Carbohydrate Research, 141 (1985) 1–12
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

DIELS–ALDER ADDUCTS OF GLYCOSYLFURANS WITH MALEIMIDE. APPLICATION OF X-RAY DIFFRACTION AND C.D. SPECTRA TO THE DETERMINATION OF THEIR STEREOCHEMISTRY*

ISAMU MAEBA, FUMITAKA USAMI, TOMOYUKI ISHIKAWA, HIROSHI FURUKAWA,
Faculty of Pharmacy, Meijo University, Tempaku, Nagoya 468 (Japan)

TOSHIMASA ISHIDA, AND MASATOSHI INOUE
Osaka College of Pharmacy, 2-10-65, Matsubara, Osaka 580 (Japan)

(Received May 11th, 1984; accepted for publication in revised form, August 20th, 1984)

ABSTRACT

Cycloaddition of 2-(β-D-ribofuranosyl)furan (**1**) with maleimide followed by treatment with acetone–TsOH gave a mixture of four diastereomers **3a–d**, which were separated by preparative t.l.c. The absolute stereochemistry of each was determined. The endo (**3a** and **3b**)/exo (**3c** and **3d**) ratio of cycloadducts was ~11:1 and the ratio of **3a** (1*R*,4*S*) and **3b** (1*S*,4*R*) was ~3:1. The Diels–Alder reaction occurs with asymmetric induction by the β-glycosyl moiety of **1** situated *anti* or *syn* to the furan ring.

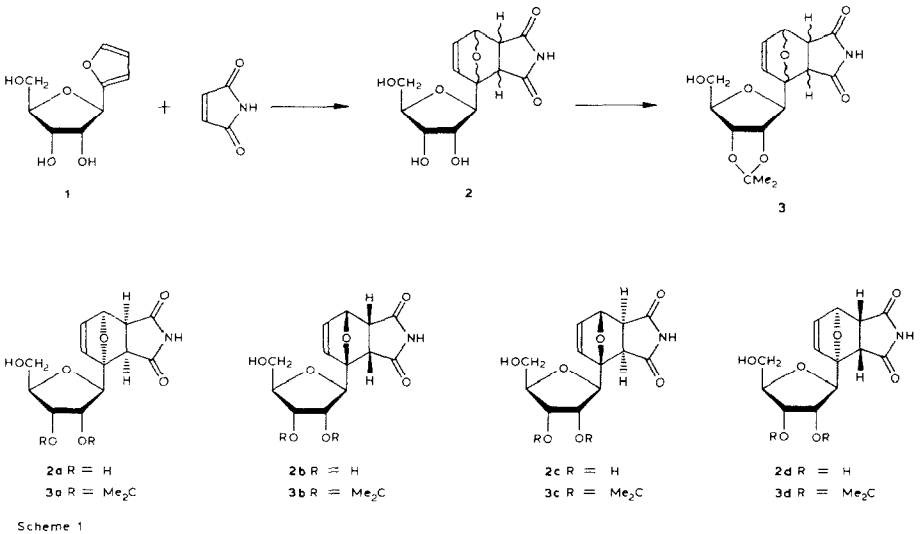
INTRODUCTION AND DISCUSSION

Recent publications[1] from our laboratory have described the preparation of the versatile *C*-nucleoside precursor 2-(2,3,5-tri-*O*-benzoyl-β-D-ribofuranosyl)-furan, and its utilization in the synthesis of pyridazine and phthalimide *C*-nucleosides. Phthalimide *C*-nucleosides[1b] were obtained by Diels–Alder reaction of glycosylfurans with maleimide, followed by aromatization without separation of the diastereomeric adducts. In this paper, we describe the separation of such adducts, and the application of X-ray crystallographic analysis and ^{1}H-n.m.r. and c.d. spectra to determine their stereochemistry.

2-(β-D-Ribofuranosyl)furan[1a] (**1**) was treated with maleimide in methanol for 20 days at room temperature. As the reaction proceeded, a crystalline adduct (**2a**) precipitated directly from the reaction mixture. Recrystallization from water afforded a stereochemically pure product as colorless crystals in 37% yield. Examination of the mother liquor from which **2a** had been obtained indicated the presence of other, chromatographically similar, diastereomers, which were detected most readily by the five carbonyl-carbon singlets in the ^{13}C-n.m.r. spectrum. This mixture could not be resolved; even in preparative t.l.c., the com-

*Part 3 in the series C-Nucleosides.

0008-6215/85/$ 03.30



Scheme 1

ponents were scarcely separated in all solvent systems used. This difficulty in separating the adducts **2** was overcome by conversion of the products into the corresponding isopropylidene acetals **3** with acetone–TsOH (Scheme 1). These were separable by preparative t.l.c. to afford four products, **3a–d**.

Assignments of anomeric configurations for all compounds separated was based mainly on ^{13}C-n.m.r. data[2], supplemented by ^{1}H-n.m.r. data[3]. The chemical shifts of the methyl carbon atoms and the quaternary carbon atoms of the isopropylidene group fall into the regions established for β anomers, and the $\Delta\delta$ values for the methyl groups also fit the established pattern. The adducts **3a–d** were thus diastereomeric in the aglycon. The relative stereochemistry at C-2 and C-3 in **3a–d** was elucidated by ^{1}H-n.m.r. spectroscopy. Table I lists the chemical shifts of protons in compounds **3a–d**, and compares them with data from the literature. The ^{1}H-n.m.r. spectra of **3a–d** show significant differences in chemical shift and multiplicity of H-2 and H-3 in exo and endo orientations. The exo protons in the endo isomers **3a** and **3b** show overlapping signals at δ 3.41–3.92 for H-5′, whereas the endo protons in the exo isomer **3c** resonate as two doublets at δ 2.98 and 3.09, and that in the exo isomer **3d** resonates as two doublets at 2.87 and 3.07, ~0.4 p.p.m. upfield[4] from the two exo proton signals of **3a** and **3b**. The endo/exo ratio of cycloadducts, obtained in 69% yield, was ~11:1. This reaction thus shows high stereoselective in favor of the endo isomers as the kinetically favored product in accord with the Alder endo rule[5]. To determine the stereochemistry at C-1 and C-4 in **3a–d**, we resorted to X-ray crystallographic analysis as described later (see experimental section for details). The X-ray structures of the endo isomer **2a** and exo isomer **3c** are shown in Figs. 1 and 2. The C.d. spectra of the endo adducts (**3a** and **3b**) and exo adducts (**3c** and **3d**) are shown in Figs. 3 and 4. The spectra of **3a** and **3c** show a negative Cotton effect at 252 nm, whereas positive Cotton effects at 252

TABLE I

100-MHz PROTON CHEMICAL SHIFTS (δ)

Compound no.	*Solvent*[a]	*H-1'*	*H-2'*	*H-3'*	*H-4'*	*H-5', H-5"*	*H-2*	*H-3*	*H-4*	*H-5*	*H-6*	*CMe_2 ($\Delta\delta$)*	*Miscellaneous*
2a	A	4.25 (d)	← 3.10–3.98 (m) →						5.19 (d)	6.48 (dd)	6.34 (d)		4.51 (t, 5'-OH) 4.81, 4.92 (each d, 2'-OH, 3'-OH), 10.85 (br s, NH)
2b	A	← 3.20–4.40 (m) →							5.12 (br s)	6.41 (s)			4.61 (t, 5'-OH), 4.85, 4.96 (each d, 2'-OH, 3'-OH), 10.76 (br s, NH)
2c	A	4.08 (d)	← 3.18–3.93 (m) →				2.78[b], (d)	2.96[b] (d)	5.05 (s)	6.42, (s)	6.47 (s)		4.44–4.97 (m, 3, OH), 10.99 (br s, NH)
2d	A	← 3.17–4.26 (m) →					2.92[b], (d)	3.03[b] (d)	5.08 (s)	6.50 (s)			4.52 (t, 5'-OH), 4.84 (m, 2'-OH, 3'-OH), 10.85 (br s, NH)
3a	B	← 4.56–4.84 (m) →			4.24 (m)	← 3.41–3.91 (m) →			5.30 (m)	6.53 (dd)	6.43 (d)	1.35, 1.58 (0.23)	3.13 (br s, OH), 8.76 (br s, NH)
3b	B	4.52 (d)	4.67–4.95 (m)		4.25 (q)	← 3.46–3.92 (m) →			5.35 (d)	6.56 (s)		1.36, 1.58 (0.22)	2.53 (br s, OH), 8.45 (br s, NH)
3c	B	4.41 (d)	4.59–4.85 (m)		4.11 (q)	3.80 (m)	2.98[b], (d)	3.09[b] (d)	5.32 (s)	6.53 (s)		1.36, 1.56 (0.20)	2.30 (br s, OH), 8.58 (br s, NH)
3d	B	← 4.52–4.92 (m) →			4.28 (m)	3.70 (m)	2.87[b], (d)	3.07[b] (d)	5.39 (s)	6.59 (dd)	6.49 (d)	1.35, 1.59 (0.24)	2.70–3.48 (br, OH), 9.42 (br s, NH)
6a	C	4.54[c]	4.92 (dd)	4.79 (dd)	4.26 (t)	← 3.58–3.80 (m) →			5.33 (dd)	6.37 (dd)	6.64 (d)	1.35, 1.50 (0.15)	4.54 (s, OH, NH)
6b	C	4.51 (d)	5 05 (dd)	4.83 (dd)	4.17 (t)	← 3.52–3.78 (m) →			5.28 (dd)	6.48 (dd)	6.68 (d)	1.37, 1.52 (0.15)	4.33 (s, OH, NH)
6c	B	4.36 (d)	5.33 (dd)	4.74 (d)	4.19 (br s)	3.60 (m)	2.95[b], (d)	3.08[b] (d)	5.16 (d)	6.42 (dd)	6.61 (d)	1.36, 1.54 (0.18)	2.18–2.82 (br, OH), 9.36 (br s, NH)
6d	B	4.55 (d)	4.74 (dd)	4.06–4.33 (m)		3.59 (m)	2.92[b], (d)	3.03[b] (d)	5.26 (d)	6.30 (dd)	6.62 (d)	1.28, 1.49 (0.21)	2.38–3.20 (br, OH), 9.59 (br s, NH)

[a]A, Me_2SO-d_6; B, $CDCl_3$; C, 2:1 $CDCl_3$–CD_3OD. [b]The designated assignment could be reversed. [c]Overlapped with OH and NH signal.

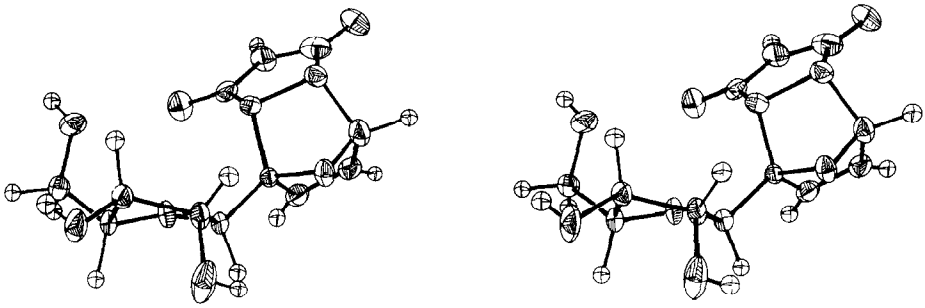


Fig. 1. Stereoscopic view of the endo adduct **2a**.

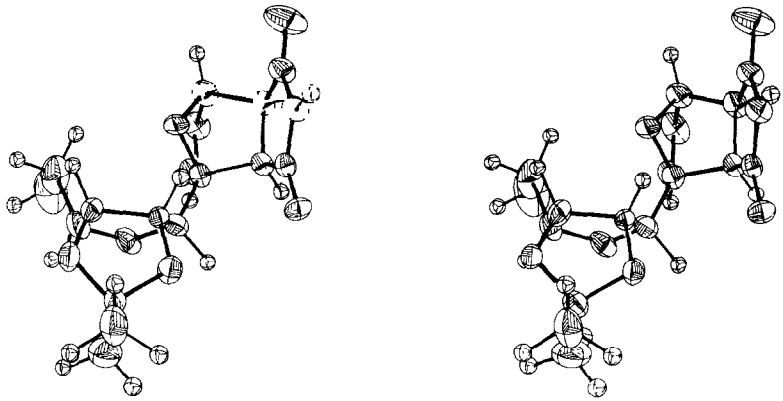


Fig. 2. Stereoscopic view of the exo adduct **3c**.

and 258 nm are observed in the spectra of **3b** and **3d**. These results provide firm evidence for the configuration at C-1 and C-4 as (1*R*, 4*S*) for **3a** and **3d**, and (1*S*, 4*R*) for **3b** and **3c**. The ratio of **3a** and **3b** was ~3:1.

The foregoing results (50% enantiomeric excess of adduct **3a**) indicate that the Diels–Alder reaction occurs with asymmetric induction by the β-glycosyl moiety of **1** situated *anti* or *syn* to the furan ring (Fig. 5). The direction of cycloaddition with the bulky dienophile would be expected to be on the sterically less-crowded *re* face of the *syn*-conformer or *si* face of the *anti*-conformer. We anticipated that the preponderant product **3a** would result from attack by the dienophile on the more-exposed *re* face of the *syn*-conformer rather than the *re* face of the *anti*-conformer, and the minor product **3b** from attack by the dienophile on the sterically exposed *si* face of the *anti*-conformer. Removal of the protecting groups of **3a–d** with trifluoroacetic acid for 3 h at 25° readily afforded the corresponding free adducts **2a–d**. Deprotected **2a** was identical with the product obtained directly by the Diels–Alder reaction of **1** with maleimide. Anomerization was not observed during the acetonation and deprotection steps.

In concurrent research, we also prepared (Scheme 2) by the same procedure the α isomers **6a–d**, starting from 2-(α-D-ribofuranosyl)furan (**4**). The products

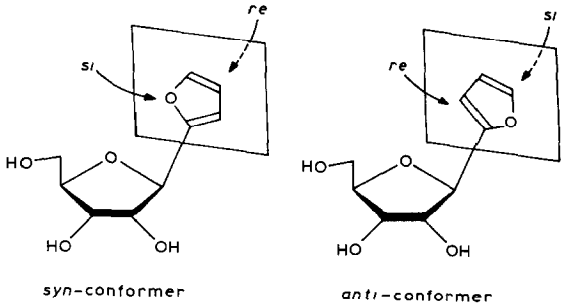
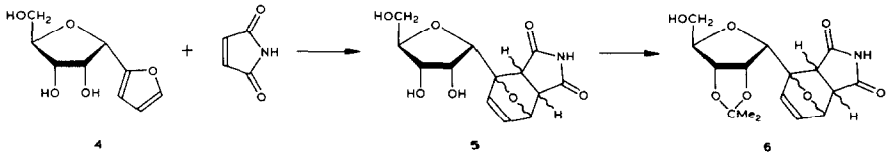
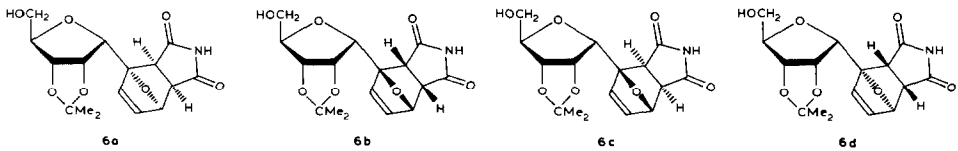


Fig. 5.

were separable by preparative t.l.c., and the relative stereochemistry at C-2 and C-3 in **6a–d** was elucidated by comparison of their ^{1}H-n.m.r. spectra (Table I). These data indicate that **6a** and **6b** are the endo isomers and that **6c** and **6d** are the exo isomers. Although the numerical difference in chemical shifts of the isopropylidene *gem*-dimethyl groups ($\Delta\delta$) for the adducts **6a–d** is not identical with that empirically determined by Imbach and Kam[6] for 2′,3′-*O*-isopropylidenated *N*-nucleosides, the α compounds, nevertheless, all exhibit smaller $\Delta\delta$ values than do their β isomers, which is consist with the more-general principles of this rule[6]. The endo/exo ratio of cycloadducts, obtained in 74% yield, was ~1:2. The preponderant products were the exo isomers, the thermodynamically favored products.





Scheme 2

We attempted to determine the configuration at C-1 and C-4 in **6a–d** but, unfortunately, these adducts could be obtained only as tiny crystals that were not sufficiently large for X-ray analysis. The configurations at C-1 and C-4 were projected to be (1*R*,4*S*) for **6a** and **6d**, and (1*S*,4*R*) for **6b** and **6c** by comparison of the spectra of **6a–d** (Figs. 6 and 7) with those of the β adducts **3a–d**. The ratios of **6a/6b** and **6c/6d** were ~1:5 and 1:1, respectively. A discussion of the orientation in this addition would not be meaningful.

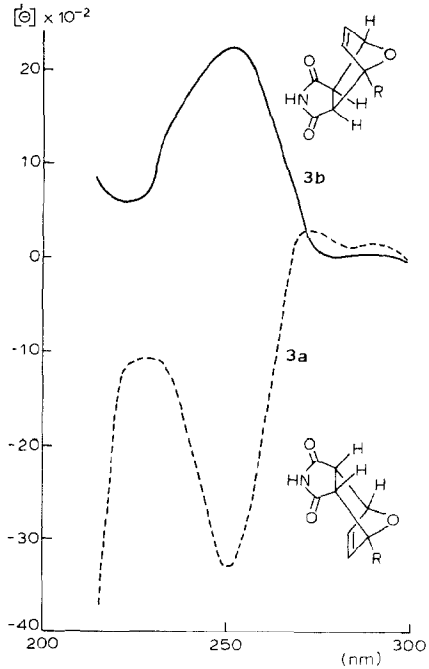


Fig. 3. C.d. spectra of adducts **3a** and **3b** in methanol. R = 2′,3′-*O*-isopropylidene-β-D-ribofuranosyl.

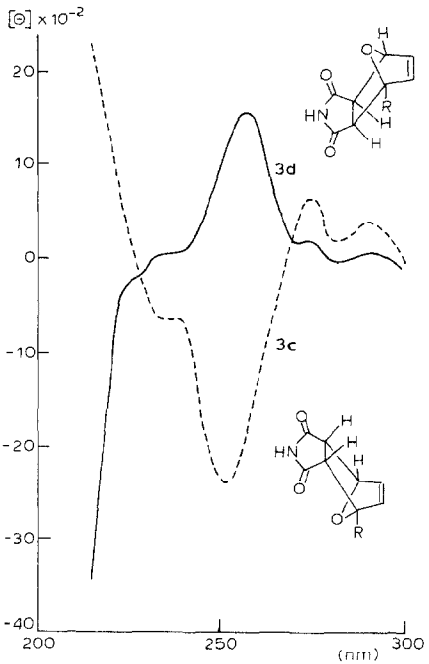


Fig 4. C.d. spectra of adducts **3c** and **3d** in methanol. R = 2′,3′-*O*-isopropylidene-β-D-ribofuranosyl.

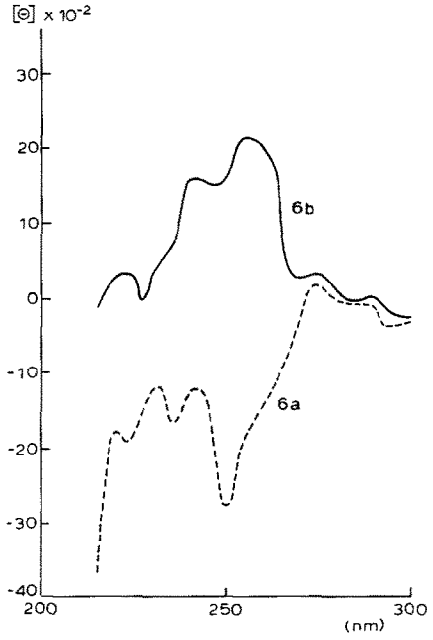


Fig. 6. C.d. spectra of adducts **6a** and **6b** in methanol.

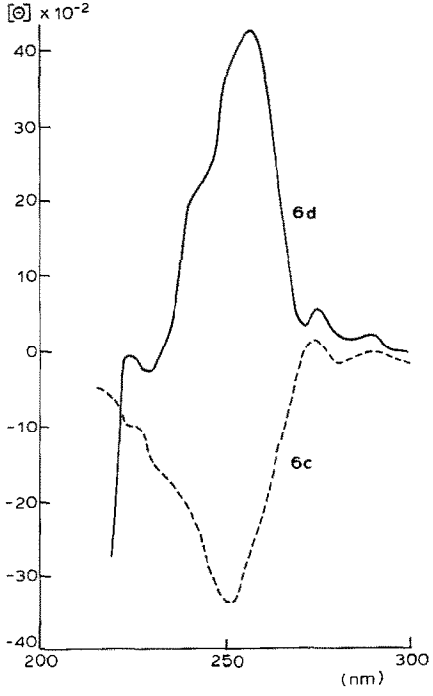


Fig. 7. C.d. spectra of adducts **6c** and **6d** in methanol.

EXPERIMENTAL

General methods. — Melting points were determined with a Yanagimoto apparatus and are uncorrected. Infrared spectra were recorded with a Jasco IRA-1 spectrometer. Mass spectra were determined with Hitachi M-52 spectrophotometer and ^{1}H-n.m.r. spectra with a Jeol JNM-PS-100 spectrometer, with tetramethylsilane as an internal standard. ^{13}C-N.m.r. spectra were recorded with a Jeol JNM-FX-100 Fourier-transform spectrometer operating at 25.00 MHz, with tetramethylsilane as the internal standard. C.d. spectra were recorded with a Jasco J-20 spectropolarimeter. Optical rotations were measured with a Jasco DIP-181 digital polarimeter. Analytical t.l.c. was performed on glass plates coated with a 0.25-mm layer of silica gel GF_{254} (Merck). The compounds were detected with u.v. light (254 nm). Column chromatography was performed on silica gel C-200 (74–149 μm, Wakogel).

Isolation of adducts **3a–d**. — A solution of **1** (900 mg, 4.5 mmol) and maleimide (562 mg, 6 mmol) in methanol (18 mL) was stirred for 20 days at room temperature. The adduct **2a**, which had precipitated as a white solid (385 mg), was collected by filtration. After evaporation of the filtrate to dryness, the residue was chromatographed on silica gel (10:1 chloroform–methanol) to give another 108 mg of **2a** (m.p. 149–150°). The yield of inseparable mixture was 550 mg of a colorless syrup which was used in the acetonation step.

Ethyl orthoformate (0.5 mL) was added during 10–20 min at room temperature to a well-stirred suspension of **2a–d** (550 mg, 1.9 mmol) in acetone (6 mL) containing *p*-toluenesulfonic acid monohydrate (40 mg), and the mixture was kept for 14 h at room temperature. Sodium hydrogencarbonate (20 mg) was then added, and the solid was collected by filtration and throughly washed with acetone. The combined filtrates were evaporaed *in vacuo* to a syrup (610 mg, 98%) that was resolved by preparative t.l.c. with 100:3 chloroform–ethanol as the eluent.

*(1*R,*4*S*)-2,3-*endo-*1-(2,3-*O*-Isopropylidene-β-*D*-ribofuranosyl)-7-oxabicyclo-[2.2.1]hept-5-ene-2,3-dicarboximide* (**3a**) was obtained as colorless foam; yield 34%; R_F 0.31 (10:1 chloroform–ethanol); $[\alpha]_D^{22.5}$ −87.5° (*c* 1.31, chloroform); ^{13}C-n.m.r. ($CDCl_3$): δ 25.39, 27.44 (CH_3), 46.92, 49.43 (C-2, C-3), 62.95 (C-5′), 79.27, 81.32, 81.96, 82.49, 85.47 (C-1′, C-2′, C-3′, C-4′, C-4), 91.50 (C-1), 114.14 (isopropylidene Cquat), 134.38, 135.61 (C-5, C-6), 175.04, and 175.45 (C=O).

*(1*S,*4*R*)-2,3-*endo-*1-(2,3-*O*-Isopropylidene-β-*D*-ribofuranosyl)-7-oxabicyclo-[2.2.1]hept-5-ene-2,3-dicarboximide* (**3b**) was obtained as colorless foam; yield 46%; R_F 0.28 (10:1 chloroform–ethanol); $[\alpha]_D^{22.5}$ +31.8° (*c* 0.69, chloroform); ^{13}C-n.m.r. ($CDCl_3$): δ 25.57, 27.55 (CH_3), 47.74, 49.20 (C-2, C-3), 62.77 (C-5′), 79.15, 80.68, 81.73, 82.72, 85.06 (C-1′, C-2′, C-3′, C-4′, C-4), 91.50 (C-1), 114.43 (isopropylidene Cquat), 135.08, 135.20 (C-5, C-6), 174.98, and 174.27 (C=O).

*(1*S,*4*R*)-2,3-*exo-*1-(2,3-*O*-Isopropylidene-β-*D*-ribofuranosyl)-7-oxabicyclo-[2.2.1]hept-5-ene-2,3-dicarboximide* (**3c**) was obtained as crystals; yield 11%; m.p. 178–180°, $[\alpha]_D^{22.5}$ −5.5° (*c* 0.58, chloroform); R_F 0.21 (10:1 chloroform–ethanol);

^{13}C-n.m.r. ($CDCl_3$): δ 25.39, 27.32 (CH_3), 48.73, 52.01 (C-2, C-3), 62.19 (C-5′), 80.91, 81.26, 82.25, 85.36 (C-1′, C-2′, C-3′, C-4′, C-4), 91.26 (C-1), 115.31 (isopropylidene Cquat), 136.55, 137.42 (C-5, C-6), 175.86, and 176.39 (C=O).

*(1*R*,4*S*)-2,3-*exo*-1-(2,3-O-Isopropylidene-β-*D*-ribofuranosyl)-7-oxabicyclo-[2.2.1]hept-5-ene-2,3-dicarboximide* (**3d**) was obtained as crystals; yield 3.5%; m.p. 184–185°, $[\alpha]_D^{22.5}$ −31.4° (*c* 0.14, chloroform); R_F 0.26 (10:1 chloroform–ethanol); ^{13}C-n.m.r. ($CDCl_3$): δ 25.39, 27.44 (CH_3), 49.26, 51.89 (C-2, C-3), 63.01 (C-5′), 80.32, 81.44, 82.49, 82.61, 85.77 (C-1′, C-2′, C-3′, C-4′, C-4), 92.43 (C-1), 114.26 (isopropylidene Cquat), 136.84, 137.60 (C-5, C-6), 174.86, and 175.45 (C=O).

Anal. Calc. for $C_{16}H_{19}NO_7 \cdot 0.5\ H_2O$ (mixture): C, 55.44; H, 5.82; N, 4.04. Found: C, 55.73; H, 5.61; N, 4.12.

General deprotection procedure. — Trifluoroacetic acid was added to the protected *C*-nucleosides in methanol. The mixture was kept for 3–6 h at room temperature, and then rendered neutral with Dowex-WGR anion-exchange resin (Cl^-). The resin was filtered off and the filtrate evaporated to dryness *in vacuo*. The residue was purified by preparative t.l.c. to afford the free *C*-nucleosides.

*(1*R*,4*S*)-2,3-*endo*-1-(β-*D*-Ribofuranosyl)-7-oxabicyclo[2.2.1]hept-5-ene-2,3-dicarboximide* (**2a**) had m.p. 149–150°, $[\alpha]_D^{22.5}$ −75.4° (*c* 0.52, methanol).

*(1*S*,4*R*)-2,3-*endo*-1-(β-*D*-Ribofuranosyl)-7-oxabicyclo[2.2.1]hept-5-ene-2,3-dicarboximide* (**2b**) had m.p. 124–126°, $[\alpha]_D^{22.5}$ +42.0° (*c* 0.31, methanol).

*(1*S*,4*R*)-2,3-*exo*-1-(β-*D*-Ribofuranosyl)-7-oxabicyclo[2.2.1]hept-5-ene-2,3-dicarboximide* (**2c**) had m.p. 144–146°, $[\alpha]_D^{22.5}$ +5.3° (*c* 0.39, methanol).

*(1*R*,4*S*)-2,3-*exo*-1-(β-*D*-Ribofuranosyl)-7-oxabicyclo[2.2.1]hept-5-ene-2,3-dicarboximide* (**2d**) was a clorless foam; $[\alpha]_D^{22.5}$ +6.2° (*c* 0.21, methanol).

The ^{1}H-n.m.r. data for these products are given in Tables I and II.

TABLE II

FIRST-ORDER COUPLING CONSTANTS (Hz)

Compound	$J_{1',2'}$	$J_{2',3'}$	$J_{3',4'}$	$J_{4',5'}$	$J_{4',5''}$	$J_{5',5''}$	$J_{2,3}$	$J_{3,4}$	$J_{4,5}$	$J_{5,6}$
2a	5.0	[a]	[a]	[a]	[a]	[a]	[a]	4.0	~1.0	6.0
2b	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	0	0
2c	[a]	[a]	[a]	[a]	[a]	[a]	6.5	0	0	0
2d	[a]	[a]	[a]	[a]	[a]	[a]	6.5	0	0	0
3a	[a]	[a]	[a]	[a]	[a]	[a]	[a]	4.0	2.0	6.0
3b	5.0	6.0	3.5	3.5	3.5	[a]	[a]	5.5	0	0
3c	4.0	[a]	3.5	3.5	3.5	[a]	6.5	0	0	0
3d	[a]	[a]	[a]	[a]	[a]	[a]	7.0	0	~1.0	6.0
6a	4.0	7.0	~1.0	5.0	5.0	[a]	[a]	6.0	2.0	6.0
6b	4.0	7.0	~1.0	5.0	5.0	[a]	[a]	6.0	2.0	6.0
6c	6.0	4.0	0	[a]	[a]	[a]	7.0	0	2.0	6.0
6d	6.0	3.5	[a]	[a]	[a]	[a]	7.0	0	2.0	6.0

[a]Unresolved.

TABLE III

CRYSTAL DATA FOR **2a** AND **3c**

	2a	**3c**
Molecular formula	$C_{13}H_{15}NO_7$	$C_{16}H_{19}NO_7$
Mr	297.26	337.33
Crystal system	Orthorhombic	Monoclinic
Space group	$P2_12_12_1$	$P2_1$
Cell constant		
a(Å)	5.609(1)	11.166(5)
b(Å)	10.316(2)	5.736(2)
c(Å)	21.805(4)	12.506(5)
β(°)	—	108.04(3)
Volume (Å^3)	1261.8(4)	761.6(5)
Z	4	2
D_m (Mg/m^3)	1.550(3)	1.467(2)
D_x (Mg/m^3)	1.565	1.471
Crystal dimension (mm)	0.3 × 0.2 × 0.2	0.2 × 0.3 × 0.1
Number of reflections (including $F_0 = 0.0$)	1278	1432
R-value (R_w)	0.053 (0.061)	0.059 (0.066)
Weighting factor (overall)	1.0	1.0
Range of intensity collection (°)	$2.0 \leqq 2\theta \leqq 130.0$	$2.0 \leqq 2\theta \leqq 130.0$

Anal. Calc. for $C_{13}H_{15}NO_7$ (mixture): C, 52.52; H, 5.09; N, 4.71. Found: C, 52.29; H, 5.10; N, 4.59.

Isolation of adducts **6a–d.** — The same procedure as in the β series was used for the reaction of **4** with maleimide and acetonation of the products **5a–d** with TsOH in acetone.

*(1*R,*4*S*)-2,3*-endo-*1-(2,3*-O-*Isopropylidene-α*-D-*ribofuranosyl)-7-oxabicyclo-[2.2.1]hept-5-ene-2,3-dicarboximide* (**6a**) was a colorless foam; yield 3.7%; R_F 0.23 (10:1 chloroform–ethanol); $[\alpha]_D^{22.5}$ −33.3° (*c* 0.19, 1:1 chloroform–methanol).

*(1*S,*4*R*)-2,3*-endo-*1-(2,3*-O-*Isopropylidene-α*-D-*ribofuranosyl)-7-oxabicyclo-[2.2.1]hept-5-ene-2,3-dicarboximide* (**6b**), yield 19%; had m.p. 98–99°, $[\alpha]_D^{22.5}$ +27.3° (*c* 1.04, 1:1 chloroform–methanol); R_F 0.26 (10:1 chloroform–ethanol).

*(1*S,*4*R*)-2,3*-exo-*1-(2,3*-O-*Isopropylidene-α*-D-*ribofuranosyl)-7-oxabicyclo-[2.2.1]hept-5-ene-2,3-dicarboximide* (**6c**) was a colorless foam; yield 18.4%; R_F 0.34 (10:1 chloroform–ethanol); $[\alpha]_D^{22.5}$ −13.3° (*c* 1.39, 1:1 chloroform–methanol).

*(1*R,*4*S*)-2,3*-exo-*1-(2,3*-O-*Isopropylidene-α*-D-*ribofuranosyl)-7-oxabicyclo-[2.2.1]hept-5-ene-2,3-dicarboximide* (**6d**), yield 22%; had m.p. 129–131°, $[\alpha]_D^{22.5}$ −4.41° (*c* 0.68, 1:1 chloroform–methanol); R_F 0.38 (10:1 chloroform–ethanol).

Anal. Calc. for $C_{16}H_{19}NO_7 \cdot 0.5\ H_2O$ (mixture): C, 55.44; H, 5.82; N, 4.04. Found: C, 55.98; H, 5.77; N, 4.17.

TABLE IV

ATOMIC COORDINATES OF NONHYDROGEN ATOMS WITH THEIR ESTIMATED STANDARD DEVIATIONS IN PARENTHESES

Atom	x	y	z
2a			
N-1	1.0197(9)	0.5255(5)	0.5093(2)
C-2	0.9902(11)	0.6228(5)	0.4660(2)
O-2	1.1169(8)	0.7179(4)	0.4640(2)
C-3	0.7786(10)	0.5874(5)	0.4255(2)
C-4	0.6941(10)	0.4528(5)	0.4502(2)
C-5	0.8600(11)	0.4246(6)	0.5037(2)
O-5	0.8593(9)	0.3300(4)	0.5362(2)
C-6	0.7313(11)	0.3642(5)	0.3932(2)
O-6	0.6665(7)	0.4548(3)	0.3450(1)
C-7	0.9983(11)	0.3517(5)	0.3821(2)
C-8	1.0716(10)	0.4662(5)	0.3606(2)
C-9	0.8489(10)	0.5498(4)	0.3574(2)
C-1′	0.8439(10)	0.6568(4)	0.3090(2)
O-1′	0.9979(7)	0.7573(3)	0.3309(2)
C-2′	0.5990(10)	0.7158(5)	0.2959(2)
O-2′	0.5466(10)	0.7145(4)	0.2322(2)
C-3′	0.6326(10)	0.8590(5)	0.3149(2)
O-3′	0.5055(8)	0.9462(3)	0.2766(2)
C-4′	0.9000(10)	0.8795(5)	0.3121(2)
C-5′	0.9935(12)	0.9811(5)	0.3567(2)
O-5′	0.9336(7)	0.9479(4)	0.4186(2)
3c			
N-1	−0.1789(4)	0.2441(11)	1.0422(4)
C-2	−0.1281(5)	0.4374(12)	1.0048(4)
O-2	−0.0160(3)	0.4695(9)	1.0263(3)
C-3	−0.2353(5)	0.5919(12)	0.9352(4)
C-4	−0.3553(5)	0.4741(15)	0.9474(5)
C-5	−0.3100(5)	0.2522(14)	1.0128(5)
O-5	−0.3718(4)	0.1008(12)	1.0376(4)
C-6	−0.4304(5)	0.4150(16)	0.8230(5)
O-6	−0.3269(3)	0.3525(9)	0.7803(3)
C-7	−0.4694(6)	0.6499(18)	0.7666(6)
C-8	−0.3668(6)	0.7501(15)	0.7542(5)
C-9	−0.2620(5)	0.5737(13)	0.8046(4)
C-1′	−0.1472(5)	0.5833(13)	0.7617(4)
O-1′	−0.1865(4)	0.6523(10)	0.6442(3)
C-2′	−0.0787(5)	0.3504(12)	0.7694(4)
O-2′	0.0551(3)	0.3850(9)	0.8003(3)
C-3′	−0.1157(5)	0.2530(14)	0.6487(5)
O-3′	0.0028(4)	0.2033(9)	0.6307(3)
C-4′	−0.1901(6)	0.4486(16)	0.5741(5)
C-5′	−0.3276(6)	0.3706(22)	0.5178(6)
O-5′	−0.3963(6)	0.5677(20)	0.4585(5)
C-1I	0.1004(5)	0.3405(14)	0.7061(5)
C-2I	0.2164(6)	0.1889(16)	0.7477(5)
C-3I	0.1222(7)	0.5634(17)	0.6534(6)

*X-Ray crystallography**. — Single crystals of **2a** and **3c** were crystallized from water and ether, respectively, and used for the X-ray analysis. The crystal data are summarized in Table III. Independent intensities were measured by means of an AFC-5 diffractometer (Regaku Co.,) with graphite-monochromated CuK_α radiation (λ 1.5405 Å) employing the $\omega - 2\theta$ scanning technique, and are corrected for Lorentz and polarization factors.

The structure for both crystals were solved by direct methods (MULTAN[7] program) and refined by the full-matrix, least-squares method with anisotropic temperature-factors for nonhydrogen atoms and with isotropic ones for hydrogen atoms. The final atomic coordinates for nonhydrogen atoms are listed in Table IV. The atomic scattering-factors for all atoms were taken from the "International Tables for X-ray Crystallography"[8]. All numerical calculations were performed with an ACOS-1000 computer at the Computation Center of Osaka University with the UNCS program[9].

The stereo-structures of **2a** and **3c** are shown in Figs. 1 and 2, respectively.

REFEENCES

1 (*a*) I. MAEBA, K. IWATA, F. USAMI, AND H. FURUKAWA, *J. Org. Chem.*, 48 (1983) 2998–3002; (*b*) I. MAEBA, F. USAMI, AND H. FURUKAWA, *ibid.*, 49 (1984) 1534–1537.
2 (*a*) T. J. COUSINEAU AND J. A. SECRIST, III, *J. Org. Chem.*, 44 (1979) 4351–4358; (*b*) H. OHRUI, G. H. JONES, J. J. MOFFATT, M. L. MADDOX, A. T. CHRISTENSEN, AND S. K. BRYAN, *J. Am. Chem. Soc.*, 97 (1975) 4602–4613; (*c*) S. Y. K. TAM, R. S KLEIN, F. G. DE LAS HERAS, AND J. J. FOX, *J. Org. Chem.*, 44 (1979) 4854–4862.
3 (*a*) L. B. TOWNSEND, *Synth. Proced. Nucleic Acid Res. Chem.*, 2 (1973) 267–398; (*b*) J. L. IMBACH, *Ann. N. Y. Acad. Sci.*, 255 (1975) 177–184; (*c*) M. MACCOSS, M. J. ROBINS, B. RAYNER, AND J. L IMBACH, *Carbohydr. Res.*, 59 (1977) 575–579; (*d*) D. W. JONES, T. T. MOKOENA, D. H. ROBINSON, AND G. SHAW, *Tetrahedron*, 37 (1981) 2995–3003.
4 T. A. EGGELTE, H. DE KONING, AND H. O. HUISMAN, *Tetrahedron*, 29 (1973) 2491–2493.
5 K. ALDER AND G. STEIN, *Angew. Chem.*, 50 (1937) 510–519.
6 J. L. IMBACH AND B. L. KAM, *J. Carbohydr. Nucleos. Nucleot.*, 1 (1974) 271–273.
7 P. MAIN, S. E. HULL, L. LESSINGER, G. GERMEIN, J. P. DECLERCQ, AND M. M. WOOLFSON, *MULTAN78, A System of Computer Programs for the Automatic Solution of Crystal Structures from X-ray Diffraction Data*, University of York, England, and Louvain, Belgium, 1978.
8 *International Tables for X-ray Crystallography*, Kynoch Press, Birmingham, Vol. IV, 1974.
9 *The Universal Crystallographic Computing System*, Library of Programs, Osaka University, Computing Center, 1979.

*The supplementary material available gives for **2a** and **3c** the table of Fo – Fc values, anisotropic temperature-factors of nonhydrogen atoms, coordinates and isotropic temperature-factors of hydrogen atoms, bond lengths, bond angles between nonhydrogen atoms, and torsion angles. They may be obtained from Elsevier Science Publishers B.V., BBA Data Deposition, P.O. Box 1527, Amsterdam, The Netherlands. Reference should be made to No. BBA/DD/312/*Carbohydr. Res.*, 141 (1985) 1–12.