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Intramolecular Cationic Cyclization of Acetoxy Derivatives of the Levoglucosenone–Cyclopentadiene *endo*-Adduct

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Abstract—Epoxidation of diastereoisomeric benzyloxy derivatives of the levoglucosenone adduct with cyclopentadiene by treatment with *m*-chloroperoxybenzoic acid afforded a mixture of 1,2- and 1,4-epoxy derivatives. Intramolecular cyclization of the hydroxy derivatives of the same adduct by the action of I_2–$NaHCO_3$–MeCN gave products resulting from cleavage of the 1,6-anhydro bridge, reduction of the acetal moiety, and olefin–aldehyde cyclization.

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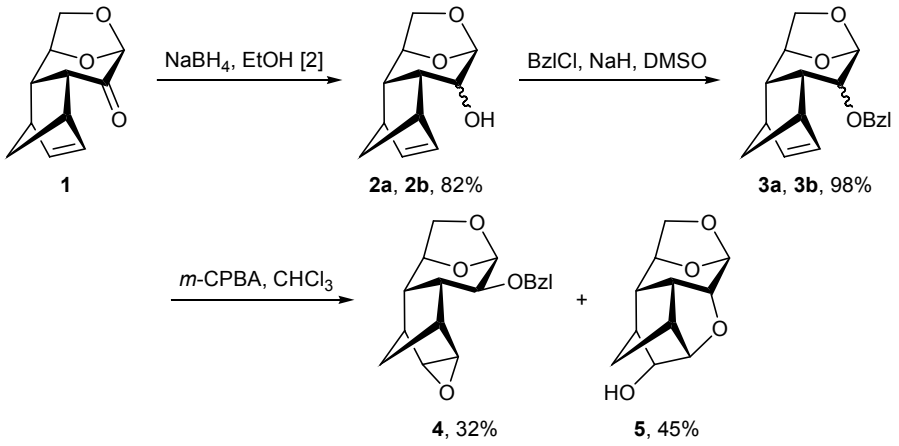
As an alternative approach [1] to the synthesis of iridoid skeleton, we have studied transformations of Diels–Alder adduct **1** derived from levoglucosenone and cyclopentadiene [2]. The ability of the *endo*-*R*-hydroxy derivative of adduct **1** to undergo intramolecular cyclization to 1,4-epoxide on treatment with *m*-chloroperoxybenzoic acid (*m*-CPBA) or I_2–EtOH [2] allows differentiation of substituents on the double bond. We anticipated that the use in these reactions of protected epimeric alcohols **2a** and **2b** should enable us to obtain both 1,2-epoxides under analogous conditions.

Benzyl ethers **3a** and **3b** were prepared by successive treatment of alcohols **2a** and **2b** with sodium hydride and benzyl chloride in DMSO, and the oxidation of mixture **3a**/**3b** with *m*-CPBA in chloroform afforded a mixture of 1,2-epoxide **4** and 1,4-epoxide **5** (Scheme 1). Removal of the benzyl protection and formation of epoxy bridge in *R*-epimer **3a** are likely to be favored by anchimeric assistance in intermediate 1,2-epoxide.

1,4-Epoxide **5** was subjected to Jones oxidation to obtain ketone **6** which was converted into lactone **7** according to Baeyer–Villiger (Scheme 2). The functional groups in **7** are differently susceptible to subsequent transformations. Our attempts to obtain compound **5** by hydrolysis of iodo derivative **8** [3] under

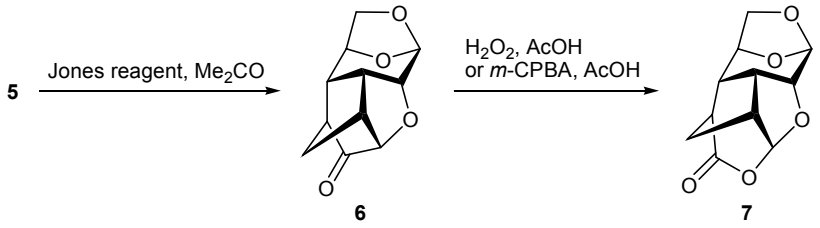
Scheme 1.



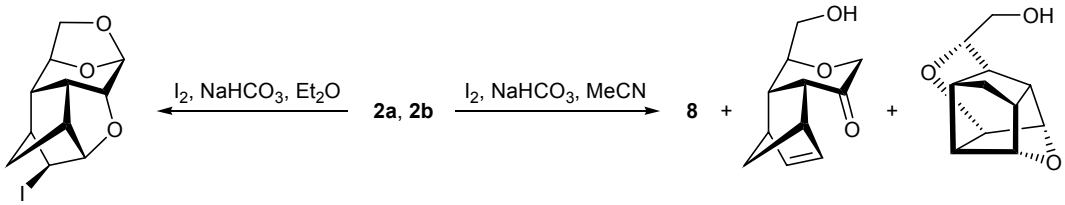
1 **2a**, **2b**, 82% **3a**, **3b**, 98%

4, 32% **5**, 45%

Scheme 2.



Scheme 3.

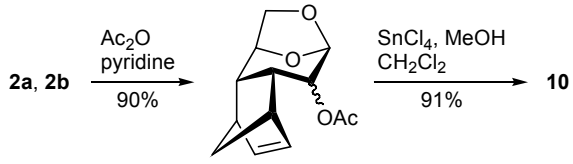


8, 26% **9**, 11% **10**, 15%

different conditions were unsuccessful, and complex mixtures of products were formed. We examined the reaction of **2a**/**2b** with iodine in acetonitrile and diethyl ether–water (5:1), i.e., in solvents other than those used in [2] (Scheme 3).

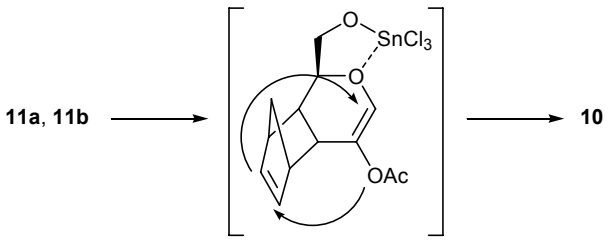
The reaction in Et_2O–H_2O followed the same iodocyclization pattern as in EtOH, whereas in acetonitrile 1,4-epoxide **8**, oxidation–reduction product **9**, and intramolecular cationic cyclization product **10** were obtained together with unreacted *S*-epimer **2b**. Cage compound **10** is likely to result from intramolecular Prins reaction which is known to be catalyzed by acids. In fact, treatment of isomeric acetate mixture **11a**/**11b** with H_3PO_4 afforded 24% of **10**. More appropriate catalysts for such Prins reactions are metal halides, in particular $SnCl_4$ [4] which was successfully used in the *O*-glycosylation of carbohydrates [5]. By treatment of **11a**/**11b** with $SnCl_4$ in MeOH–CH_2Cl_2 we obtained compound **10** in 91% yield, regardless of the initial diastereoisomer ratio (Scheme 4). These findings suggest intermediacy of structure **A** in the cationic cyclization. In the presence of $SnCl_4$ the major path is the transformation of both diastereoisomers **11a** and **11b** into product **10** through intermediate **A** (Scheme 5).

Scheme 4.



11a, **11b** (1:1)

Scheme 5.



A

EXPERIMENTAL

The ^1H and ^{13}C NMR spectra were recorded on a Bruker AM-300 spectrometer at 300 and 75.47 MHz, respectively, as well as on a Bruker Avance III spectrometer at 500 MHz; $CDCl_3$ was used as solvent unless otherwise stated. The mass spectra were obtained on a Hewlett Packard HP 5973 mass-selective detector coupled with an HP 6890 gas chromatograph. Sorbfil PTSKh-AF-A plates (*Sorbpolimer*, Krasnodar) were used for analytical TLC. The melting points were measured on a Boetius PHMK 05 melting point apparatus. The elemental compositions were determined on a Euro 2000 CHNS(O) analyzer. The optical rotations were measured on a Perkin Elmer-341 polarimeter.

(1*S*,2*S*,3*R*,6*S*,7*R*,9*R*)-10,12-Dioxatetracyclo[7.2.1.1^{3,6}.0^{2,7}]tridec-4-en-8-one (**1**) and (1*S*,2*S*,3*R*,6*S*,7*R*,8*RS*,9*R*)-10,12-dioxatetracyclo[7.2.1.1^{3,6}.0^{2,7}]tridec-4-en-8-ol (**2a**/**2b**) were synthesized according to the procedure described in [2].

(1*S*,2*S*,3*R*,6*S*,7*R*,8*RS*,9*R*)-8-Benzyloxy-10,12-dioxatetracyclo[7.2.1.1^{3,6}.0^{2,7}]tridec-4-ene (3a/3b).

A solution of 0.06 g (2.70 mmol) of sodium hydride in 2.3 mL of dimethyl sulfoxide was stirred for 30 min under argon, a solution of 0.35 g (1.80 mmol) of epimer mixture **2a**/**2b** in 3.0 mL of DMSO was added, the mixture was stirred for 5 min, 0.34 g (2.7 mmol) of benzyl chloride was added dropwise, and the mixture was stirred at room temperature until the initial alcohols disappeared (TLC). The mixture was treated with 5.0 mL of water and extracted with ethyl acetate (3×5.0 mL), the extract was dried over $MgSO_4$, the solvent was distilled off, and the residue was purified by silica gel chromatography. Yield of **3a**/**3b** 0.50 g (98%), epimer ratio 1:1; oily material, R_f 0.4 (petroleum ether–EtOAc, 3:1).

(8*R*)-Epimer **3a**. ^{1}H NMR spectrum, δ, ppm: 1.20 d (1H, 13-H$_B$, ^2J = 8.0 Hz), 1.31 d.t (1H, 13-H$_A$, ^2J = 8.0, $^3J_{13A,3}$ = 1.8, $^3J_{13A,6}$ = 1.8 Hz), 2.03 d.d (1H, 2-H, $^3J_{2,7}$ = 9.7, $^3J_{2,3}$ = 3.4 Hz), 2.76 d.d.d (1H, 7-H, $^3J_{7,2}$ = 9.7, $^3J_{7,6}$ = $^3J_{7,8}$ = 3.8 Hz), 2.90 m (1H, 3-H), 2.92 m (1H, 6-H), 2.97 d.d (1H, 8-H, $^3J_{8,7}$ = 3.8, $^3J_{8,9}$ = 3.0 Hz), 3.67 d (1H, 11-H$_B$, ^2J = 6.7 Hz), 3.71 d.d (1H, 11-H$_A$, ^2J = 6.7, $^3J_{11A,1}$ = 4.4 Hz), 4.33 d (1H, 1-H, $^3J_{1,11A}$ = 4.4 Hz), 4.62 d (2H, 1′-H, ^2J = 12.9 Hz), 5.27 d (1H, 9-H, $^3J_{9,8}$ = 3.0 Hz), 6.12 d.d (1H, 5-H, $^3J_{5,6}$ = 5.5, $^3J_{5,4}$ = 3.0 Hz), 6.30 d.d (1H, 4-H, $^3J_{4,3}$ = 5.5, $^3J_{4,5}$ = 3.0 Hz), 7.35 m (5H, Ph). ^{13}C NMR spectrum, δ$_C$, ppm: 37.86 (C^2), 41.10 (C^7), 46.64 (C^6), 47.39 (C^3), 48.83 (C^{13}), 70.33 (C^{11}), 72.25 (C$^{1'}$), 74.64 (C^1), 74.44 (C^8), 99.85 (C^9); 127.27, 127.60, 128.11, 138.05 (Ph); 135.36 (C^5), 138.65 (C^4).

(8*S*)-Epimer **3b**. ^{1}H NMR spectrum, δ, ppm: 1.35 d (1H, 13-H$_B$, ^2J = 8.2 Hz), 1.40 d.t (1H, 13-H$_A$, ^2J = 8.2, $^3J_{13A,3}$ = $^3J_{13A,6}$ = 1.8 Hz), 2.27 d.d (1H, 2-H, $^3J_{2,7}$ = 10.0, $^3J_{2,3}$ = 3.2 Hz), 2.43 d.d.d (1H, 7-H, $^3J_{7,2}$ = $^3J_{7,8}$ = 10.0, $^3J_{7,6}$ = 4.4 Hz), 2.86 m (1H, 3-H), 3.10 m (1H, 6-H), 3.55 d.d (1H, 8-H, $^3J_{8,7}$ = 10.0 Hz), 3.60 d.d (1H, 11-H$_A$, ^2J = 6.6, $^3J_{11A,1}$ = 4.7 Hz), 3.84 d (1H, 11-H$_B$, ^2J = 6.6 Hz), 4.32 d (1H, 13-H, $^3J_{1,11A}$ = 4.7 Hz), 4.64 d (2H, 1′-H, ^2J = 12.9 Hz), 5.20 s (1H, 9-H), 5.98 d.d (1H, 5-H, $^3J_{5,6}$ = 5.8, $^3J_{5,4}$ = 3.0 Hz), 6.23 d.d (1H, 4-H, $^3J_{4,3}$ = 5.8, $^3J_{4,5}$ = 3.0 Hz), 7.35 m (5H, Ph). ^{13}C NMR spectrum, δ$_C$, ppm: 37.88 (C^2), 41.16 (C^7), 46.76 (C^6), 47.53 (C^3), 50.23 (C^{13}), 70.84 (C^{11}), 71.24 (C$^{1'}$), 74.14 (C^1), 76.02 (C^8), 98.25 (C^9); 127.27, 127.60, 128.11, 138.05 (Ph); 130.21 (C^5), 135.66 (C^4). Mass spectrum: *m*/*z* 285.0 [*M* – H]$^+$. Found, %: C 75.99; H 7.01. $C_{18}H_{20}O_3$. Calculated, %: C 75.96; H 7.03. *M* 284.3496.

(1*S*,2*S*,3*S*,4*S*,5*R*,6*R*,7*R*,8*R*,9*R*)-8-Benzyloxy-4,5-epoxy-10,12-dioxatetracyclo[7.2.1.1^{3,6}.0^{2,7}]tridecane (4) and (1*S*,2*S*,3*R*,4*R*,6*S*,7*S*,8*S*,10*R*,11*R*)-9,12,14-trioxapentacyclo[9.2.1.0^{2,6}.0^{3,10}.0^{4,8}]tetradecan-7-ol (5). *m*-Chloroperoxybenzoic acid, 2.76 g (16.0 mmol), was added to a solution of 1.18 g (4.0 mmol) of epimeric benzyl ethers **3a**/**3b** in 20.0 mL of chloroform, and the mixture was stirred at room temperature until the initial compounds disappeared (TLC). The mixture was treated with 20 mL of water, the organic phase was separated, and the aqueous phase was extracted with chloroform (3×30 mL). The extracts were combined with the organic phase, washed with a saturated aqueous solution of $NaHCO_3$ and brine, and dried over $MgSO_4$, the solvent was distilled off, and the residue was subjected to silica gel chromatography to isolate 0.3 g (32%) of **4** and 0.3 g (45%) of **5**.

Compound **4**. Oily material, R_f 0.5 (petroleum ether–EtOAc, 2:1), $[\alpha]_D^{20}$ = –8° (*c* = 0.26, $CHCl_3$). IR spectrum, ν, cm^{-1}: 3447, 2959, 1721, 1096, 847, 740, 700, 442. ^{1}H NMR spectrum, δ, ppm: 0.70 d (1H, 13-H$_B$, ^2J = 10.0 Hz), 1.40 d.t (1H, 13-H$_A$, ^2J = 10.0, $^3J_{13A,3}$ = $^3J_{13B,6}$ = 1.7 Hz), 2.08 d.d (1H, 2-H, $^3J_{2,7}$ = 10.2, $^3J_{2,3}$ = 3.8 Hz), 2.28 quint (1H, 7-H, $^3J_{7,2}$ = 10.2, $^3J_{7,6}$ = $^3J_{7,8}$ = 3.3 Hz), 2.50 m (1H, 6-H), 2.60 m (1H, 4-H), 3.10 d (1H, 5-H, $^3J_{5,4}$ = 3.10 Hz), 3.37 d (1H, 4-H, $^3J_{4,5}$ = 3.10 Hz), 3.46 t (1H, 8-H, $^3J_{8,9}$ = $^3J_{8,7}$ = 3.3 Hz), 3.80 d (1H, 11-H$_B$, ^2J = 6.7 Hz), 3.82 d.d (1H, 11-H$_A$, ^2J = 6.7, $^3J_{11A,1}$ = 4.1 Hz), 4.55 d (1H, 1-H, $^3J_{1,11A}$ = 4.1 Hz), 4.68 s (2H, 1′-H), 5.40 d (1H, 9-H, $^3J_{9,8}$ = 3.3 Hz), 7.38 m (5H, Ph). ^{13}C NMR spectrum, δ$_C$, ppm: 27.06 (C^{13}), 39.62 (C^6), 39.80 (C^3), 42.04 (C^7), 44.49 (C^2), 49.65 (C^5), 50.10 (C^4), 71.16 (C$^{1'}$), 71.79 (C^1), 73.71 (C^8), 98.32 (C^9); 128.05, 128.59, 129.85, 137.84 (Ph). Mass spectrum: *m*/*z* 301 [*M* – H]$^+$. Found, %: C 71.95; H 6.68. $C_{18}H_{20}O_4$. Calculated, %: C 71.92; H 6.66. *M* 300.349.

Compound **5**. Colorless crystals, mp 118°C, R_f 0.3 (petroleum ether–EtOAc, 2:1), $[\alpha]_D^{20}$ = –13° (*c* = 0.16, $CHCl_3$). ^{1}H NMR spectrum, δ, ppm: 1.35 d (1H, 5-H$_B$, ^2J = 10.6 Hz), 1.66 d.d (1H, 2-H, $^3J_{2,3}$ = 10.0, $^3J_{2,6}$ = 3.2 Hz), 2.00 d (1H, 5-H$_A$, ^2J = 10.6 Hz), 2.21 m (1H, 6-H), 2.47 quint (1H, 3-H, $^3J_{3,2}$ = 10.0, $^3J_{3,4}$ = $^3J_{3,10}$ = 5.0 Hz), 2.77 t (1H, 4-H, $^3J_{4,3}$ = $^3J_{4,8}$ = 5.0 Hz), 3.78 d.d (1H, 13-H$_A$, ^2J = 6.8, $^3J_{13A,1}$ = 5.0 Hz), 3.81 d (1H, 13-H$_B$, ^2J = 6.8 Hz), 3.83 d.d (1H, 10-H, $^3J_{10,3}$ = 5.0, $^3J_{10,11}$ = 2.1 Hz), 4.09 d (1H, 1-H, $^3J_{1,13A}$ = 5.0 Hz), 4.58 s (1H, 7-H), 4.61 d (1H, 8-H, $^3J_{8,4}$ = 5.0 Hz), 5.35 d (1H, 11-H, $^3J_{11,10}$ = 2.1 Hz). ^{13}C NMR spectrum, δ$_C$, ppm: 32.52 (C^5), 33.97 (C^3), 40.52 (C^2), 44.78 (C^6), 46.87 (C^4), 68.83 (C^{13}), 73.71 (C^7), 75.03 (C^1), 76.88 (C^{10}), 89.17 (C^8), 99.21 (C^{11}). Mass spectrum: *m*/*z* 211 [*M* – H]$^+$. Found, %: C 62.77; H 6.68. $C_{11}H_{14}O_4$. Calculated, %: C 62.79; H 6.66. *M* 210.2265.

(1*S*,2*R*,3*R*,4*R*,6*S*,8*S*,10*R*,11*R*)-9,12,14-Trioxapentacyclo[9.2.1.0^{2,6}.0^{3,10}.0^{4,8}]tetradecan-7-one (6). A solution of 0.61 g (2.90 mmol) of alcohol **5** in 20 mL of acetone was cooled to –15°C, 1.1 mL of Jones' reagent was added dropwise under vigorous stirring, and the mixture was stirred for 15 min (TLC). The mixture was then treated with 10 mL of propan-2-ol, filtered, treated with a saturated aqueous solution of $NaHCO_3$, and extracted with ethyl acetate (3×30 mL). The extract was washed with saturated aqueous solutions of $NaHCO_3$ and NaCl and dried over $MgSO_4$, the solvent was distilled off, and the residue was purified by silica gel chromatography. Yield 0.55 g (91%), colorless crystals, mp 138°C, R_f 0.6 (EtOAc), $[\alpha]_D^{20}$ = +21.2° (*c* = 0.35, DMSO). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 1.62 d.t (1H, 5-H$_B$, ^2J = 11.2, $^3J_{5B,6}$ = $^3J_{5B,4}$ = 1.3 Hz), 1.70 d.t (1H, 5-H$_A$, ^2J = 11.2, $^3J_{5A,6}$ = 1.5, $^3J_{5A,4}$ = 1.3 Hz), 2.10 d.d (1H, 2-H, $^3J_{2,3}$ = 9.6, $^3J_{2,6}$ = 3.3 Hz), 2.43 m (1H, 7-H), 2.80 d.t (1H, 3-H, $^3J_{3,2}$ = 9.6, $^3J_{3,10}$ = $^3J_{3,4}$ = 5.6 Hz), 2.93 t.d (1H, 4-H, $^3J_{4,3}$ = 5.6, $^3J_{4,8}$ = 5.4, $^3J_{4,5B}$ = 1.5, $^3J_{4,5A}$ = 1.3 Hz), 3.68 d.d (1H, 13-H$_A$, ^2J = 7.2, $^3J_{13A,1}$ = 5.4 Hz), 3.81 d (1H, 13-H$_B$, ^2J = 7.2 Hz), 4.53 d (1H, 8-H, $^3J_{8,4}$ = 5.4 Hz), 5.24 d (1H, 11-H, $^3J_{11,10}$ = 2.2 Hz). ^{13}C NMR spectrum (DMSO-d_6), δ_C, ppm: 28.75 (C^5), 33.64 (C^3), 39.93 (C^4), 40.83 (C^2), 48.64 (C^6), 67.27 (C^{13}), 72.12 (C^1), 76.55 (C^{10}), 80.69 (C^8), 98.93 (C^{11}), 211.41 (C^7). Found, %: C 63.38; H 5.70. $C_{11}H_{12}O_4$. Calculated, %: C 63.40; H 5.76.

(1*S*,2*R*,3*S*,4*R*,6*S*,9*R*,11*R*,12*R*)-8,10,13,15-Tetraoxapentacyclo[10.2.1.0^{2,6}.0^{3,11}.0^{4,9}]pentadecan-7-one (7). *a*. *m*-Chloroperoxybenzoic acid, 0.62 g, was added to a solution of 0.015 g (0.07 mmol) of ketone **6** in 2.0 mL of glacial acetic acid, and the mixture was stirred for 24 h (TLC). The mixture was treated with water and extracted with chloroform (3×5 mL), the extract was washed with an aqueous solution of $Na_2S_2O_3$ and dried over $MgSO_4$, the solvent was distilled off, and the residue was subjected to silica gel chromatography. Yield 0.05 g (20%).

b. Ketone **6**, 0.25 g (1.2 mmol), was dissolved in 7.0 mL of glacial acetic acid, 2.5 mL of a 35% solution of hydrogen peroxide was added, and the mixture was stirred until initial ketone **6** disappeared (TLC). The mixture was treated with water, 1 g of $NaHCO_3$ was added, and the mixture was extracted with chloroform (3×30 mL). The extract was dried over $MgSO_4$, the solvent was distilled off, and the residue was purified by silica gel chromatography. Yield 0.01 g (63%), colorless crystals, mp 145°C, R_f 0.3 (EtOAc), $[\alpha]_D^{20}$ = –3.9° (*c* = 1.65, MeOH). IR spectrum, ν, cm^{-1}: 2951, 2929, 2852, 1730, 1460, 1101, 1035, 418. ^{1}H NMR spectrum, δ, ppm: 1.79 d.t (1H, 5-H$_B$, ^2J = 12.7, $^3J_{5B,6}$ = $^3J_{5B,4}$ 4.1 Hz), 2.05 d (1H, 5-H$_A$, ^2J = 12.7 Hz), 2.23 d.d (1H, 2-H, $^3J_{2,3}$ = 9.8, $^3J_{2,6}$ = 6.0 Hz), 2.97 d.t (1H, 3-H, $^3J_{3,2}$ = 9.8, $^3J_{3,4}$ = $^3J_{3,11}$ = 7.4 Hz), 3.05 m (2H, 4-H, 6-H), 3.83 d (1H, 14-H$_B$, ^2J = 7.2 Hz), 3.90 d.d (1H, 14-H$_A$, ^2J = 7.2, $^3J_{14A,1}$ = 5.3 Hz), 4.14 d (1H, 11-H, $^3J_{11,3}$ = 7.4 Hz), 4.71 d (1H, 1-H, $^3J_{1,14A}$ = 5.3 Hz), 5.44 s (1H, 12-H), 5.79 d (1H, 9-H, $^3J_{9,4}$ = 5.4 Hz). ^{13}C NMR spectrum, δ_C, ppm: 32.66 (C^5), 38.63 (C^4), 43.17 (C^6), 50.57 (C^2), 51.81 (C^3), 69.99 (C^{14}), 73.95 (C^1), 76.16 (C^{11}), 101.38 (C^{12}), 108.71 (C^9), 176.30 (C^7). Mass spectrum: *m*/*z* 225 $[M - H]^+$. Found, %: C 58.85; H 5.37. $C_{11}H_{12}O_5$. Calculated, %: C 58.87; H 5.35. *M* 224.21.

(1*S*,2*R*,3*R*,4*R*,6*S*,7*S*,8*S*,10*R*,11*R*)-7-Iodo-9,12,14-trioxapentacyclo[9.2.1.0^{2,6}.0^{3,10}.0^{4,8}]tetradecane (8). A solution of 0.50 g (1.60 mmol) of epimer mixture **2a**/**2b** in a mixture of 15.0 mL of diethyl ether and 3.0 mL of water was cooled to 0°C, 0.27 g (3.20 mmol) of $NaHCO_3$ and 0.81 g (3.20 mmol) of I_2 were added, and the mixture was allowed to warm up to room temperature and stirred until the initial compounds disappeared (TLC). The mixture was then extracted with ethyl acetate (3×5 mL), the organic extract was washed with an aqueous solution of $Na_2S_2O_3$ and with water and dried over $MgSO_4$, the solvent was distilled off, and the residue was purified by silica gel chromatography. Yield 0.57 g (64%), colorless crystals, mp 128°C, R_f 0.7 (petroleum ether–EtOAc, 1:1), $[\alpha]_D^{20}$ = +70.6° (*c* = 1.50, $CHCl_3$). IR spectrum, ν, cm^{-1}: 1350, 1340, 1035, 966, 956, 721, 690. ^{1}H NMR spectrum (C_6D_6), δ, ppm: 0.76 d.d (1H, 2-H, $^3J_{2,6}$ = 2.3, $^3J_{2,3}$ = 9.6 Hz), 1.05 d (1H, 5-H$_A$, ^2J = 10.7 Hz), 1.81 d.d.d.d (1H, 3-H, $^3J_{3,4}$ = 4.9, $^3J_{3,10}$ = 5.4, $^3J_{3,2}$ = 9.6 Hz), 2.06 d (1H, 5-H$_B$, ^2J = 10.7 Hz), 2.11 m (1H, 6-H), 2.19 m (1H, 4-H), 3.12 d (1H, 13-H$_A$, ^2J = 6.8 Hz), 3.42 d.d (1H, 13-H$_B$, $^3J_{13B,1}$ = 5.3, ^2J = 6.8 Hz), 3.66 d.d (1H, 10-H, $^3J_{10,11}$ = 1.6, $^3J_{10,3}$ = 5.4 Hz), 3.77 d (1H, 1-H, $^3J_{1,13B}$ = 5.3 Hz), 4.91 d (1H, 8-H, $^3J_{8,4}$ = 4.8 Hz), 5.10 d (1H, 7-H, $^3J_{7,6}$ = 2.2 Hz), 5.40 d (1H, 11-H, $^3J_{11,10}$ = 1.6 Hz). ^{13}C NMR spectrum (C_6D_6), δ_C, ppm: 33.52 (C^7), 33.56 (C^3), 37.17 (C^5), 47.11 (C^2), 47.93 (C^6), 48.80 (C^4), 68.49 (C^{13}), 73.18 (C^1), 76.61 (C^{10}), 91.12 (C^8), 99.31 (C^{11}). Mass spectrum: *m*/*z* 320 $[M - H]^+$. Found, %: C 41.20; H 4.09. $C_{11}H_{13}IO_3$. Calculated, %: C 41.23; H 4.06. *M* 320.1236.

(1*R*,2*S*,3*S*,7*R*,8*S*)-3-(Hydroxymethyl)-4-oxatricyclo[6.2.1.0^{2,7}]undec-9-en-6-one (9) and {(1*S*,2*R*,3*R*,5*S*,6*R*,8*S*,9*S*,10*S*,12*S*)-4,12-dioxapenta-

cyclo[6.4.0.0^{2,6}.0^{3,10}.0^{5,9}]dodec-11-yl}methanol (10). A solution of 1.0 g (5.20 mmol) of **2a**/**2b** in 35.0 mL of acetonitrile was cooled to 0°C, 0.87 g (10.40 mmol) of $NaHCO_3$ and 2.65 g (10.40 mmol) of I_2 were added, and the mixture was stirred for 1 h at room temperature (TLC). The mixture was treated with 10 mL of water and extracted with ethyl acetate (3×40 mL), The extract was washed with an aqueous solution of $Na_2S_2O_3$ and with water and dried over $MgSO_4$; the solvent was distilled off, and the residue was subjected to silica gel chromatography to isolate 0.34 g (26%) of iodide **8**, 0.11 g (11%) of hydroxy ketone **9**, and 0.13 g (15%) of compound **10**.

Compound **9**. Oily material, R_f 0.35 (petroleum ether–EtOAc, 1:1), $[\alpha]_D^{20}$ = –162.9° (*c* = 1.4, $CHCl_3$). ^{1}H NMR spectrum (C_6D_6), δ, ppm: 0.82 d and 1.21 d (1H each, 11-H, ^2J = 8.4 Hz), 2.26 d.d.d (1H, 2-H, $^3J_{2,7}$ = 3.1, $^3J_{2,3}$ = $^3J_{2,1}$ = 10.6 Hz), 2.33 d.d (1H, 7-H, $^3J_{7,2}$ = 3.1, $^3J_{7,8}$ = 10.4 Hz), 2.36 m (1H, 1-H), 2.61 d.d.d.d (1H, 3-H, $^3J_{3,1'A}$ = 2.8, $^3J_{3,1'B}$ = 6.8, $^3J_{3,2}$ = 10.6 Hz), 3.21 m (1H, 8-H), 3.38 d.d (1H, 5-H$_A$, $^3J_{5A,7}$ = 1.0, ^2J = 18.0 Hz), 3.46 d.d (1H, 1′-H$_A$, $^3J_{1'A,3}$ = 2.8, ^2J = 11.8 Hz), 3.77 d.d (1H, 1′-H$_B$, $^3J_{1'B,3}$ = 6.8, ^2J = 11.8 Hz), 3.95 d (1H, 5-H$_B$, ^2J = 18.0 Hz), 5.61 d.d (1H, 10-H, $^3J_{10,9}$ = 2.6, $^3J_{10,1}$ = 5.3 Hz), 6.15 d.d (1H, 9-H, $^3J_{9,10}$ = 2.6, $^3J_{9,8}$ = 5.3 Hz). ^{13}C NMR spectrum (C_6D_6), δ_C, ppm: 42.06 (C^2), 44.16 (C^1), 45.14 (C^8), 48.47 (C^{11}), 48.76 (C^7), 64.89 (C$^{1'}$), 73.66 (C^5), 81.54 (C^3), 134.51 (C^{10}), 138.10 (C^9), 210.68 (C^6). Mass spectrum: *m*/*z* 195 $[M - H]^+$. Found, %: C 67.90; H 7.22. $C_{11}H_{14}O_3$. Calculated, %: C 67.96; H 7.21. *M* 194.2271.

Compound **10**. Oily material, R_f 0.2 (petroleum ether–EtOAc, 1:1), $[\alpha]_D^{20}$ = –147.0° (*c* = 1.45, $CHCl_3$). ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 1.31 d (1H, 7-H$_B$, ^2J = 10.2, $^3J_{7B,8}$ = $^3J_{7B,6}$ = 1.5 Hz), 1.48 d (1H, 7-H$_A$, ^2J = 10.2 Hz), 1.78 d.d.d.d (1H, 1-H, $^3J_{1,8}$ = 6.5, $^3J_{1,2}$ = 5.3, $^3J_{1,11}$ = 3.0 Hz), 2.01 d.d.d (1H, 9-H, $^3J_{9,5}$ = $^3J_{9,10}$ = 6.5, $^3J_{9,8}$ = 5.7 Hz), 2.07 m (1H, 8-H), 2.26 d.d.d (1H, 2-H, $^3J_{2,1}$ = 6.5, $^3J_{2,3}$ = $^3J_{2,6}$ = 5.3 Hz), 2.42 m (1H, 6-H), 3.29 d.d.d.d (1H, 1′-H$_B$, ^2J = 11.0, $^3J_{1'B,11}$ = 6.3, $^3J_{1'B,OH}$ = 5.6 Hz), 3.36 d.d.d.d (1H, 1′-H$_A$, ^2J = 11.0, $^3J_{1'A,11}$ = 6.3, $^3J_{1'A,OH}$ = 5.6 Hz), 3.51 d.d (1H, 10-H, $^3J_{10,9}$ = 6.5, $^3J_{10,3}$ = 3.0 Hz), 3.76 d.d.d (1H, 11-H, $^3J_{11,1'B}$ = $^3J_{11,1'A}$ = 6.3, $^3J_{11,1}$ = 3.0 Hz), 4.25 d.d (1H, 3-H, $^3J_{3,2}$ = 5.3, $^3J_{3,10}$ = 3.0 Hz), 4.57 d.d (1H, 5-H, $^3J_{5,9}$ = 6.5, $^3J_{5,6}$ = 3.5 Hz), 4.67 t (1H, OH, $^3J_{OH,1'A}$ = $^3J_{OH,1'B}$ = 5.6 Hz). ^{13}C NMR spectrum (C_6D_6), δ_C, ppm: 31.49 (C^7), 35.32 (C^2), 36.01 (C^9), 38.51 (C^8), 38.89 (C^1), 48.39 (C^6), 64.01 (C$^{1'}$), 71.54 (C^{11}), 73.59 (C^{10}), 75.80 (C^3), 86.09 (C^5). Found, %: C 67.91; H 7.22. $C_{11}H_{14}O_3$. Calculated, %: C 67.96; H 7.21.

(1*S*,2*S*,3*R*,6*S*,7*R*,8*RS*,9*R*)-10,12-Dioxatetracyclo-[7.2.1.1^{3,6}.0^{2,7}]tridec-4-en-8-yl acetate (11a/11b). Acetic anhydride, 0.25 mL (2.30 mmol), was added to a solution of 0.30 g (1.60 mmol) of epimeric alcohols **2a**/**2b** in 7.0 mL of anhydrous pyridine, and the mixture was stirred until the initial compounds disappeared (TLC). The mixture was then treated with 5 mL of water and 3 mL of a saturated aqueous solution of $NaHCO_3$ and extracted with ethyl acetate (3×20 mL). The extract was washed with 5% aqueous HCl and brine and dried over $MgSO_4$, the solvent was distilled off, and the residue was purified by silica gel chromatography. Yield 0.33 g (90%), epimer ratio 1:1; oily material, R_f 0.5 (petroleum ether–EtOAc, 3:1).

(*R*)-Epimer **11a**. ^{1}H NMR spectrum, δ, ppm: 1.18 d and 1.29 d (1H each, 13-H, ^2J = 8.5 Hz), 2.07 s (3H, CH_3), 2.28 m (1H, 2-H), 2.77 m (1H, 7-H), 2.90 m (1H, 3-H), 3.04 m (1H, 6-H), 3.70 d.d (1H, 8-H, $^3J_{8,7}$ = 6.8, $^3J_{8,9}$ = 3.0 Hz), 4.27 d.d (1H, 11-H$_B$, ^2J = 7.4, $^3J_{11B,1}$ = 4.4 Hz), 4.31 d (1H, 11-H$_A$, ^2J = 7.4 Hz), 4.38 d (1H, 1-H, $^3J_{1,11B}$ = 4.4 Hz), 5.17 d (1H, 9-H, $^3J_{9,8}$ = 3.0 Hz), 6.12 m (1H, 5-H), 6.26 m (1H, 4-H). ^{13}C NMR spectrum, δ_C, ppm: 20.98 (CO**C**H$_3$), 37.07 (C^2), 41.08 (C^7), 46.42 (C^6), 47.71 (C^3), 49.98 (C^{13}), 69.39 (C^1), 71.40 (C^{11}), 72.33 (C^8), 99.79 (C^9), 136.13 (C^5), 137.42 (C^4), 170.01 (C=O).

(*S*)-Epimer **11b**. ^{1}H NMR spectrum, δ, ppm: 1.20 d and 1.38 d (1H each, 13-H, ^2J = 8.5 Hz), 2.07 s (3H, CH_3), 2.28 m (1H, 2-H), 2.77 m (1H, 7-H), 2.80 m (1H, 3-H), 2.87 m (1H, 6-H), 3.55 d.d (1H, 11-H$_B$, ^2J = 6.6, $^3J_{11B,1}$ = 4.1 Hz), 3.68 d (1H, 11-H$_A$, ^2J = 6.6 Hz), 3.79 d (1H, 1-H, $^2J_{1,11B}$ = 4.1 Hz), 4.83 d (1H, 8-H, $^3J_{8,7}$ = 9.8 Hz), 5.02 s (1H, 9-H), 6.12 m (1H, 5-H), 6.26 m (1H, 4-H). ^{13}C NMR spectrum, δ_C, ppm: 21.06 (CO**C**H$_3$), 37.07 (C^2), 40.36 (C^7), 46.71 (C^5), 47.02 (C^6), 49.12 (C^{13}), 70.42 (C^{11}), 74.21 (C^1), 74.54 (C^8), 97.61 (C^9), 131.91 (C^5), 135.60 (C^4), 170.47 (C=O). Found, %: C 66.11; H 6.78. $C_{13}H_{16}O_4$. Calculated %: C 66.09; H 6.83.

{(1*S*,2*R*,3*R*,5*S*,6*R*,8*S*,9*S*,10*S*,12*S*)-4,12-Dioxa-pentacyclo[6.4.0.0^{2,6}.0^{3,10}.0^{5,9}]dodec-11-yl}methanol (10). *a*. Epimer mixture **11a**/**11b,** 0.12 g (0.48 mmol), was dissolved in 5.0 mL of anhydrous methylene chloride, 0.08 mL (0.72 mmol) of $SnCl_4$ was added at room temperature, and the mixture was stirred for 15 min. Methanol, 0.03 mL (0.72 mmol), was added dropwise, and the mixture was stirred until the initial compounds disappeared (TLC). The mixture was

treated with 3.0 mL of a saturated aqueous solution of $NaHCO_3$ and extracted with methylene chloride (3×7 mL). The extract was dried over $MgSO_4$, the solvent was distilled off, and the residue was purified by silica gel chromatography. Yield 0.08 g (91%).

b. Epimer mixture **11a**/**11b,** 0.14 g (0.60 mmol), was dissolved in 3.0 mL of 92% H_3PO_4, and the mixture was stirred at 50°C until the initial compounds disappeared (TLC). The mixture was cooled to room temperature, treated with 1 mL of water and 3 mL of a saturated aqueous solution of $NaHCO_3$, and extracted with ethyl acetate (3×5 mL). The extract was washed with 5% aqueous HCl and brine and dried over anhydrous magnesium sulfate, the solvent was distilled off, and the residue was subjected to silica gel chromatography. Yield 0.03 g (24%).

The NMR and IR spectra were recorded using the equipment of the *Khimiya* Shared Use Center (Institute of Organic Chemistry, Ufa Research Center, Russian Academy of Sciences).

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