Functionalised Carbocycles from Carbohydrates. Part 3.[1] The Synthesis of the Epoxy Lactone Prostaglandin Intermediate *via* an Isoxazolidine Derivative.[2] *X*-Ray Crystal Structure of (1*R*,5*R*)-6-*exo*,7-*endo*-Dibenzoyloxy-8-*exo*-iodo-3-oxo-2-oxabicyclo[3.3.0]octane

Robert J. Ferrier * and Petpiboon Prasit
Department of Chemistry, Victoria University of Wellington, Private Bag, Wellington, New Zealand
Graeme J. Gainsford
Chemistry Division, Department of Scientific and Industrial Research, Private Bag, Petone, New Zealand

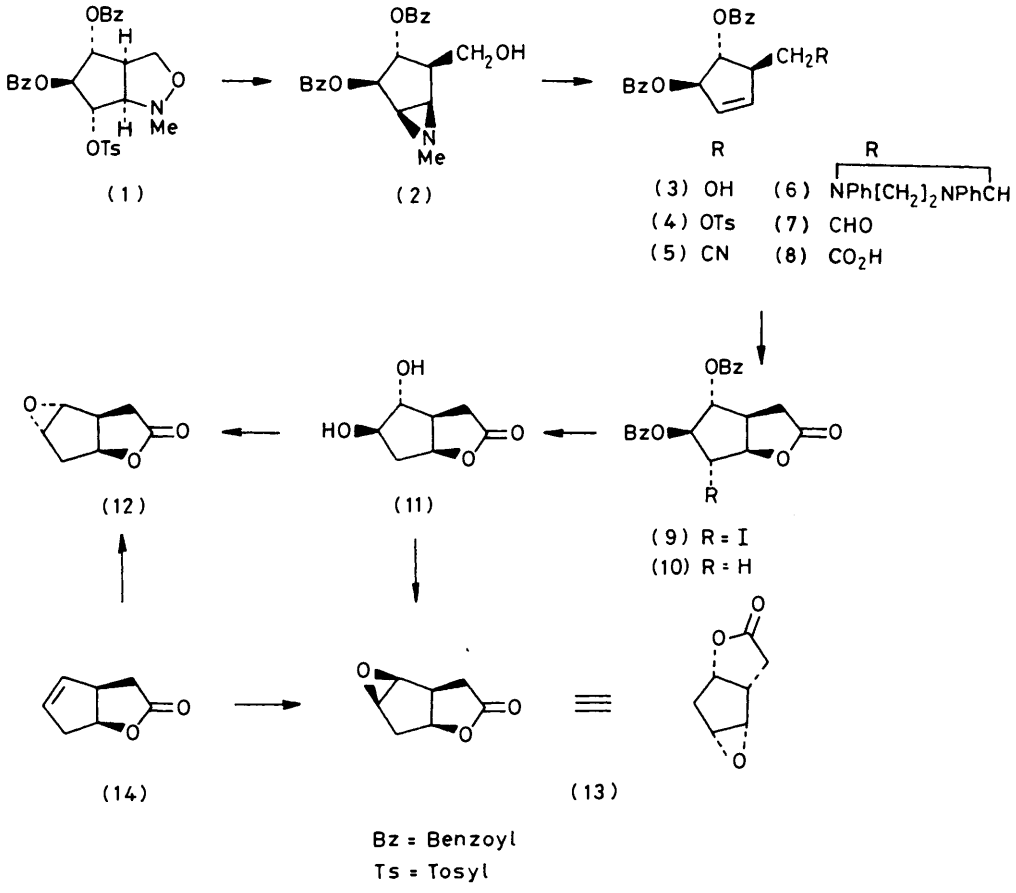
The bicyclic isoxazolidine 6,7-dibenzoyloxy-*N*-methyl-8-tosyloxy-3-oxa-2-azabicyclo[3.3.0]octane (1), which is easily obtained from a readily available D-glucose derivative, has been converted into the epoxy lactone 8-oxo-3,7-dioxatricyclo[4.3.0.0^{2,4}]nonane (13), *via* a series of cyclopentane derivatives, in ten steps. Since the product (13) can be used to prepare prostaglandins this sequence represents a new route to these compounds in their enantiomerically pure natural form.

A major recent development in carbohydrate chemistry has been the recognition of the value of sugars as starting materials for the synthesis of a wide range of enantiomerically pure non-carbohydrate natural products.[3] Furanoid and pyranoid monosaccharide derivatives can be used to produce compounds with five- and six-membered oxygen-containing rings, and specifically functionalised acyclic compounds can also be made, but in addition, the sugars offer access to carbocyclic compounds. While cyclohexane derivatives have been prepared by several methods and on many occasions, conversions into cyclopropanes, cyclobutanes, and cycloheptanes are less common, and the synthesis of cyclopentanes has, until recently, not received detailed attention.[1,4] Now, however, several methods of making such compounds from carbohydrates have been reported, and one of the first natural products of this category to have been specifically produced from a sugar derivative was pentenomycin.[5] Immediately following this a major development was reported in the elegant synthesis of prostaglandin $F_{2\alpha}$ from D-*glycero*-D-*gulo*-heptono-1,4-lactone[6] which is readily available from D-glucose. In earlier work Stork and his associates had used triose and tetrose fragments of higher sugars as critical synthons for other prostaglandins[7] but in the prostaglandin $F_{2\alpha}$ synthesis all of the carbohydrate carbon atoms were incorporated into the framework of the product (C-1, C-7 becoming C-16, C-10). Further, in relation to prostanoid chemistry, D-glucose has been used as a starting material for synthesising thromboxane B_2,[8] and other workers have synthesised cyclopentane derivatives related to the prostaglandins starting from monosaccharides,[9] but it remained to develop a method of converting sugars into an advanced intermediate of the kind required for synthesising a range of prostaglandins and their analogues.[10] We now report the synthesis of compound (13) in enantiomerically pure form from a readily obtained derivative of D-glucose. This epoxy lactone (13) has previously been prepared in both its racemic[11] and required enantiomeric[12] modifications and has been converted into prostaglandins,[11] and the present approach therefore represents a carbohydrate-into-prostaglandin conversion of some general applicability.

In the preceding paper[1] it was demonstrated that the method of Bernet and Vasella[13] is of appreciable value for converting 6-deoxy-6-halogenohexopyranose derivatives, *via* the 6-deoxyhex-5-enopyranose analogues, into 3-oxa-2-azabicyclo[3.3.0]octane derivatives, and the present synthesis of the epoxy lactone (13) (see Scheme) depends upon reactions which can be effected specifically in the neighbourhood of C-8 of this oxa-azabicyclic system consequent upon the introduction of a specific leaving group at that position. The preceding paper also describes reactions at C-4 made possible by the conversion of this atom into an acetal centre.

Whereas reduction of isoxazolidines to ring-opened amino alcohols can be effected by use of zinc–acetic acid, lithium aluminium hydride, titanium(III) chloride, or by catalytic hydrogenation,[14] treatment of the bicyclic triester (1), obtained from methyl 3,4-di-*O*-benzoyl-6-deoxy-6-iodo-2-*O*-tosyl-α-D-glucopyranoside,[1] with hydrogen over Raney nickel gave the crystalline aziridine (2) in good yield. Under these conditions the amine initially formed apparently displaced the sulphonyloxy group thus indicating their *trans*-relationship, and this follows a precedent which reveals that isoxazolidines containing suitable sulphonyl ester groups react under hydrogenation conditions to give cyclic amines.[15] In the cited example, however, palladium–charcoal was used as hydrogenolysis catalyst whereas compound (1) resisted reduction in the presence of either this catalyst or platinum oxide.

N-Alkylaziridines, on treatment with equivalent proportions of *m*-chloroperbenzoic acid at room temperature, undergo an elimination reaction by way of *N*-oxides to afford alkenes in high yield[16] and, in this way, compound (2) was efficiently converted into the alkene (3). To effect the required extension of the side-chain the unsaturated alcohol was tosylated and the product (4) was converted into the syrupy nitrile (5) by use of sodium cyanide in dimethyl sulphoxide. Specific hydrolysis of the cyano group of this compound proved to be difficult and ' reductive hydrolysis ' with Raney nickel in the presence of sodium hypophosphite (sodium phosphinite) in aqueous pyridine–acetic acid[17] was therefore employed, the product being isolated as the *N*,*N*-diphenylimidazolidine derivative (6). Mild acid-catalysed hydrolysis gave the aldehyde (7) which was converted to the acid (8) with pyridinium dichromate in *N*,*N*-dimethylformamide.[18] Compounds (5)—(8) were syrupy and were not formally characterised. They did, however, afford appropriate ^{1}H n.m.r. spectra and the acid (8) was quantitatively converted into the crystalline iodo lactone (9), the structure and absolute configuration of which were determined by *X*-ray diffraction analysis (Figure). In the crystal the cyclopentane ring adopts the envelope conformation with C(8) projecting 0.44 Å in the *exo*-direction from the plane of the other atoms. In this way the stereochemical relationship of the carbon-bonded substituent on the cyclopentane ring and the neighbouring benzoyloxy group was established which, in turn, confirms the stereochemistry of the ring-closure reaction leading to the initial isoxazolidine (1) and that of its direct conversion into the aziridine (2). Iodolactonisation has



Scheme.

proved of great value in the chemical synthesis of prostaglandins, providing efficient and stereospecific means of introducing hydroxy groups into the cyclopentane ring; [19] it was used in the initial synthesis of the current target compound, although to control the stereochemistry at the epoxide ring centres rather than at the lactone ring alcohol position.[11a]

Reductive deiodination of the lactone (9) was effected by use of tri-n-butyltin hydride in refluxing benzene [20] and the crystalline product (10) was de-esterified to give the crystalline diol (11) by heating in methanol in the presence of potassium carbonate. *trans*-α-Diols are convertible into oxiranes by activation of one of the hydroxy groups so that it can be nucleophilically displaced by the other, and usually in carbohydrate chemistry selective sulphonylation is used for the purpose.[21] A convenient alternative procedure, however, involves the use of diethyl azodicarboxylate and triphenylphosphine which generate triphenylphosphonium intermediates and hence the oxiranes.[22] The reaction has been employed successfully in carbohydrate chemistry,[23] in particular to obtain epoxides of furanosyl compounds—sometimes without protection of other hydroxy groups.[24] Since the sterically more accessible hydroxy groups are activated and displaced during this procedure, it was anticipated that the diol (11) would yield the *endo*-epoxide (13). In practice, however, the *exo*-isomer (12) was formed quantitatively, conceivably because the triphenylphosphonium intermediate derived from the *endo*-hydroxy group was stabilised by co-ordination with the lactone ring oxygen atoms. Although this compound has been synthesised before (in racemic form) together with the *endo*-isomer by treatment of the alkene (14) with *m*-chloroperbenzoic acid (the product ratios being highly dependent on solvent),[11a] it apparently has not been specifically described. The epoxidation of the alkene was therefore repeated (using benzene as solvent to favour the required product) and the crystalline *exo* and *endo* epoxides were isolated in 44 and 14% yield, respectively. The former was identical to the product of dehydration (12) of the diol (11) obtained with diethyl azodicarboxylate and triphenylphosphine.

A further direct method of preparing oxiranes from α-diols involves the use of sodium hydride followed by *N*-tosylimidazole [25] or tri-isopropylphenylsulphonylimidazole; [26] when treated in *N*,*N*-dimethylformamide with the former reagents, the diol (11) gave the required *endo*-epoxide (13) exclusively. This was characterised by comparison with an authentic sample; the ^{1}H n.m.r. spectra were identical and consistent with literature data.[27]

Experimental

^{1}H N.m.r. spectra were measured in deuteriochloroform solutions with a Varian FT 80A instrument. Optical rotations were measured in chloroform (unless otherwise noted) and within the concentration range 0.5—1.5%. Light petroleum refers to that fraction boiling in the range 60—80 °C.

(1R)-2-endo,3-exo-*Dibenzoyloxy*-4-endo-*hydroxymethyl*-N-*methyl*-6-*azabicyclo*[3.1.0]*hexane* (2).—The isoxazolidine derivative (1) [1] (10 g) in ethyl acetate (100 ml) was hydrogenated over W-2 Raney nickel (10 g) for 4 h at atmospheric pressure. After removal of the catalyst and evaporation of the solvent the residue was passed through a short column of silica gel to give the *aziridine* (2) as a syrup (5.06 g, 74%) which was

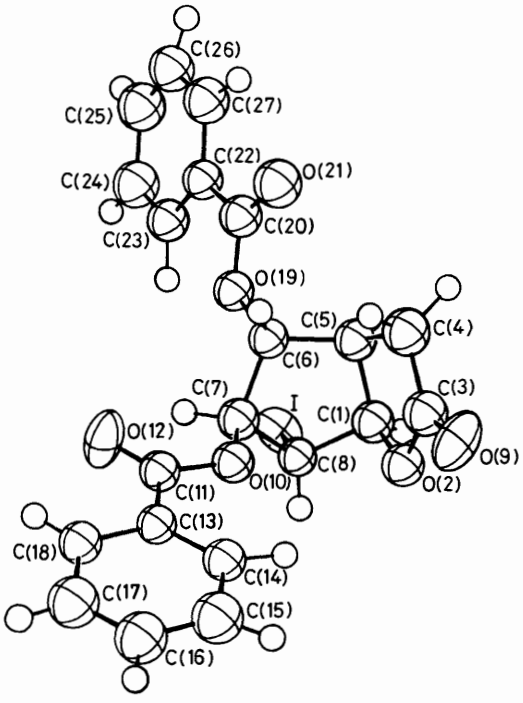


Figure. *X*-Ray crystal structure of the iodo lactone (9)

crystallised slowly from diethyl ether–light petroleum and had m.p. 116—118 °C, $[\alpha]_D$ −117° (Found: C, 68.6; H, 5.6; N, 3.8. $C_{21}H_{21}NO_5$ requires C, 68.7; H, 5.7; N, 3.8%); δ 2.31 (3 H, s, NMe), 2.65—2.05 (3 H, m, 1-, 4-, and 5-H), 4.25—3.55 (3 H, m, OH and CH_2), 5.61—5.31 (2 H, m, 2- and 3-H), and 7.3—8.1 (10 H, ArH).

(3R,4R,5R)-3,4-*Dibenzoyloxy*-5-(*hydroxymethyl*)*cyclopent*-1-*ene* (3).—A solution of the aziridine (2) (2.75 g) and (85%) *m*-chloroperbenzoic acid (1.52 g, 1.0 mol equiv.) in dichloromethane (75 ml) was kept at 20 °C for 30 h and was then washed successively with aqueous sodium hydrogen carbonate and water and dried. Removal of the solvent gave a syrup (2.48 g) which, after chromatographic purification, gave the *alkene* (3) (2.10 g, 83%), $[\alpha]_D$ −185° (Found: C, 70.4; H, 5.5 $C_{20}H_{18}O_5$ requires C, 71.0; H, 5.4%); *m*/*z* (70 eV) 339 (M^+ + H), 321 (M^+ + H − H_2O), 217 (M^+ − BzO, 100%), and 199 (M^+ − BzO − H_2O); δ 3.04—2.87 (2 H, m, OH and 5-H), 3.90—3.55 (2 H, m, CH_2), 5.48 (1 H, t, *J* 3 Hz, 4-H), 6.02 (2 H, s, 1- and 2-H), 6.18—5.94 (1 H, m, 3-H), and 8.13—7.28 (10 H, ArH).

(3R,4R,5R)-3,4-*Dibenzoyloxy*-5-(*tosyloxymethyl*)*cyclopent*-1-*ene* (4).—The alkene (3) (2.0 g) was treated with toluene-*p*-sulphonyl chloride (1.69 g, 1.5 mol equiv.) in pyridine (15 ml) at 20 °C for 15 h. Chloroform was added and the mixture was washed successively with water and dilute hydrochloric acid and dried to give the syrupy *tosylate* (4) (2.73 g, 94%) which was used in the subsequent reaction. Purification of a sample by column chromatography followed by crystallisation from methanol gave a product with m.p. 99—100 °C, $[\alpha]_D$ −115° (Found: C, 66.0; H, 5.1. $C_{27}H_{24}O_7S$ requires C, 65.9; H, 4.9%); δ 2.36 (3 H, s, Me), 3.05 (1 H, m, 5-H), 4.32 (2 H, 2 × d, *J* 5.8 and 1.4 Hz, CH_2), 5.32 (1 H, t, *J* 3 Hz, 4-H), 6.01 (3 H, br s, 1-, 2-, and 3-H, and 8.1—7.2 (14 H, ArH).

(1R,5R)-6-exo,7-endo-*Dibenzyloxyloxy*-8-exo-*iodo*-3-*oxo*-2-*oxabicyclo*[3.3.0]*octane* (9).—The crude tosylate (4) (2.0 g) was stirred with sodium cyanide (0.4 g, 2 mol equiv.) in dimethyl sulphoxide (10 ml) for 20 h at 20 °C. Most of the solvent was then removed under reduced pressure and the residue was dissolved in chloroform and washed successively with aqueous sodium chloride and water. The solution was dried and the solvent removed to give the corresponding nitrile (5) (1.12 g, 80%). Repeated chromatography of a sample gave an oil ($[\alpha]_D$ −110°) which was pure as indicated by t.l.c. and ^1H n.m.r. spectroscopy; $\nu_{max.}$ 2 230 cm^{-1}; δ 3.25—2.70 (3 H, m, 5-H and CH_2), 5.36 (1 H, t, *J* 3 Hz, 4-H), 6.3—5.9 (3 H, m, 1-, 2-, and 3-H), and 8.1—7.3 (10 H, ArH).

A solution of the nitrile (2.96 g) in acetic acid (5 ml) was added to a suspension of Raney nickel (10 g) in pyridine–acetic acid–water (40 ml, 2:1:1) containing sodium hypophosphite (sodium phosphinite) (7.45 g) and *N*,*N*′-diphenyl-1,2-diaminoethane (2.54 g, 1.2 mol equiv.) and the mixture was stirred at 20 °C for 1.5 h. The solids were filtered off, the filtrate was taken to low volume under reduced pressure, and the product was extracted into chloroform. The extract was washed, dried, and taken to dryness to leave an oil which was dissolved in dichloromethane (30 ml) and a solution of toluene-*p*-sulphonic acid (2.5 mol equiv.) in acetone (20 ml) was added. The mixture was kept at 0 °C for 10 min, allowed to warm during 40 min, and stirred at 20 °C for 30 min. The solids and solvent were removed, the residue was dissolved in dichloromethane, and the organic phase was washed with water, dried, and evaporated to give the aldehyde (7) (2.33 g, 78%). Preparative t.l.c. of a sample gave the 3,4-dibenzoyloxy-5-(formylmethyl)cyclopent-1-ene (7) as an oil, $[\alpha]_D$ −180°; δ 2.70 (1 H, ddd, $J_{6,6}$, 17, $J_{5,6}$ 8.8, and $J_{6,7}$ 1.2 Hz, CH*H*CHO), 3.15 (1 H, dd, $J_{5,6}$, 5.4 Hz, C*H*HCHO), 3.24 (1 H, m, 5-H), 5.39 (1 H, t, $J_{3,4} = J_{4,5}$ 2.8 Hz, 4-H), 5.94—6.15 (3 H, m, 1-, 2-, and 3-H), 7.3—8.1 (10 H, ArH), and 9.84 (1 H, d, CHO).

Pyridinium dichromate (6.62 g, 3 mol equiv.) was added to a solution of the aldehyde (1.94 g) in *N*,*N*-dimethylformamide (5 ml) and the dark orange solution was stirred at 20 °C for 3 h and then poured into water. The product was extracted into diethyl ether and the extract was dried and passed through a short column of silica gel. Evaporation of the eluate gave the acid (8) (1.72 g, 85%) as an oil.

Iodine (0.95 g, 1.5 mol equiv.) was added to a stirred solution of the acid (8) (0.92 g) in tetrahydrofuran (10 ml) at 5—10 °C and the mixture was stirred for 2 h at that temperature while protected from direct light. The solvent was removed and the residue was partitioned between chloroform and aqueous sodium thiosulphate and the crystalline *iodo lactone* (9) (1.22 g, 98%) was isolated from the organic phase and recrystallised from ethyl acetate–light petroleum, m.p. 162—164 °C; $[\alpha]_D$ +11° (Found: C, 51.4; H, 3.6; I, 25.9. $C_{21}H_{17}IO_6$ requires C, 51.2; H, 3.5; I, 25.8%); $\nu_{max.}$ 1 775 cm^{-1} (C=O); δ 2.90 (1 H, d, $J_{4,4}$, 12 Hz, 4-H), 3.10 (1 H, dd, $J_{4,5}$ 4 Hz, 4-H), 3.40 (1 H, m, 5-H), 4.62 (1 H, d, $J_{7,8}$ 0.6 Hz, 8-H), 5.35 (1 H, d, $J_{5,6}$ 5.9 Hz, 6-H), 5.41 (1 H, d, $J_{1,5}$ 10.8 Hz, 1-H), 5.90 (1 H, br s, 7-H), and 8.2—7.3 (10 H, ArH).

(1S,5S)-6-exo,7-endo-*Dibenzoyloxy*-3-*oxo*-2-*oxabicyclo*-[3.3.0]*octane* (10).—A solution of the iodo lactone (9) (0.71 g) in dry benzene (15 ml) containing tri-n-butyltin hydride (1.26 3 mol equiv.) was heated under reflux for 0.5 h. The solvent was removed and the residue was partitioned between hexane and acetonitrile. The acetonitrile phase was washed with hexane (× 2) and concentrated under reduced pressure to give an oil which was purified on a column of silica gel to give the *de-iodinated lactone* (10) (0.46 g, 88%) which, after recrystallisation from ethyl acetate–light petroleum, had m.p. 108—110 °C, $[\alpha]_D$ −98° (Found: C, 68.7; H, 5.2. $C_{21}H_{18}O_6$ requires C, 68.9; H, 4.9%); δ 2.50 (1 H, d, $J_{1,8}$ 3.5 Hz, 8-H), 2.55 (1 H, d, $J_{1,8}$, 3.5 Hz, 8-H), 3.0—2.8 (2 H, m, 4-H_2), 3.17

Table 1. Atomic co-ordinates for compound (9) with e.s.d.s in parentheses

	10^4x	10^4y	10^4z		10^4x	10^4y	10^4z
I	−1 595.1(7)	541.6(3)	−5 757(1)	C(14)	2 119(11)	−1 509(5)	−2 063(14)
C(1)	907(11)	604(5)	−4 674(15)	C(15)	2 877(13)	−2 026(6)	−1 869(17)
O(2)	2 024(7)	275(3)	−4 676(9)	C(16)	2 508(12)	−2 521(5)	−1 001(16)
C(3)	2 709(12)	490(5)	−3 350(15)	C(17)	1 465(12)	−2 552(5)	356(16)
C(4)	2 092(12)	952(6)	−2 318(19)	C(18)	738(11)	−2 041(5)	−344(14)
C(5)	824(11)	912(5)	−2 876(14)	O(19)	−1 084(7)	790(3)	−1 489(8)
C(6)	32(10)	485(5)	−1 803(14)	C(20)	−1 136(11)	1 255(5)	−371(14)
C(7)	−241(12)	−75(5)	−2 904(14)	O(21)	−267(8)	1 447(3)	344(10)
C(8)	−51(10)	114(4)	−4 724(13)	C(22)	−2 330(10)	1 503(5)	−206(14)
O(9)	3 680(7)	295(4)	−3 264(10)	C(23)	−3 231(12)	1 275(5)	−1 148(15)
O(10)	571(6)	−561(3)	−2 504(8)	C(24)	−4 333(12)	1 530(5)	−959(18)
C(11)	177(11)	−1 025(4)	−1 486(14)	C(25)	−4 492(13)	2 017(5)	150(16)
O(12)	−745(7)	−1 023(3)	−794(12)	C(26)	−3 663(13)	2 237(6)	1 071(17)
C(13)	1 057(10)	−1 526(4)	−1 293(13)	C(27)	−2 496(12)	2 001(5)	943(16)

(1 H, m, 5-H), 5.26 (1 H, m, 1-H), 5.36 (1 H, s, 6-H), 5.62 (1 H, d, 7-H), and 7.3—8.2 (10 H, ArH).

(1S,5S)-6-exo,7-endo-Dihydroxy-3-oxo-2-oxabicyclo[3.3.0]*octane* (11).—The lactone (10) (0.6 g) was debenzoylated in refluxing methanol during 20 min in the presence of anhydrous potassium carbonate (0.64 g). The cooled solution was filtered, the filtrate was acidified with aqueous hydrogen chloride and the solvent was removed. Extraction of the residue with dry dioxane (× 3) and removal of the solvent gave a crystalline residue (0.26 g, 100%). Recrystallisation from ethyl acetate–light petroleum gave the *diol* (11) (0.22 g, 85%), m.p. 110—111 °C; $[\alpha]_D$ −15° (*c* 0.5 in MeOH) (Found: C, 53.0; H, 6.6. $C_7H_{10}O_4$ requires C, 53.2; H, 6.3%).

(1S,2S,4R,6S)-8-*Oxo*-3,7-*dioxatricyclo*[4.3.0.$0^{2,4}$]*nonane* (13).—The diol (11) (0.06 g) was added at 0 °C under nitrogen to *N,N*-dimethylformamide (3 ml) containing sodium hydride (0.04 g, 2.2 mol equiv.). The mixture was stirred at 20 °C for 0.5 h, cooled at 0 °C, and a solution of *N*-tosylimidazole (0.085 g, 1.0 mol equiv.) in *N,N*-dimethylformamide (0.5 ml) was added and the mixture was stirred for a further 1 h at 0 °C and then for 1 h at 20 °C. The mixture was then poured into water and extracted with dichloromethane to give, after work-up, a product devoid of the isomeric epoxide (12) and which, after purification on a column of silica gel, gave the *endo*-epoxy lactone (13) (0.027 g, 51%). Recrystallisation from ethyl acetate gave m.p. 76—77 °C, undepressed on admixture with an authentic sample, $[\alpha]_D$ −108° (lit.,[12] m.p. 76—77 °C; $[\alpha]_D$ −115°); δ 2.15 (1 H, ddd, $J_{4,5}$ 1.1, $J_{5,5}$, 16.1, and $J_{5,6}$ 6.7 Hz, 5-H_{exo}), 2.51 (1 H, d, 5-H_{endo}), 2.75—2.6 (3 H, m, 9-Hz), 3.00 (1 H, m, 1-H), 3.62 (1 H, s, 4-H), 3.63 (1 H, s, 2-H), 4.98 (1 H, dt, 6-H). The spectrum was identical to that of an authentic sample (*cf.* also ref. 27).

(1S,2R,4S,6S)-8-*Oxo*-3,7-*dioxatricyclo*[4.3.0.$0^{2,4}$]*nonane* (12).—(a) *From the diol* (11). A solution of diethyl azodicarboxylate (0.14 g, 3 mol equiv.) in dioxane (1 ml) was added dropwise at 70 °C to a stirred solution of the diol (11) (0.04 g) in dioxane containing triphenylphosphine (0.21 g, 3 mol equiv.). After 10 min the mixture was concentrated under reduced pressure and the residue was fractionated on a column of silica gel to give the crystalline exo-*epoxy lactone* (0.036 g, 100%) which was recrystallised from ethyl acetate–light petroleum, m.p. 68—70 °C; $[\alpha]_D$ +69° (Found: C, 60.5; H, 5.5%. $C_7H_8O_3$ requires C, 60.0; H, 5.7%); δ 2.74—1.83 (4 H, m, 5- and 9-H_2), 3.13 (1 H, m, 1-H), 3.65—3.50 (2 H, m, 2- and 4-H), 4.82 (1 H, dt, $J_{1,6} = J_{5,6} = 6.7$, $J_{5,6}$ 3.3 Hz, 6-H).

(b) *From 3-oxo-2-oxabicyclo*[3.3.0]*oct-6-ene* (14). 85% *m*-Chloroperbenzoic acid (0.01 g, 1.2 mol equiv.) was added to a solution of the (−)-alkene (14) (0.05 g) in benzene (1.5 ml) and the solution was kept at 20 °C for 15 h. Ethyl acetate was added and the solution was washed successively with aqueous sodium sulphite, aqueous sodium hydrogen carbonate, and water. The organic phase was dried and evaporated to leave an oil which, on fractionation on a column of silica gel, afforded as the first fraction the *exo*-epoxide (12) (0.025 g, 44% after crystallisation from ethyl acetate–light petroleum), m.p. 68—70 °C; $[\alpha]_D$ +67° and which gave a ^{1}H n.m.r. spectrum identical to that of the sample produced by method (a).

A second fraction (0.008 g, 14% after crystallisation from ethyl acetate–light petroleum) had m.p. 76—78 °C and gave the same ^{1}H n.m.r. spectrum as did the *endo*-epoxide (13) prepared by use of *N*-tosylimidazole.

Table 2. Intramolecular bond distances and angles for compound (9) with e.s.d.s in parentheses

Atoms	Distance (Å)	Atoms	Distance (Å)
C(1)–O(2)	1.47(1)	C(13)–C(14)	1.36(2)
C(1)–C(8)	1.53(2)	C(14)–C(15)	1.43(2)
C(1)–C(5)	1.55(2)	C(15)–C(16)	1.33(2)
O(2)–C(3)	1.38(1)	C(16)–C(17)	1.35(2)
C(3)–C(4)	1.46(2)	C(17)–C(18)	1.39(2)
C(3)–O(9)	1.20(1)	C(13)–C(18)	1.38(1)
C(4)–C(5)	1.53(2)	O(19)–C(20)	1.33(1)
C(5)–C(6)	1.54(1)	C(20)–O(21)	1.22(1)
C(6)–C(7)	1.51(1)	C(20)–C(22)	1.49(2)
C(6)–O(19)	1.47(1)	C(22)–C(23)	1.36(2)
C(7)–C(8)	1.48(2)	C(23)–C(24)	1.39(2)
C(7)–O(10)	1.44(1)	C(24)–C(25)	1.37(2)
C(8)–I	2.162(11)	C(25)–C(26)	1.29(2)
O(10)–C(11)	1.35(1)	C(26)–C(27)	1.44(2)
C(11)–O(12)	1.19(1)	C(22)–C(27)	1.41(1)
C(11)–C(13)	1.49(1)		

Atoms	Angle (°)	Atoms	Angle (°)
C(5)–C(1)–O(2)	105.2(9)	C(4)–C(5)–C(6)	116.8(11)
C(1)–O(2)–C(3)	109.9(8)	O(2)–C(1)–C(8)	107.5(8)
O(2)–C(3)–C(4)	110.9(11)	O(2)–C(3)–O(9)	117.4(11)
C(3)–C(4)–C(5)	105.8(11)	C(4)–C(3)–O(9)	131.6(12)
C(4)–C(5)–C(1)	102.7(10)	C(5)–C(6)–O(19)	110.1(8)
C(1)–C(5)–C(6)	105.5(8)	C(7)–C(6)–O(19)	105.5(9)
C(5)–C(6)–C(7)	107.2(9)	C(6)–C(7)–O(10)	108.9(9)
C(6)–C(7)–C(8)	106.6(8)	C(8)–C(7)–O(10)	108.0(10)
C(7)–C(8)–C(1)	105.8(9)	C(7)–C(8)–I	110.3(9)
C(8)–C(1)–C(5)	105.9(9)	C(1)–C(8)–I	108.2(6)

Table 3. Selected torsion angles for compound (9). The torsion angle of the bonded atoms A–X–Y–B is the angle between the planes A–X–Y and X–Y–B and is positive when clockwise [a]

Atoms	Angle (°)
C(5)–C(1)–O(2)–C(3)	−16.4
C(8)–C(1)–O(2)–C(3)	−129.0
C(1)–O(2)–C(3)–C(4)	2.7
C(1)–O(2)–C(3)–O(9)	−175.0
O(2)–C(3)–C(4)–C(5)	12.4
O(9)–C(3)–C(4)–C(5)	−170.4
C(3)–C(4)–C(5)–C(6)	93.6
C(3)–C(4)–C(5)–C(1)	−21.2
C(4)–C(5)–C(1)–O(2)	22.6
C(4)–C(5)–C(1)–C(8)	136.4
C(6)–C(5)–C(1)–O(2)	−100.1
C(6)–C(5)–C(1)–C(8)	13.6
C(4)–C(5)–C(6)–C(7)	−108.5
C(4)–C(5)–C(6)–O(19)	137.1
C(1)–C(5)–C(6)–C(7)	4.7
C(1)–C(5)–C(6)–O(19)	−109.6
C(5)–C(6)–C(7)–C(8)	−21.9
C(5)–C(6)–C(7)–O(10)	94.3
O(19)–C(6)–C(7)–C(8)	95.5
O(19)–C(6)–C(7)–O(10)	−148.3
C(6)–C(7)–C(8)–C(1)	30.5
C(6)–C(7)–C(8)–I	−86.2
O(10)–C(7)–C(8)–C(1)	−86.3
O(10)–C(7)–C(8)–I	156.9
C(7)–C(8)–C(1)–C(5)	−27.3
C(7)–C(8)–C(1)–O(2)	84.8
I–C(8)–C(1)–C(5)	90.8
I–C(8)–C(1)–O(2)	−157.1
C(6)–C(7)–O(10)–C(11)	102.9
C(8)–C(7)–O(10)–C(11)	−141.8
C(7)–O(10)–C(11)–O(12)	−7.2
C(7)–O(10)–C(11)–C(13)	174.9
O(10)–C(11)–C(13)–C(14)	−0.2
O(12)–C(11)–C(13)–C(14)	−178.2
O(10)–C(11)–C(13)–C(18)	−177.2
O(12)–C(11)–C(13)–C(18)	4.9
C(11)–C(13)–C(14)–C(15)	−176.9
C(5)–C(6)–O(19)–C(20)	−73.0
C(7)–C(6)–O(19)–C(20)	171.6
C(6)–O(19)–C(20)–O(21)	2.9
C(6)–O(19)–C(20)–C(22)	−179.6
O(19)–C(20)–C(22)–C(23)	−1.4
O(21)–C(20)–C(22)–C(23)	176.0
O(19)–C(20)–C(22)–C(27)	−179.8
O(21)–C(20)–C(22)–C(27)	−2.4

[a] W. Klyne and V. Prelog, *Experientia*, 1960, **16**, 521.

X-Ray Crystal Analysis of Compound (9).—*Crystal data.* $C_{21}H_{17}IO_6$, orthorhombic, $a = 11.551(1)$, $b = 21.571(1)$, $c = 7.7481(5)$ Å, $U = 1\,930.5$ Å^3, $Z = 4$, $D_c = 1.69$ g cm^{-3}. Space group $P2_12_12_1$, μ(Cu-K_α) = 136.3 cm^{-1}. Intensities were collected on a Hilger and Watts Y290 diffractometer on a crystal *ca.* 0.10 × 0.17 × 0.26 mm in size and using nickel-filtered, Cu-K_α radiation.

A total of 1 405 reflections, within the limit $\theta \leqslant 66°$, were measured with intensities greater than 4 times their standard deviation (from counting statistics). Intensities were corrected for Lorentz and polarisation effects; absorption corrections were applied [28] (transmission factor range 0.132—0.360). The structure was solved by direct methods.[29] Refinement by full-matrix least-squares, minimizing $\Sigma\omega\Delta^2$ [$\Delta = |F_o| - |F_c|$, $\omega = 4F_o^2/\sigma^2(I)$], was carried out using standard scattering factors [30] and the SHELX-78 programme suite.[31]

For a non-hydrogen atom model in which all atoms except iodine had isotropic thermal parameters, convergence was achieved for both possible absolute configurations (by inverting the molecule). The weighted (R_w) and unweighted (R) factors for correct, incorrect configurations were 0.091, 0.112 and 0.075, 0.097, respectively, indicating >99.5% assignment probability.[32]

Atomic co-ordinates are listed in Table 1 and bond lengths and angles and torsion angles in Tables 2 and 3. Weighted mean plane data, structure factors, additional bond lengths and bond angles, and thermal parameters are listed in Supplementary Publication No. SUP 23632 (16 pages).*

* For details of the Supplementary Publications scheme, see Instructions for Authors (1983), *J. Chem. Soc., Perkin Trans. 1*, 1983, Issue 1.

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