Me), 1.49 (3 H, s, Me), 3.33 (3 H, s, OMe), 3.66 (1 H, d, J 11.5, 5-H), 3.76 (3 H, s, CO_2Me), 4.59 (1 H, d, J 6.1, 2-H), 4.70 (1 H, dd, J 6.1, 1.0, 3-H), 4.73 (1 H, m, 1′-H), 4.78 (1 H, dd, J 11.2, 1.0, 4-H) and 4.96 (1 H, br s, 1-H).

For the *epimer* II: δ_H 0.71–2.06 (18 H, m, 3 × Me, 3 × CH_2, 3 × CH), 1.32 (3 H, s, Me), 1.51 (3 H, s, Me), 3.34 (3 H, s, OMe), 3.65 (1 H, d, J 11.0, 5-H), 3.73 (3 H, s, CO_2Me), 4.59 (1 H, d, J 6.1, 2-H), 4.75 (1 H, m, 1′-H), 4.76 (1 H, br d, J 11.2, 4-H), 4.77 (1 H, br d, J 6.8, 3-H) and 4.96 (1 H, br s, 1-H).

Methyl 5-Deoxy-5-hydroxymethyl-2,3-O-isopropylidene-β-L-ribohexofuranoside **7**.—$LiAlH_4$ (9 mg, 0.2 mmol) was added to a solution of the diester **17** (20 mg, 0.047 mmol) in dry Et_2O (4 ml) at 0 °C and the reaction mixture was stirred at room temperature for 3 h under nitrogen. The reaction was quenched with saturated aqueous Na_2SO_4 at 0 °C. After 0.5 h at 0 °C, the precipitate was filtered off and washed with acetone (25 ml). The filtrate was evaporated to give an oil which was purified by PLC (AcOEt) to afford the *diol* **7** (6 mg, 52%) as an oil (Found: M^+, 234.1095. $C_{16}H_{18}O_6$ requires M, 234.1102); $[\alpha]_D^{27}$ +29.6° (c 0.44, $CHCl_3$); $\nu_{max}(CHCl_3)/cm^{-1}$ 3450 (OH); δ_H 1.33 (3 H, s, Me), 1.49 (3 H, s, Me), 2.50 (2 H, br, 2 × OH), 3.49 (3 H, s, OMe), 3.64–3.80 (5 H, m, 2 × CH_2, 5-H), 4.48 (1 H, br s, 4-H), 4.57 and 4.99 (2 H, each d, J 5.9, 2- and 3-H) and 5.00 (1 H, s, 1-H); m/z 249 (M^+ + 1), 233 (M^+ − Me) and 217 (M^+ − OMe or CH_2OH).

(1S,4S,5S,6S)-2-(*Hydroxymethyl*)-5,6-(*isopropylidenedioxy*)-3-(2-*pyridylsulphenyl*)-7-*oxabicyclo*[2.2.1]*hept*-2-*ene* **20**.—A 1.0 mol dm^{-3} solution of DIBAL-H in toluene (0.218 ml, 0.218 mmol) was added to a solution of the ester **6** (20 mg, 0.044 mmol) in dry Et_2O (2 ml) at 0 °C. After 4.5 h at room temperature under nitrogen, the reaction was quenched with saturated aqueous Na_2SO_4 at 0 °C. After 1 h at 0 °C, the precipitate was filtered off and washed with Et_2O. The filtrate was concentrated to give a brown oil (21 mg). Purification of this by PLC [Et_2O–hexane (2:1)] afforded the *alcohol* **20** (9 mg, 67%) as an oil (Found: M^+, 307.0881. $C_{15}H_{17}NO_4S$ requires M, 307.0879); $\nu_{max}(CHCl_3)/cm^{-1}$ 3400 (OH); δ_H 1.32 (3 H, s, Me), 1.50 (3 H, s, Me), 4.26 (1 H, d, J 13.7, C*H*HOH), 4.39 (1 H, d, J 5.4, 5- or 6-H), 4.47 (1 H, d, J 13.7, CH*H*OH), 4.55 (1 H, d, J 5.4, 5- or 6-H), 4.84 and 5.01 (2 H, each s, 1- and 4-H) and 7.10–7.63 (4 H, m, 4 × ArH); m/z 307 (M^+) and 292 (M^+ − Me).

2,5-*Anhydro*-3,4-O-*isopropylidene*-D-*allose* **9**.—Ozone in oxygen was passed through a solution of the vinyl sulphide **20** (30 mg, 0.098 mmol) in dry CH_2Cl_2 (6 ml) at −78 °C until persistence of a blue colour. Excess of ozone was purged with nitrogen and the mixture was concentrated. The residue was dissolved in dry MeOH (6 ml) and $NaBH_4$ (18.5 mg, 0.489 mmol) was added portionwise to the solution at 0 °C. After storage overnight at room temperature, the solution was cooled to 0 °C and acidified with 50% aqueous AcOH (1.5 ml); it was then set aside for 1 h at 0°C. Evaporation of the solvent gave a pale yellow solid (248 mg). $NaIO_4$ (31 mg, 0.15 mmol) was added portionwise to a solution of the solid (248 mg) in MeOH–water (1:1; 5 ml) at room temperature. After 3 h at room temperature, the precipitate was filtered off and washed with AcOEt (40 ml). The filtrate was evaporated to give a pale yellow oil (18 mg), purification of which by PLC [hexane–AcOEt (1:1)] afforded the anhydroallose **9** [an anomeric mixture (3:1)] (6.5 mg, 33%) as a white solid, m.p. 164–165 °C (lit.,[5] m.p. 165 °C) (Found: C, 53.25; H, 6.85. Calc. for $C_9H_{14}O_5$: C, 53.47; H, 6.93%); $[\alpha]_D^{26}$ +5.8° (c 0.65, $CHCl_3$) {lit.,[5] $[\alpha]_D^{25}$ +6.3° (c 0.29, $CHCl_3$)}; ν_{max}(KBr)/cm^{-1} 3460 (OH); δ_H([$^2H_6$]acetone) 1.31 (3 H, s, Me), 1.38 (3 H, s, Me), 3.34 (1 H, d, J 12, 6-H), 3.85 (0.25 H, br d, J 2, OH), 3.89 (0.75 H, s, OH), 3.98 (0.25 H, br s, 5-H), 4.03 (0.75 H, br s, 5-H), 4.09 (1 H, dd, J 12, 2, 6-H), 4.70 (0.25 H, d, J 6, 3- or 4-H), 4.73 (0.75 H, d, J 8, 2-H), 4.74 (0.75 H, d, J 6, 3- or 4-H), 4.79 (1 H, d, J 6, 3- or 4-H), 4.86 (0.25 H, d, J 6, 3- or 4-H), 5.39 (0.75 H, d, J 8, 1-H) and 5.97 (0.25 H, d, J 6, 1-H); m/z 187 (M^+ − Me).

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