Use of Diethylaminosulphur Trifluoride (DAST) in the Preparation of Synthons of Carbocyclic Nucleosides

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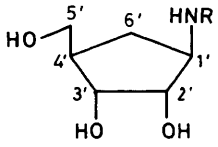
Diethylaminosulphur trifluoride (DAST) converted the protected amino triol (**4**) into the fluorine-containing compounds (**8**) and (**10**). The same reagent converted the alcohol (**9**) into compounds (**10**), (**5**), and (**11**) and transformed the azido alcohol (**15**) into the fluoroazides (**16**) and (**19**). The fluorinated compounds (**5**), (**8**), and (**16**) are useful synthons for fluorocarbocyclic nucleosides. The effect of neighbouring groups on the course of some DAST reactions is discussed.

The dialkylaminosulphur trifluoride reagents were introduced by Middleton [1] and Markovskii *et al.*[2] some 12 years ago. These reagents, particularly diethylaminosulphur trifluoride (DAST),[3] are now widely employed to effect the conversion of an alcohol into an alkyl fluoride.

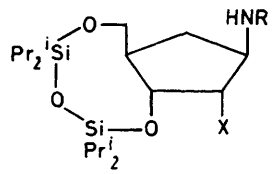
For simple secondary alcohols the reaction proceeds with inversion of configuration, but in more complex substrates neighbouring-group participation can lead to partial or complete retention of configuration at the reacting carbon centre.[4] The reaction is believed to take place through formation of an activated hydroxy group [C–O–$SF_2(NEt_2)$] and fragmentation of the C–O– bond with build up of positive charge on the carbon atom. Subsequent attack by an attendant fluoride ion completes the transformation.[5] DAST has been used to good effect in carbohydrate chemistry,[6] for example in the synthesis of glycosyl fluorides.[7] It has also been used to prepare fluorinated carbapenems,[8] prostaglandins,[9] and steroids.[10] Herein we describe the use of DAST for the preparation of synthons for antiviral carbocyclic nucleosides.

The known amino triol (**1**)[11] was a convenient starting point for the preparation of selected carbocyclic 2′-fluorofuranosyl derivatives of various uracils, adenine, and guanine. Before attempting the exchange of the 2′-hydroxy group for a fluorine atom, the 3′- and 5′-hydroxy groups as well as the amino group required protection.[12] The amino triol (**1**) was converted selectively into the trityl derivative (**2**) using 1 equivalent of trityl chloride. Further reaction with 1,3-dichloro-1,1,3,3-tetra-isopropyldisiloxane afforded protection for the 3′-and 5′-hydroxy groups as expected to give the required 2′-hydroxy compound (**3**). Reaction of (**3**) with DAST in methylene dichloride containing dimethylaminopyridine (DMAP) furnished, after chromatography and crystallization, the aziridine (**6**). Interestingly, Somekh and Shanzer have described a related transformation involving the intermediacy of an aziridinium ion when DAST was allowed to react with a β-hydroxy α-amino acid.[13] Conducting the DAST reaction in the absence of DMAP or at −70 °C failed to alter its course.

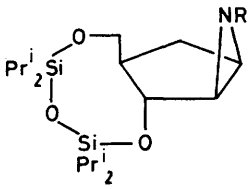
In order to prohibit the participation of the amino group in the DAST reaction, the strongly electron-withdrawing dinitrophenyl (DNP)-protecting group was appended to the nitrogen atom. The protected amino triol (**4**) was smoothly converted using DAST into the protected amino fluoro diol (**8**) which proved to be a key intermediate in our synthetic work towards carbocyclic 2′-fluoroarabinofuranosyl nucleosides.[14] We found that addition of the substrate to a solution of DAST was the preferred order. Incorporation of the fluorine atom at C-2′ in compound (**8**) was clearly indicated by the ^{1}H n.m.r.



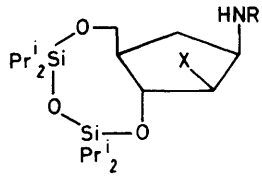
(**1**) R = H
(**2**) R = CPh_3



(**3**) R = CPh_3, X = OH
(**4**) R = $C_6H_3(NO_2)_2$-2,4, X = OH
(**5**) R = $C_6H_3(NO_2)_2$-2,4, X = F



(**6**) R = CPh_3
(**7**) R = $C_6H_3(NO_2)_2$-2,4



(**8**) R = $C_6H_3(NO_2)_2$-2,4, X = F
(**9**) R = $C_6H_3(NO_2)_2$-2,4, X = OH

spectrum {δ[$(CD_3)_2SO$] (*inter alia*) 5.16 (1 H, ddd, J_{HF} 53 Hz, 2′-H), 4.46 (1 H, m, J_{HF} 6 Hz, 1′-H), and 4.26 (1 H, ddd, J_{HF} 26 Hz, 3′-H)} and the relative stereochemistry of the groups on the five-membered ring was confirmed by *X*-ray crystallography.[14] N.m.r. spectroscopy on the crude product from the reaction of (**4**) with DAST showed the presence of a small amount of the rearranged product (**10**) (*vide infra*).

Carbocyclic 2′-fluororibofuranosyl nucleoside analogues were also compounds of interest to us. To gain access to these compounds the free hydroxy group in compound (**4**) was inverted by way of the corresponding 2′-α-mesylate and the 2′-β-acetate to afford compound (**9**). An attempted Mitsunobu reaction on compound (**4**) gave the aziridine (**7**). The latter reaction indicates that, in the absence of a suitable anion, the adjacent dinitrophenylamino group *can* participate in the formation of an aziridine ring: presumably the incipient carbenium ion at C-2′ is more fully developed in the Mitsunobu reaction (compared with the analogous DAST reaction) strongly favouring formation of the three-membered ring.

The alcohol (**9**) was treated with DAST in methylene dichloride at 0 °C. Three products were obtained, the desired fluoro compound (**5**), the protected fluorohydrin (**10**), and the imine (**11**). The presence of the fluorine substituent at C-2′ in compound (**5**) was evident from the ^{1}H n.m.r. spectrum {(δ[$(CD_3)_2SO$] (*inter alia*) 4.93 (1 H, dd, J_{HF} 53 Hz, 2′-H), 4.32 (1 H, dm, J_{HF} 26 Hz, 1′-H), and 4.10 (1 H, ddd, J_{HF} 26 Hz, 3′-H)}. Compound (**10**) is formed, we believe, by loss of the activated

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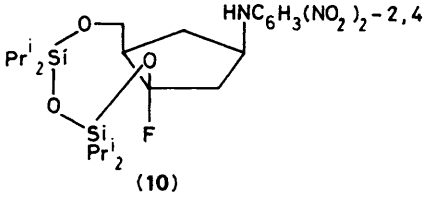

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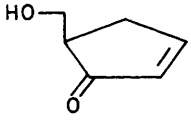

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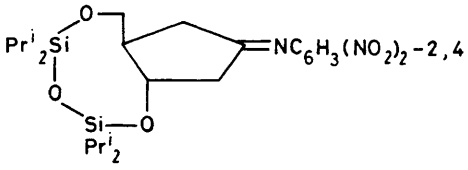
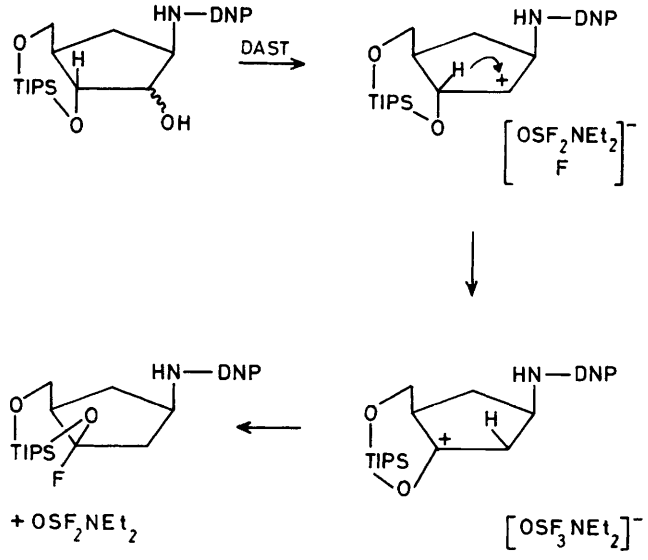


(11)

hydroxy group, migration of the adjacent hydrogen atom, and attack by the fluoride ion at C-3′ from the less hindered side (see Scheme). In this case, migration of the hydrogen atom takes precedence over participation of the arylamino moiety. The structure of (**10**) was indicated by ^{13}C n.m.r. spectroscopy



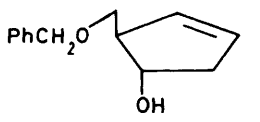
DNP = $C_6H_3(NO_2)_2$-2,4

Scheme.

($CDCl_3$) which displayed a diagnostic quaternary resonance at δ 119.0 (J_{CF} 230 Hz, C-3′) and by conversion of (**10**) into the enone (**12**) using fluoride ion, and confirmed by *X*-ray crystallography. The imine (**11**) is undoubtedly formed by dehydration of (**9**) to give an enamine which rearranges under the reaction conditions.

A further series of potential anti-viral agents we wished to prepare were 6′-fluorocarbocyclic-2′-deoxynucleoside derivatives.[15] Once again we turned to the DAST reagent in the key step.

5-Benzyloxymethylcyclopentadiene was hydrated using a chiral hydroborating agent[16] to furnish the alcohol (**13**). Sharpless oxidation and protection of the free hydroxy group gave the epoxide (**14**). Nucleophilic attack by azide ion occurred with high regioselectivity to afford the azido alcohol (**15**) in good yield. A small amount of the isomer (**18**) was isolated from the reaction mixture and characterized. Treatment of



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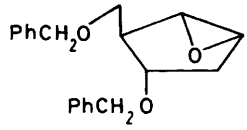

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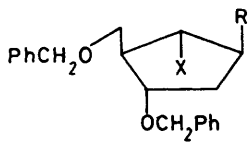
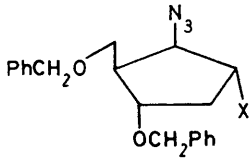


(15) R = N_3, X = OH

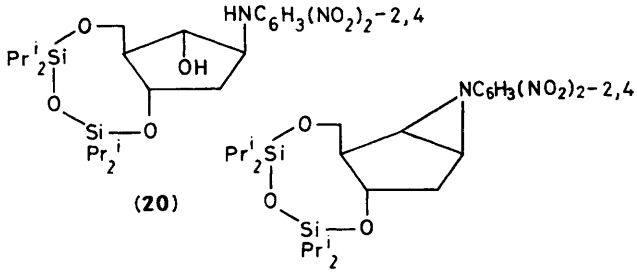
(16) R = N_3, X = F

(17) R = N_3, X = OSO_2CF_3



(18) X = OH

(19) X = F



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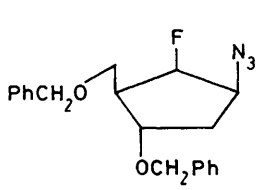

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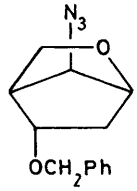

(23)

compound (**15**) with DAST gave a mixture of the fluoro azides (**16**) and (**19**) in the ratio 2:3. The involvement of the azido group in the reaction leads to the observed retention of configuration at the participating carbon centre and the partial migration of the azido group itself. A similar participation of an azido group in a DAST reaction has been reported by Nicolaou.[17] The azide (**16**), produced in a relative low yield, was nevertheless a useful intermediate to anti-herpes agents.[15]

Reaction of the 2,4-dinitrophenylaminocyclopentanol (**20**) with DAST gave the aziridine (**21**). Presumably under these reaction conditions fluoride ion cannot readily gain access to the 6′-position from the β-face due to excessive crowding by the two adjacent bulky groups; as a consequence the amine moiety participates in the preferred intramolecular pathway. A synthon for 6′-β-fluorocarbocyclic nucleosides was prepared by conversion of the azido alcohol (**15**) into the corresponding triflate (**17**) and treatment of the latter compound with fluoride ion. The required fluoroazide (**22**) was formed: the azido group has no opportunity to participate in the S_N2 reaction.

A final example of neighbouring group participation in a DAST reaction is the conversion of the azido alcohol (**18**) into the oxabicyclo[2.2.1]heptane (**23**) in 50% yield.

In summary, our experience in the use of DAST for the conversion of substituted cyclopentanols to substituted

fluorocyclopentanes has been as follows: (a) A good yield can be obtained in the DAST reaction if the approach path of the incoming fluoride ion to the rearside of the activated alcohol unit is relatively unhindered [(**4**) ⟶ (**8**) *cf.* (**20**) ⟶ (**21**)]. (b) An electron rich secondary amino group *anti* to the departing hydroxy group can participate to form (after deprotonation) an aziridine [(**3**) ⟶ (**6**)]. A less electron rich amino group (*e.g.* the 2,4-dinitrophenylamino group) attached to the β-carbon atom can participate to form an aziridine if the approach path of the competing fluoride ion is hindered [(**20**) ⟶ (**21**)]. (c) Proton migration from an adjacent carbon atom can occur when a substituent is present on the neighbouring carbon atom which can delocalize the build up of positive charge. The migrating hydrogen atom can be *syn* or *anti* to the departing hydroxy group [(**4**) ⟶ (**10**) and (**9**) ⟶ (**10**)]. (d) An azido group at the β-position and in the *anti* configuration to the activated hydroxy group can get involved in neighbouring group participation leading to (i) retention of configuration in the OH⟶F conversion and (ii) partial migration of the azido group [(**15**) ⟶ (**16**) + (**19**)]. (e) The tetraisopropyloxadisilyl (TIPS) protecting group is (somewhat surprisingly) stable to the conditions of the DAST reaction. The participating fluoride ion cannot be free to migrate from the site of the reaction and/or must be in a form which cannot attack the susceptible silicon atoms.

Experimental

Petroleum refers to the fractions boiling in the range 40—60 °C. Ether is diethyl ether. Organic solvents were routinely dried over $MgSO_4$ or Na_2SO_4 and evaporation refers to solvent removal on a rotary evaporator under reduced pressure. T.l.c. was performed on pre-coated plates (Merck silica gel 60F 254). Flash chromatography refers to the method of Still *et al.*[18] I.r. spectra were recorded on a Perkin-Elmer 297 grating spectrophotometer and were measured in bromoform solution. ^1H N.m.r. and ^{13}C n.m.r. spectra were recorded on a Bruker WM 250 MHz spectrometer and a Perkin-Elmer 200 MHz spectrometer.

(1R,2R,3S,4R)- *and* (1S,2S,3R,4S)-1-*Hydroxymethyl*-4-*triphenylmethylaminocyclopentane*-2,3-*diol* (**2**).—Triphenylmethyl chloride (2.8 g) was added to a stirred mixture of the triol (**1**)[11] (1.84 g) in pyridine (AnalaR; 17 ml) and triethylamine (2.0 g). Stirring was continued for 2.5 h after which the reaction mixture was evaporated and the residue partitioned between dichloromethane and water. The organic layer was dried and evaporated to give a residue (3.82 g). A portion was crystallized to give the *title compound* (**2**), m.p. 137—138 °C (methyl acetate–petroleum) (Found: C, 76.0; H, 6.9; N, 3.4. $C_{25}H_{27}NO_3 \cdot 0.25H_2O$ requires C, 76.2; H, 6.9; N, 3.55%).

(1R,8R,10R,11S)- *and* (1S,8S,10S,11R)-10-*Triphenylmethylamino*-3,3,5,5-*tetraisopropyl*-2,4,6-*trioxa*-3,5-*disilabicyclo*-[6.3.0]*undecan*-11-*ol* (**3**).—The triol (**2**) (3.88 g) and imidazole 3.0 g) in dimethylformamide was treated with 1,3-dichloro-1,1,3,3-tetraisopropyldisiloxane (3.5 g). After 3 h the mixture was diluted with water and extracted with ethyl acetate. The organic extract was washed with water, dried, and evaporated. The residue was chromatographed over silica using petroleum–ethyl acetate (6:1) as eluant to give the desired product (5.5 g). A portion was crystallized to give the *title compound* (**3**), m.p. 103—104 °C (hexane) (Found: C, 70.2; H, 8.5; N, 2.2. $C_{37}H_{53}NO_4Si_2$ requires C, 70.3; H, 8.45; N, 2.2%).

(1R,8R,10R,12R) *and* (1S,8S,10S,12S)-11-*Triphenylmethylamino*-3,3,5,5-*tetraisopropyl*-2,4,6-*trioxa*-11-*aza*-3,5-*disilatricyclo*[6.4.0.0^{10,12}]*dodecane* (**6**).—A solution of the alcohol (**3**) (0.32 g) in dry dichloromethane (4 ml) was added dropwise over 25 min to a stirred, ice-cold solution of DAST (0.12 g) and dimethylaminopyridine (0.09 g) in dry dichloromethane (3 ml). After 4 h at room temperature a few drops of water were added and stirring was continued for 5 min. The mixture was evaporated and the residue was subjected to preparative layer chromatography using petroleum–ethyl acetate (6:1) to develop the plates. The major band gave the product (0.17 g) which was crystallized to give the *title compound* (**6**), m.p. 159—160 °C (Found: C, 72.5; H, 8.4; N, 2.3. $C_{37}H_{51}NO_3Si_2$ requires C, 72.4; H, 8.4; N, 2.3%).

(1R,2S,3R,5R)- *and* (1S,2R,3S,5S)-3-(2,4-*Dinitroanilino*)-5-*hydroxymethylcyclopentane*-1,2-*diol*.—A solution of the amino triol (**1**) hydrochloride (44 g), anhydrous sodium carbonate (101.6 g), and 2,4-dinitrofluorobenzene (29.5 ml) in dry dimethylformamide (275 ml) was stirred at room temperature for 89 h. The suspension was evaporated under reduced pressure to give a brown oil which, dissolved in chloroform, was filtered and evaporated. Silica gel was added to the residue and the bed of silica was washed with chloroform, methanol, and acetone. The chloroform extract was evaporated to give a yellow oil (5.0 g). The methanol was evaporated and the residue was triturated with acetone. The combined acetone fractions were evaporated to give a yellow solid (56 g). The yellow solid and the yellow oil were combined and triturated with diethyl ether to give the *title compound* (54 g); $\nu_{max.}$ 3 530, 3 325, 3 270, 3 110, 1 625, 1 592, 1 522, and 1 335 cm^{-1}; δ[$(CD_3)_2SO$] 8.9—7.36 (4 H, m, ArH and NH), 5.0—4.75 (3 H, m, 3 × OH), 4.04 (1 H, m, 3-H), 3.90—3.74 (2 H, m, 1- and 2-H), 3.57—3.28 (2 H, m, CH_2O), 2.38 and 1.34 (2 H, 2 × m, CH_2), and 2.04 (1 H, m, 5-H) (Found: C, 45.8; H, 4.6; N, 13.0. $C_{12}H_{15}N_3O_7$ requires C, 46.0; H, 4.8; N, 13.4%).

(1R,8R,10R,11S)- *and* (1S,8S,10S,11R)-10-(2,4-*Dinitroanilino*)-3,3,5,5-*tetraisopropyl*-2,4,6-*trioxa*-3,5-*disilabicyclo*-[6.3.0]*undecan*-11-*ol* (**4**).—3-(2,4-Dinitroanilino)-5-hydroxymethylcyclopentane-1,2-diol (1.2 g) in dimethylformamide (10 ml) was treated with imidazole (1.04 g) and dichlorotetraisopropyldisiloxane (1.33 ml). After 3 h the solution was partitioned between water and ethyl acetate and the aqueous phase was separated. The organic phase was washed with water (× 2) and the combined aqueous washes were back extracted with ethyl acetate. The combined organic extracts were dried and evaporated. The residual oil was chromatographed over silica using petroleum–ethyl acetate as eluant to give the *title compound* (**4**) (1.55 g); $\nu_{max.}$ 3 650, 3 530, 3 360, 1 615, 1 588, 1 518, and 1 330 cm^{-1}; δ($CDCl_3$) 8.90—7.36 (4 H, m, ArH and NH), 4.96 (1 H, OH), 4.03—3.72 (5 H, m, 1-, 10-, and 11-H, and CH_2O), 2.39—1.31 (3 H, m, 8-H and CH_2), and 1.18—0.76 (28 H, m, 4 × Pr^i).

(1R,8R,10R,11R)- *and* (1S,8S,10S,11S)-11-*Fluoro*-10-(2,4-*dinitroanilino*)-3,3,5,5-*tetraisopropyl*-2,4,6-*trioxa*-3,5-*disilabicyclo*[6.3.0]*undecane* (**8**).—A solution of the hydroxy compound (**4**) (0.7 g) in dry dichloromethane (20 ml) was slowly added to a solution of DAST (0.31 ml) in dry dichloromethane (20 ml) at −78 °C. After the solution had been allowed to warm to room temperature it was cooled again to −78 °C and was poured onto a mixture of ice and sodium hydrogen carbonate. The aqueous phase was separated and washed with dichloromethane. The combined organic phases were dried and evaporated and the residue was chromatographed over silica using hexane–ethyl acetate as eluant to give the *title compound* (**8**) (0.43 g), m.p. 134—136 °C (ethanol); $\nu_{max.}$ 3 620—3 060, 1 623, 1 595, 1 526, and 1 325 cm^{-1}; δ[$(CD_3)_2SO$] 8.59 (1 H, NH), 8.38—7.36 (3 H, m, ArH), 5.16 (1 H, ddd, J_{HF} 53 Hz, 11-H), 4.46 (1 H, dm, J_{HF} 6 Hz, 10-H), 4.26 (1 H, ddd, J_{HF} 26 Hz, 1-H), 3.95—3.70 (2 H, m, 2 × 7-H), 2.00 (1 H, m, 8-H), 2.36 and 1.55 (2 H,

2 × m, 2 × 9-H), 1.20—0.85 (28 H, m, 4 × Pr^i) (Found: C, 51.8; H, 7.3; N, 7.5. $C_{24}H_{40}FN_3O_7Si_2$ requires C, 51.7; H, 7.2; N, 7.5%).

(1R,8R,10R,11R)- *and* (1S,8S,10S,11S)-10-(2,4-*Dinitroanilino*)-3,3,5,5-*tetraisopropyl*-2,4,6-*trioxa*-3,5-*disilabicyclo*[6.3.0]-*undecan*-11-*ol* (**9**).—Triethylamine (0.091 g), 4-dimethylaminopyridine (0.101 g), and methanesulphonyl chloride (0.103 g) were added to the alcohol (**4**) (0.485 g) dissolved in dichloromethane (2.5 ml). After 17 h at room temperature the mixture was diluted with dichloromethane and poured into a saturated aqueous sodium hydrogen carbonate. The organic phase was separated, dried, and evaporated under reduced pressure. Chromatography of the residue over silica using hexane–ethyl acetate (4:1) as eluant gave the 2α-mesylate (0.38 g) as a yellow crystalline solid (Found: C, 47.4; H, 6.9; N, 6.5. $C_{25}H_{43}N_3O_{10}SSi_2$ requires C, 47.4; H, 6.8; N, 6.6%). 18-Crown-6 (0.078 g) and caesium acetate (0.342 g) were added to the mesylate (0.36 g) dissolved in dry benzene (7 ml) and the mixture was stirred under reflux for 3 h before being diluted with ethyl acetate and poured into water. The organic phase was separated, dried, and evaporated under reduced pressure to give the 2β-acetate (0.337 g) as a yellow solid (Found: C, 52.6; H, 7.35; N, 6.9. $C_{26}H_{43}N_3O_9Si_2$ requires C, 52.2; H, 7.25; N, 7.0%). 5% Sodium methoxide in methanol (47 ml) was added to the acetate (21.6 g) in dioxane (50 ml) and this was followed after 5 min by Amberlite IR-120 ion exchange resin; the mixture was then filtered through a Kieselguhr silica pad. The latter was washed with methanol and dichloromethane. The methanol extract was evaporated to a small volume and washed with dichloromethane. The combined dichloromethane extracts were dried and evaporated to give the *title compound* (**9**) as a yellow solid (19.57 g); $\nu_{max.}$ 3 340, 1 620, 1 589, 1 523, 1 335, 1 060, and 1 032 cm^{-1}; δ($CDCl_3$) 9.15—6.88 (4 H, m, ArH and NH), 4.28 (1 H, m, 10-H), 4.19—4.03 (2 H, m, 1- and 11-H), 3.99 and 3.69 (2 H, m, CH_2O), 2.38 and 1.61 (2 H, m, CH_2), 2.30 (1 H, OH), 1.96 (1 H, m, 8-H), and 1.20—0.90 (28 H, m, 4 × Pr^i) (Found: C, 51.8; H, 7.6; N, 7.3. $C_{24}H_{41}N_3O_8Si_2$ requires C, 51.9; H, 7.4; N, 7.6%).

(1S,8R,10R)- *and* (1R,8S,10S)-10-*Dinitroanilino*-1-*fluoro*-3,3,5,5-*tetraisopropyl*-2,4,6-*trioxa*-3,5-*disilabicyclo*[6.3.0]-*undecane* (**10**).—The alcohol (**9**) (12.4 g) in dry dichloromethane (220 ml) was added over 0.5 h to a stirred solution of DAST (4.10 ml) in dry dichloromethane (440 ml) at 0 °C. After 0.5 h cold, saturated aqueous sodium hydrogen carbonate (250 ml) was added with stirring. After 15 min the organic phase was separated, dried, and evaporated to give a dark red gum. Chromatography of this over silica using petroleum–ethyl acetate as eluant gave in the first fractions a solid (4.54 g) containing compounds (**5**) and (**11**) in the ratio 8:3 (by n.m.r. spectroscopy). Later fractions were evaporated to give a yellow solid (2.91 g) which was recrystallised from ethanol to give the *title compound* (**10**), m.p. 144—146 °C; $\nu_{max.}$ 3 370, 1 620, 1 590, 1 523, and 1 336 cm^{-1}; δ($CDCl_3$) 9.16—6.84 (4 H, m, ArH and NH), 4.18 (1 H, m, 10-H), 3.96—3.77 (2 H, m, CH_2O), 2.8—1.36 (5 H, m, 2 × 9-H, 2 × 11-H and OH), and 1.2—0.85 (28 H, m, 4 × Pr^i); δ_C($CDCl_3$) *inter alia* 119.0 (J_{CF} 230 Hz, C-1), 48.6 (J_{CF} 7.5 Hz, C-10), 48.3 (J_{CF} 24 Hz, C-8), 46.4 (J_{CF} 26 Hz, C-11), and 33.7 (J_{CF} 5.5 Hz, C-9) (Found: C, 51.5; H, 7.2; N, 7.35. $C_{24}H_{40}FN_3O_7Si_2$ requires C, 51.7; H, 7.2; N, 7.5%).

(1R,8R,10R,11S)- *and* (1S,8S,10S,11R)-10-*Dinitroanilino*-11-*fluoro*-3,3,5,5-*tetraisopropyl*-2,4,6-*trioxa*-3,5-*disilabicyclo*-[6.3.0]*undecane* (**5**).—The alcohol (**9**) (7.02 g) in dichloromethane (125 ml) was added to a solution of DAST (2.32 ml) in dry dichloromethane (250 ml) at 0 °C. After the mixture had been stirred for 10 min, ice-cold aqueous sodium hydrogen carbonate (200 ml) was added and the mixture was stirred for a further 10 min. The organic phase was separated, dried, and evaporated to give a dark red syrup which was chromatographed over silica using petroleum–ethyl acetate (5:1) as eluant. Early fractions contained the *title compound* (**5**) (1.77 g) as orange crystals, δ[$(CD_3)_2SO$] 8.90—7.27 (4 H, m, ArH and NH), 4.93 (1 H, dd, J_{HF} 53 Hz, 11-H), 4.32 (1 H, dm, J_{HF} 26 Hz, 10-H), 4.10 (1 H, ddd, J_{HF} 26 Hz, 1-H), 4.00—3.75 (2 H, 2 × m, CH_2O), 2.18 (1 H, m, 8-H), 2.37 and 1.45 (2 H, 2 × m, 2 × 9-H), and 1.2—0.85 (28 H, m, 4 × Pr^i) (Found: C, 51.45; H, 7.25; N, 7.5. $C_{24}H_{40}FN_3O_7Si_2$ requires C, 51.7; H, 7.2; N, 7.5%). Later fractions were evaporated to give a red syrup (1.89 g) which was dissolved in warm ethanol (10 ml). On cooling, a yellow crystalline solid (0.56 g) was obtained which on t.l.c. evidence was shown to consist of compound (**5**) and a second more polar compound. Evaporation of the ethanol mother liquors gave an oil which was chromatographed over silica using petroleum–diethyl ether (2:1). The slow-running component was obtained as an oil which on addition of ethanol crystallised with time at 0 °C to give the *imine* (**11**), m.p. 111—114 °C; δ($CDCl_3$) 8.90—6.99 (3 H, ArH), 4.36 (1 H, m, 1-H), 4.07 and 3.75 (2 H, 2 × m, CH_2O), 2.80—2.33 (4 H, m, 2 × CH_2), 2.12 (1 H, m, 8-H), and 1.2—0.9 (28 H, m, 4 × Pr^i) (Found: C, 53.3; H, 7.5; N, 7.6. $C_{24}H_{39}N_3O_7Si_2$ requires C, 53.6; H, 7.3; N, 7.8%).

(±)-5-*Hydroxymethylcyclopent*-2-*enone* (**12**).—The protected fluorohydrin (**10**) (0.2 g) in tetrahydrofuran (1.3 ml) was treated with tetrabutylammonium fluoride (1M in tetrahydrofuran; 0.32 ml). After 1 h the solvent was evaporated to give a gum which was purified by chromatography over silica using ethyl acetate as eluant, to give the *title compound* (**12**)[19] as a yellow oil; $\nu_{max.}$ 1 692 cm^{-1}; δ($CDCl_3$) 7.74 (1 H, m, 3-H), 6.17 (1 H, m, 2-H), 3.88 and 3.77 (2 H, 2 × m, CH_2O), and 2.85—2.43 (4 H, m, 2 × 4- and 5-H and OH).

(1R,8R,10R,12R)- *and* (1S,8S,10S,12S)-11-*Dinitroanilino*-3,3,5,5-*tetraisopropyl*-2,4,6-*trioxa*-11-*aza*-3,5-*disilatricyclo*-[6.4.0.0^{10,12}]*dodecane* (**7**).—A solution of diethyl azodicarboxylate (0.078 g) in toluene (1 ml) was added to a stirred solution of the alcohol (**4**) (0.2 g) and triphenylphosphine (0.118 g) in toluene (2.5 ml). The mixture was stirred for 5 min at room temperature after which a solution of methyl toluene-*p*-sulphonate (0.084 g) in toluene (2 ml) was added. After 65 h the solution was loaded onto preparative silica chromatography plates which were developed with hexane–ethyl acetate (5:1). Extraction of the major band with ethyl acetate and evaporation of the solvent gave the *title compound* as a yellow solid (0.137 g); $\nu_{max.}$ 1 605, 1 592, 1 530, 1 520, 1 335, 1 065, and 832 cm^{-1}; δ($CDCl_3$) 8.88—7.18 (3 H, m, ArH), 4.76 (1 H, m, 1-H), 3.82 and 3.58 (2 H, 2 × m, CH_2O), 3.19—3.07 (2 H, m, CH_2), 1.40—0.72 (28 H, m, 4 × Pr^i) (Found: C, 53.9; H, 7.4. $C_{24}H_{39}N_3O_7Si_2$ requires C, 53.6; H, 7.3%).

2-*Benzyloxymethylcyclopent*-3-*enol* (**13**).—A 50% sodium dispersion in paraffin (9.2 g) was broken down in sodium-dried toluene and the finely particulate sodium was filtered off and washed with dried toluene (3 × 10 ml). The sodium was suspended in dry tetrahydrofuran and cooled to −5 °C under nitrogen. Cold, freshly distilled cyclopentadiene (18 ml) was added with stirring over 30 min. After 1.5 h the cold solution was added over 20 min to a vigorously stirred solution of benzyl chloromethyl ether (30 ml) in dry tetrahydrofuran at −50 °C under a nitrogen atmosphere. The mixture was stirred for 1 h at −45 °C and then cooled to −60 °C. A suspension of (−)-diisopinan-3-ylborane (66.3 g) in dry tetrahydrofuran at −60 °C was added and the mixture was stirred at −60 °C for 1 h. The solution was allowed to warm to 5 °C and was stirred at this temperature for 18 h. Approximately half of the tetrahydrofuran was then evaporated and diethyl ether (200 ml) added. Sodium

hydroxide (3M; 70 ml) was added dropwise to the solution, the temperature being held below 5 °C; hydrogen peroxide (30%; 70 ml) was then added dropwise the temperature of the solution being held below 12 °C. After the mixture had been stirred for 1 h at 0—10 °C the organic phase was separated and the aqueous phase was washed with diethyl ether (50 ml). The combined organic fractions were washed with brine (100 ml), dried, and evaporated. Chromatography over silica using petroleum–diethyl ether (1:1) followed by diethyl ether as eluant gave the crude product (29.0 g). Distillation gave the *title compound* (**13**) (15.8 g), b.p. 120—130 °C at 10^{-1} mmHg; $[\alpha]_D^{22}$ + 89° (*c* 1.0, $CHCl_3$); $\nu_{max.}$ 3 590 cm^{-1}; $\delta(CDCl_3)$ 7.42—7.20 (5 H, m, ArH), 5.74 and 5.57 (2 H, m, 3- and 4-H), 4.54 (2 H, m, $PhCH_2O$), 4.32 (1 H, m, 1-H), 3.57 and 3.32 (2 H, m, OCH_2), 2.88 (1 H, m, 2-H), 2.71 and 2.31 (2 H, m, 2 × 5-H), and 2.09 1-H, OH) (Found: C, 76.15; H, 7.9. $C_{13}H_{16}O_2$ requires C, 76.4; H, 7.9%). The optical purity of the alcohol was shown to be ⩾98% by n.m.r. spectroscopy following reaction of (**13**) with (4*R*,5*R*)-2-chloro-4,5-dimethyl-2-oxo-1,3,2-dioxaphospholane according to the method of Anderson and Shapiro.[20]

(2R,3S)-*Benzyloxy*-2-*benzyloxymethyl*-6-*oxabicyclo*[3.1.0]-*hexane* (**14**).—t-Butyl hydroperoxide (70%; 20 ml) was mixed with 1,2-dichloroethane (34 ml). The organic layer was separated and treated with anhydrous sodium sulphate. The inorganic salt was filtered off and the solution was added dropwise over 45 min to a stirred solution of the alkene (**13**) (15 g) and vanadium(v) acetylacetonate (0.2 g) in 1,2-dichloroethane (10 ml). The temperature was kept below 30 °C. The mixture was stirred for 2.75 h, cooled in ice, and treated with aqueous sodium sulphite (75 ml). The mixture was allowed to warm to room temperature and stirred for 2 h. The organic phase was separated and the aqueous phase was washed with dichloromethane (10 ml). The combined organic fractions were washed with water, dried, and evaporated to give a pale yellow syrup. Chromatography of this over silica using ether–petroleum (4:1) as eluant gave starting material (2.5 g) and (2R,3S)- 2-benzyloxymethyl-6-oxabicyclo[3.1.0]hexan-3-ol (12.0 g), $[\alpha]_D^{23}$ + 51° (*c* 1.0, $CHCl_3$); $\delta(CDCl_3)$ 7.42—7.22 (5 H, m, ArH), 4.48 (2 H, s, $PhCH_2O$), 3.89 (1 H, m, 3-H), 3.63 and 3.61 (2 H, 2 × m, 1- and 5-H), 3.45 and 3.38 (2 H, m, OCH_2), 2.51 (1 H, m, 2-H), 2.22 (1 H, d, *J* 12 Hz, OH), and 2.06 (2 H, m, 2 × 4-H) (Found: C, 70.65; H, 7.5. $C_{13}H_{16}O_3$ requires C, 70.9; H, 7.3%). This epoxy alcohol (4.34 g) in dry tetrahydrofuran (20 ml) was added dropwise to a stirred suspension of sodium hydride [60% dispersion in oil; 867 mg (the oil was removed after weighing using petroleum)] in tetrahydrofuran (40 ml) under nitrogen. After 2 h, benzyl bromide (2.58 ml) and tetrabutylammonium iodide (70 mg) were added. Stirring was continued for 2.5 h whereupon ethanol (1 ml) was added. The mixture was evaporated and the residue was partitioned between ether (25 ml) and water (25 ml). The aqueous phase was washed with ether (10 ml). The combined ether extracts were dried and evaporated to give an orange syrup (6.5 g) which was purified by chromatography over silica using ether–petroleum (2:1) as eluant to give the desired *epoxide* (**14**) (5.8 g); $[\alpha]_D^{24}$ + 37° (*c* 1.0, $CHCl_3$); $\nu_{max.}$ 1 075, 841, and 739 cm^{-1}; $\delta(CDCl_3)$, 7.5—7.16 (10 H, m, ArH), 4.55—4.38 (4 H, 2 × s, 2 × $PhCH_2$), 3.89 (1 H, m, 3-H), 3.56—3.33 (4 H, m, 1- and 5-H and OCH_2), 2.60 (1 H, m, 2-H), and 2.15 and 2.03 (2 H, 2 × m, 2 × 4-H) (Found: C, 77.3; H, 7.3. $C_{20}H_{22}O_3$ requires C, 77.4; H, 7.1%).

(1S,2S,3R,4S)-1-*Azido*-4-*benzyloxy*-3-*benzyloxymethylcyclopentan*-2-*ol* (**15**).—A solution of the epoxide (**14**) (3.35 g), sodium azide (1.4 g), and ammonium chloride (1.4 g) in a mixture of water (10 ml) and ethanol (40 ml) was heated under reflux for 22 h. The ethanol was evaporated and the aqueous residue was diluted with water (10 ml) and extracted with ether (1 × 30 ml and 1 × 10 ml). The combined organic extracts were washed with brine (20 ml), dried, and evaporated. The residue was chromatographed over silica using chloroform–ethanol (25:1) and petroleum–ether (3:2) as eluant to give the *azido alcohol* (**15**) (3.3 g), $[\alpha]_D^{22}$ + 26° (*c* 0.5, $CHCl_3$); $\nu_{max.}$ 3 680, 3 598, 2 105, and 1 070 cm^{-1}; $\delta(CDCl_3)$ 7.4—7.2 (10 H, m, ArH), 5.6—5.35 (4 H, 2 × s, 2 × $PhCH_2$), 3.93 (1 H, m, 1-H), 3.82 (1 H, m, 2-H), 3.71 (1 H, m, 4-H), 3.66 and 3.49 (2 H, m, OCH_2), 2.47 (1 H, OH), and 2.30—1.77 (3 H, m, 3-H and 2 × 5-H) (Found: C, 67.5; H, 6.5. $C_{20}H_{23}N_3O_3$ requires C, 68.0; H, 6.6%); and the *azido alcohol* (**18**) (0.2 g); $\nu_{max.}$ 3 595, 3 500, 2 108, and 1 072 cm^{-1}; $\delta(CDCl_3)$ 7.4—7.2 (10 H, m, ArH), 4.6—4.4 (4 H, 2 × s, 2 × $PhCH_2$), 4.17 (1 H, m, 1-H), 4.07 (1 H, m, 2-H), 3.82 (1 H, m, 4-H), 3.7—3.4 (2 H, m, OCH_2), 2.72 (1 H, m, 3-H), and 2.34—1.88 (3 H, m, OH and 2 × 5-H).

(1S,2S,3R,4S)-1-*Azido*-4-*benzyloxy*-3-*benzyloxymethyl*-2-*fluorocyclopentane* (**16**) *and* (1R,2R,3S,4R)-2-*Azido*-4-*benzyloxy*-3-*benzyloxymethyl*-1-*fluorocyclopentane* (**19**).—A solution of the azido alcohol (**15**) (0.35 g) in dry dichloromethane (5 ml) was added dropwise over 20 min to a stirred ice-cold solution of DAST (0.12 ml) in dichloromethane (5 ml) under nitrogen. The mixture was allowed to warm to room temperature over 1.5 h after which it was evaporated and the residue taken up in diethyl ether. This solution was passed over a bed of silica gel using diethyl ether–petroleum (1:1) as eluant. Evaporation of the solvent gave a crude product which was subjected to preparative layer chromatography using benzene–petroleum (3:1) for development of the plates to give the *fluoro azide* (**16**) (0.055 g); $\nu_{max.}$ 2 105 cm^{-1}; $\delta(CDCl_3)$ 7.4—7.2 (10 H, m, ArH), 4.7 (1 H, dm, J_{HF} 53 Hz, 2-H), 4.56—4.37 (4 H, m, 2 × $PhCH_2$), 4.19 (1 H, m, 1-H), 3.86 (1 H, m, 4-H), 3.55 (2 H, m, OCH_2), 2.41 (1 H, dm, J_{HF} 24 Hz, 3-H), 2.20 and 1.82 (2 H, 2 × m, 2 × 5-H); and the *fluoro azide* (**19**) (0.114 g); $\nu_{max.}$ 2 150 cm^{-1}; $\delta(CDCl_3)$ 7.4—7.2 (10 H, m, ArH), 4.97 (1 H, dm, J_{HF} 53 Hz, 1-H), 4.58—4.36 (4 H, m, 2 × $PhCH_2$), 4.29 (1 H, dm, J_{HF} 16 Hz, 2-H), 3.8 (1 H, m, 4-H), 3.7—3.5 (2 H, m, OCH_2), 2.67 (1 H, m, 3-H), and 2.43 and 1.94 (2 H, 2 × m, 2 × 5-H).

(1S,8S,9R,11S)-10-*Dinitroanilino*-3,3,5,5-*tetraisopropyl*-2,4,6-*trioxa*-10-*aza*-3,5-*disilatricyclo*[6.4.0.$0^{9,11}$]*dodecane* (**21**).—The alcohol (**20**) (0.21 g) in dry dichloromethane (5 ml) was added dropwise to a stirred ice-cold solution of DAST (0.067 ml) in dichloromethane (5 ml). After 10 min ice-cold aqueous sodium hydrogen carbonate (5 ml) was added dropwise with stirring. After a further 10 min the organic phase was separated, dried, and evaporated. The residue was chromatographed over silica using dichloromethane as eluant to give the *aziridine* (**21**) (0.125 g); $\nu_{max.}$ 1 607, 1 592, 1 520, 1 335, 1 068, and 1 030 cm^{-1}; $\delta(CDCl_3)$ 8.86—7.07 (3 H, m, ArH), 4.25 (1 H, m, 1-H), 4.40 and 4.11 (2 H, 2 × m, OCH_2), 3.04 and 2.92 (2 H, 2 × m, 9- and 11-H), 2.34 (1 H, m, 8-H), 2.88 (1 H, m, 12-H), and 2.36—1.77 (29 H, m, 12-H and 4 × Pr^i).

(1S,8R,9S,10S)-10-*Dinitroanilino*-3,3,5,5-*tetraisopropyl*-2,4,6-*trioxa*-3,5-*disilabicyclo*[6.3.0]*undecan*-9-*ol* (**20**).—Compound (**14**) (2.2 g) was debenzylated by hydrogenolysis over 10% Pd/C (400 mg) to give the corresponding diol (100%). A solution of 1,3-dichloro-1,1,3,3-tetraisopropyldisiloxane (3.23 ml) in dry dichloromethane (10 ml) was added to a stirred solution of the diol (1.2 g) in dry pyridine (15 ml) and dry dichloromethane (30 ml). After 4 h, 1,3-dichloro-1,1,3,3-tetraisopropyldisiloxane (0.31 ml) was added and stirring continued for 1 h. The solvent was evaporated and the residue was partitioned between water (225 ml) and ethyl acetate (25 ml). The organic phase was separated, and washed with ice-cold hydrochloric acid (0.5M; 25 ml), ice-cold aqueous sodium hydrogen carbonate (25 ml), and brine (25 ml). The solution was dried and the solvent

evaporated to give a pale syrup which was chromatographed over silica using dichloromethane as eluant to give the protected epoxide (1.58 g).

A solution of this epoxide (1.58 g), sodium azide (0.55 g), and ammonium chloride (0.25 g) in a mixture of water (4 ml) and ethanol (16 ml) was heated under reflux for 4 h. The ethanol was evaporated and the aqueous residue was diluted with water (5 ml) and extracted with ethyl acetate (1 × 15 ml, 1 × 5 ml). The combined extracts were washed with brine (5 ml), dried, and evaporated to give a pale syrup (1.73 g). Flash chromatography over silica using petroleum–ether (4:1) as eluant gave the required protected azido alcohol (1.29 g), m.p. 33—37 °C and a small amount of diastereoisomer (0.09 g). The major product (0.65 g) was dissolved in ethanol (10 ml) and hydrogenated over Lindlar catalyst (0.2 g) at atmospheric pressure for 2 h. The catalyst was removed by filtration through Kieselguhr and the filtrate was evaporated to give the amino alcohol (0.63 g). This material was dissolved in dry dimethylformamide (5 ml) and 2,4-dinitrofluorobenzene (0.26 g) and sodium carbonate (0.64 g) were added. The mixture was stirred at room temperature for 18 h and partitioned between water (20 ml) and ethyl acetate (20 ml). The organic phase was separated, washed with water (10 ml), dried, and evaporated to give an orange syrup. The crude product was purified by column chromatography over silica using dichloromethane–ether (10:1) as eluant to give the *title compound* (**20**) (0.63 g); $\nu_{max.}$ 3 590, 3 350, 1 618, 1 590, 1 518, and 1 332 cm^{-1}; $\delta(CDCl_3)$ 9.15—7.14 (4 H, m, NH and ArH), 4.32 (1 H, m, 10-H), 4.17—3.84 (4 H, m, OCH_2, 1- and 9-H), 2.42 (1 H, m, 11-H), 2.19 (1 H, m, OH), 2.03—1.86 (2 H, m, 8- and 11-H), and 1.36—0.76 (28 H, m, 4 × Pr^i).

(1S,2R,3R,4S)-1-*Azido*-4-*benzyloxy*-3-*benzyloxymethyl*-2-*fluorocyclopentane* (**22**).—Trifluoromethanesulphonyl chloride (0.2 ml) was added to a stirred, ice-cold solution of the alcohol (**15**) (0.565 g), 4-dimethylaminopyridine (0.195 g), and triethylamine (0.245 ml) in dichloromethane (5 ml). After 30 min at 0 °C the mixture was diluted with water (5 ml) and the organic phase separated. The aqueous phase was extracted with dichloromethane (5 ml), and the combined dichloromethane extracts were dried and evaporated. The crude product was purified by chromatography over silica using dichloromethane as eluant, to give the trifluoromethanesulphonate (**17**) (0.52 g). Tetrabutylammonium fluoride trihydrate (0.67 g) was added to a stirred cold (−10 °C) solution of the trifluoromethanesulphonate (**17**). The mixture was warmed to 15 °C over 1 h and then was evaporated. The residue was partitioned between water (10 ml) and ether (10 ml) and the organic phase was separated, washed with water (2 × 5 ml), dried, and evaporated. The residue was purified by preparative layer chromatography over silica using ether–petroleum for development of the plates, to give the *fluoro azide* (**22**) (0.13 g); $\nu_{max.}$ 2 100, 1 070, and 738 cm^{-1}; $\delta(CDCl_3)$ 7.4—7.2 (10 H, m, ArH), 5.13 (1 H, dm, J_{HF} 55 Hz, 2-H), 4.6—4.4 (4 H, m, 2 × $PhCH_2O$), 3.90 (1 H, m, 4-H), 3.81 (1 H, dm, *J* 28 Hz, 1-H), 3.67 and 3.59 (2 H, m, OCH_2), 2.45 (1 H, dm, *J* 32 Hz, 3-H), and 2.3—2.1 (2 H, m, 2 × 5-H) (Found: C, 67.0; H, 6.2; N, 11.8. $C_{20}H_{22}FN_3O_2$ requires C, 67.6; H, 6.2; N, 11.8%).

(5S,7R)-7-*Azido*-5-*benzyloxy*-2-*oxabicyclo*[2.2.1]*heptane* (**23**).—A solution of the azido alcohol (**18**) (0.185 g) in dry dichloromethane (2.5 ml) was added dropwise over 10 min to a stirred, ice-cold solution of DAST (0.06 ml, 1 equiv.) in dichloromethane (2.5 ml). The mixture was allowed to warm to room temperature over 30 min and then stirred at this temperature for 1 h. The solvent was removed under reduced pressure and the residue was triturated with ether. The ethereal solution was passed through a bed of silica, using ether as eluant. The ether was evaporated and the crude product was chromatographed over silica using ether–petroleum (1:1) as eluant to give the *title compound* (**23**) (50%); $\nu_{max.}$ 2 150 cm^{-1}; $\delta(CDCl_3)$ 7.45—7.30 (5 H, m, ArH), 4.51 (2 H, m, OCH_2), 4.25 and 4.14 (2 H, 2 × m, 1- and 7-H), 3.95 (1 H, m, 3-*exo*-H), 3.79 (1 H, m, 5-H), 3.41 (1 H, m, 3-*endo*-H), 2.65 (1 H, m, 4-H), 2.15 (1 H, m, 6-*endo*-H), and 1.83 (1 H, m, 6-*exo*-H).

References

1 W. J. Middleton, *J. Org. Chem.*, 1975, **40**, 574.
2 L. N. Markovskii, V. E. Pashinnik, and A. V. Kirsanov, *Synthesis*, 1973, 787; *Z. Org. Khim.*, 1976, **12**, 965.
3 W. J. Middleton and E. M. Bingham, *Org. Synth.*, 1977, **52**, 50.
4 S. Castillon, A. Dessinges, R. Faghih, G. Lukacs, A. Olesker, and T. T. Thang, *J. Org. Chem.*, 1985, **50**, 4913.
5 G. M. Blackburn and D. E. Kent, *J. Chem. Soc., Perkin Trans. 1*, 1986, 913 and references therein.
6 P. J. Card, *J. Carbohydrate Chem.*, 1985, **4**, 451.
7 P. Kovac, H. J. C. Yeh, G. L. Jung, and C. P. J. Glaudemans, *J. Carbohydrate Chem.*, 1986, **5**, 497; W. Rosenbrook, D. A. Riley, and P. A. Lartey, *Tetrahedron Lett.*, 1985, **26**, 3; G. H. Posner and S. R. Haines, *ibid.*, 1985, **26**, 5.
8 C. P. Mak and H. Fliri, Ger. Offen, DE 3434504 A1, 1985; see also C. P. Mak, K. Wagner, C. Mayerl, and H. Fliri, *Heterocycles*, 1982, **19**, 1399.
9 V. V. Bezuglov, I. V. Serkov, R. G. Gafurov, E. M. Llerena, V. E. Pashinnik, L. N. Markovskii, and L. D. Bergel'son, *Dokl. Akad., Nauk SSSR*, 1984, **279**, 378; K. Bannai, T. Toru, T. Oba, T. Tanaka, N. Okamura, K. Watanabe, A. Hazato, and S. Kurozumi, *Tetrahedron*, 1983, **39**, 3807.
10 T. Kobayashi, M. Maeda, H. Komatsu, and M. Kojima, *Chem. Pharm. Bull.*, 1982, **30**, 3082; T. G. C. Bird, G. Felsky, P. M. Fredericks, E. R. H. Jones, and G. D. Meakins, *J. Chem. Res.*, 1979, (*S*), 388; (*M*), 4728; S. Rozen, Y. Faust, and H. Ben-Yakov, *Tetrahedron Lett.*, 1979, **20**, 1823.
11 R. C. Cermak and R. Vince, *Tetrahedron Lett.*, 1981, **22**, 2331.
12 In the Discussion section the numbering and naming of the carbocyclic nucleosides follows the trivial system used by G. V. Madhavan and J. C. Martin, *J. Org. Chem.*, 1986, **51**, 1287; in the Experimental section IUPAC nomenclature is used.
13 L. Somekh and A. Shanzer, *J. Am. Chem. Soc.*, 1982, **104**, 5836; see also D. R. Crist and N. J. Leonard, *Angew. Chem., Int. Ed. Engl.*, 1969, **8**, 962.
14 K. Biggadike, A. D. Borthwick, D. Evans, A. M. Exall, B. E. Kirk, S. M. Roberts, L. Stephenson, P. Youds, A. M. Z. Slawin, and D. R. Williams, *J. Chem. Soc., Chem. Commun.*, 1987, 251.
15 K. Biggadike, A. D. Borthwick, A. M. Exall, B. E. Kirk, S. M. Roberts, P. Youds, A. M. Z. Slawin, and D. R. Williams, *J. Chem. Soc., Chem. Commun.*, 1987, 255.
16 *Cf.* J. J. Partridge, N. K. Chadha, and M. R. Uskokovic, *J. Am. Chem. Soc.*, 1973, **95**, 532.
17 K. C. Nicolaou, T. Ladduwahetty, J. L. Randall, and A. Chucholowski, *J. Am. Chem. Soc.*, 1986, **108**, 2466; see also R. Faghih, F. C. Escribano, S. Castillon, J. Garcia, G. Lukacs, A. Olesker, and T. T. Thang, *J. Org. Chem.*, 1986, **51**, 4558.
18 W. C. Still, M. Kahn, and A. Mitra, *J. Org. Chem.*, 1978, **43**, 2933.
19 H. Paulsen and U. Maass, *Chem. Ber.*, 1981, **114**, 346.
20 R. C. Anderson and N. J. Shapiro, *J. Org. Chem.*, 1984, **49**, 1304.

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