Synthesis of 2,6-dioxabicyclo[3.3.0]octanes and 3,8-dioxabicyclo[4.4.0]dec-1(6)-enes by electrophilic cyclization of 3,4-dimethylene-1,6-hexanediols

M. E. Gurskii,[a]* *S. B. Golovin,*[a] *M. O. Dekaprilevich,*[a] *Yu. T. Struchkov,*[b] *and Yu. N. Bubnov*[a]*

[a]*N. D. Zelinsky Institute of Organic Chemistry, Russian Academy of Sciences,*
47 Leninsky prosp., 117913 Moscow, Russian Federation.
Fax: +7 (095) 135 5328
[b]*A. N. Nemeyanov Institute of Organoelement Compounds, Russian Academy of Sciences,*
28 ul. Vavilova, 117813 Moscow, Russian Federation.
Fax: +7 (095) 135 5085

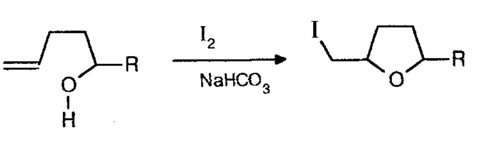
3,4-Dimethylene-1,6-hexane diols **2** obtained by allylboration of ketones with 2,3-dimethylene-1,4-bis(dipropylboryl)butane **1** undergo cyclization on treatment with I_2/$NaHCO_3$ to give 1,5-*cis*-di(iodomethyl)-2,6-dioxabicyclo[3.3.0]octanes (**4**) and/or 3,8-dioxabicyclo[4.4.0]dec-1(6)-enes (**5**). 4,4,9,9-Tetramethyl-3,8-dioxacyclodeca-1,6-dione (**9**) was synthesized by ozonolysis of bicyclic compound **5b**. The structure of compound **5e** was confirmed by X-ray diffraction analysis.

Key words: allylboronation, intramolecular iodocyclization, tetrahydrofurans, 3-methylenetetrahydrofurans, 2,6-dioxabicyclo[3.3.0]octanes, 3,8-dioxabicyclo[4.4.0]dec-1(6)-enes.

The 2,6-dioxabicyclo[3.3.0]octane moiety is a typical constituent of the metabolites of certain red algae[1] and marine mollusks.[2] However, the stereoselective construction of such systems is as yet a complicated synthetic task.[1,2]

On the other hand, it is well known that δ,ε-unsaturated alcohols readily undergo cyclization on treatment with electrophiles, *e.g.*, iodine,[3,4] to give tetrahydrofuran derivatives, and that this intramolecular cyclization often occurs in a stereospecific way[4] (Scheme 1).

Scheme 1

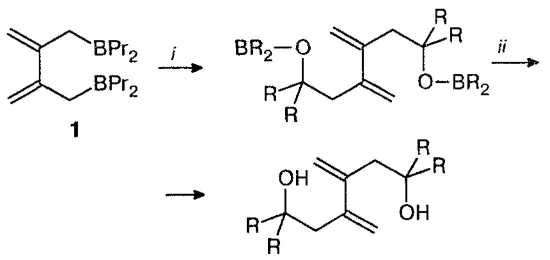


We have recently shown[5,6] that 2,3-dimethylene-1,4-bis(dipropylboryl)butane (**1**) smoothly allylates two molecules of carbonyl compounds to give, after deboronation, diene diols **2** (Scheme 2).

The resulting unsaturated 1,6-diols **2** contain appropriately located double bonds (in the γ,δ- and δ,ε-positions relative to each hydroxyl group) and are good starting compounds for double cyclization, whose general view is presented in Scheme 3.

However in the case of diols **2**, certain deviations from Scheme 3 were anticipated, since the 1,3-diene

Scheme 2



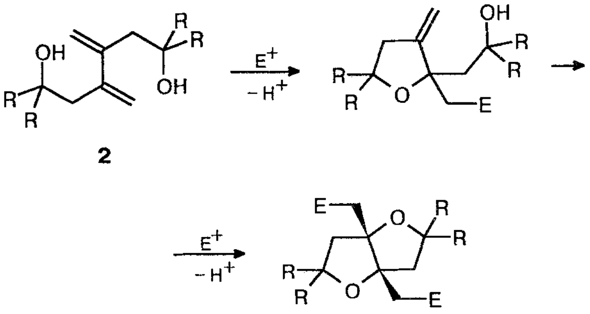
1

2a—e

i. $R_2C=O$
ii. TEA or [O]

2	R	R
a	H	H
b	Me	Me
c	—$(CH_2)_4$—	
d	—$(CH_2)_5$—	
e	Ph	Ph

Scheme 3



2

Translated from *Izvestiya Akademii Nauk. Seriya Khimicheskaya,* No. 7, pp. 1308—1314, July, 1995.

1066-5285/95/4407-1262$12.50 ©1995 Plenum Publishing Corporation

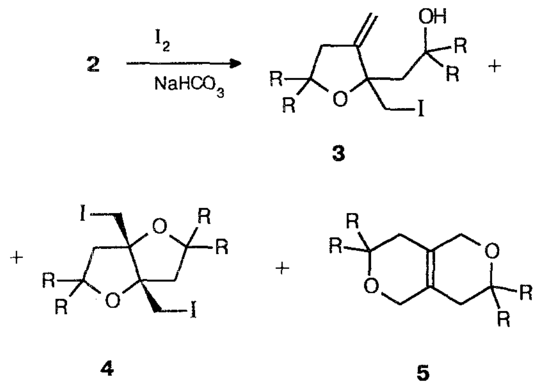
Table 1. Yields (%) of the products of intramolecular iodocyclization of diols **2**

Starting diol	**3**	**4**	**5**
2a	12	11	12
2b	3	15	33
2c	5	25	24
2d	13	31	45
2e	8	0	75

system displays a specific reactivity in comparison with monoolefins (1,4-addition, formation of allylic cations, *etc.*).

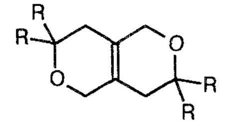
We found that iodocyclization of diols **2a—e** under standard conditions (treatment with iodine and $NaHCO_3$ in a water—ether mixture at room temperature)[3] gives three products: one monocyclic compound (**3**) and two bicyclic compounds (**4** and **5**), whose ratio depends on the nature of radicals R (Scheme 4, Table 1).

Scheme 4

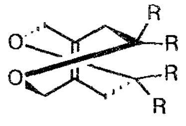


The 3-methylenetetrahydrofuran derivatives **3** and bicyclic diiodides **4** are products of mono- and double cyclization of diols **2**, respectively. Their structures were reliably determined by spectral methods. In each case, column chromatography of the reaction mixtures gave, along with compounds **3** and **4**, a considerable amount of the corresponding bicyclic compound **5** containing no iodine. The determination of the structure of these compounds was the main problem of the present study (for a preliminary communication, see Ref. 7).

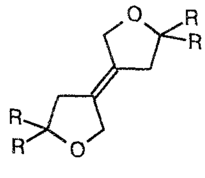
For example, the product isolated from the reaction of diol **2b** ($R = CH_3$) with iodine had a ^1H NMR spectrum consisting of three singlets at δ 1.21, 1.80, and 3.93. Its ^{13}C NMR spectrum contains five signals, one of which corresponds to a carbon atom of the tetrasubstituted double bond. The high resolution mass spectrum gives a peak with *m/z* 196.14646 (calculated for $C_{12}H_{20}O_2$: 196.14622). These data make it possible to ascribe one of the following isomers, including the exotic di-*trans*-cycloolefin **6**, to the product.



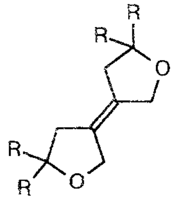
5



6



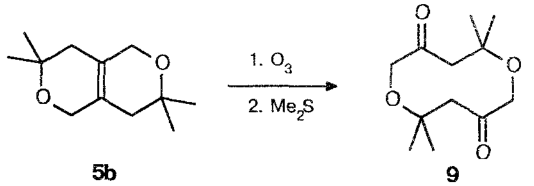
7



8

Since we could not discriminate the alternative structures **5—8** based on spectral data, chemical degradation was performed. Ozonolysis of product **5b** followed by treatment with dimethylsulfide gave 4,4,9,9-tetramethyl-3,8-dioxacyclodecane-1,6-dione (**9**) (Scheme 5), whose structure agrees with mass spectrometric (*m/z* = 228.13689) and ^1H and ^{13}C NMR spectroscopic data. The ^1H NMR spectrum of compound **9** contains three singlets with chemical shifts of 1.23 (CH_3), 2.76 (CH_2), and 4.00 (OCH_2) ppm, respectively. The ^{13}C NMR spectrum contains signals at δ 27.1 (CH_3), 45.8 (CH_2), 69.9 (CH_2O), 75.6 (C—O), and 209.5 (C=O).

Scheme 5



Hence, the second bicyclic product resulting from the iodocyclization of diols **2** is 3,8-dioxabicyclo[4.4.0]dec-1(6)-ene **5**.

The structures of these products were finally confirmed by X-ray diffraction analysis carried out for compound **5e** as an example.

The general view of molecule **5e** is presented in Fig. 1. The bond lengths and bond angles are given in Tables 2 and 3. As follows from the data in the Tables, the geometries of the two crystallographically independent molecules **5e** and **5e′** are almost identical.

The dihydropyran ring in the bicyclic system has a flattened half-chair conformation: the O(3) and C(4) atoms are shifted out of the plane of the C(1)C(2)C(5)C(1a) moiety by 0.215 and −0.537 Å in molecule **5e** and by −0.290 and 0.453 Å in molecule

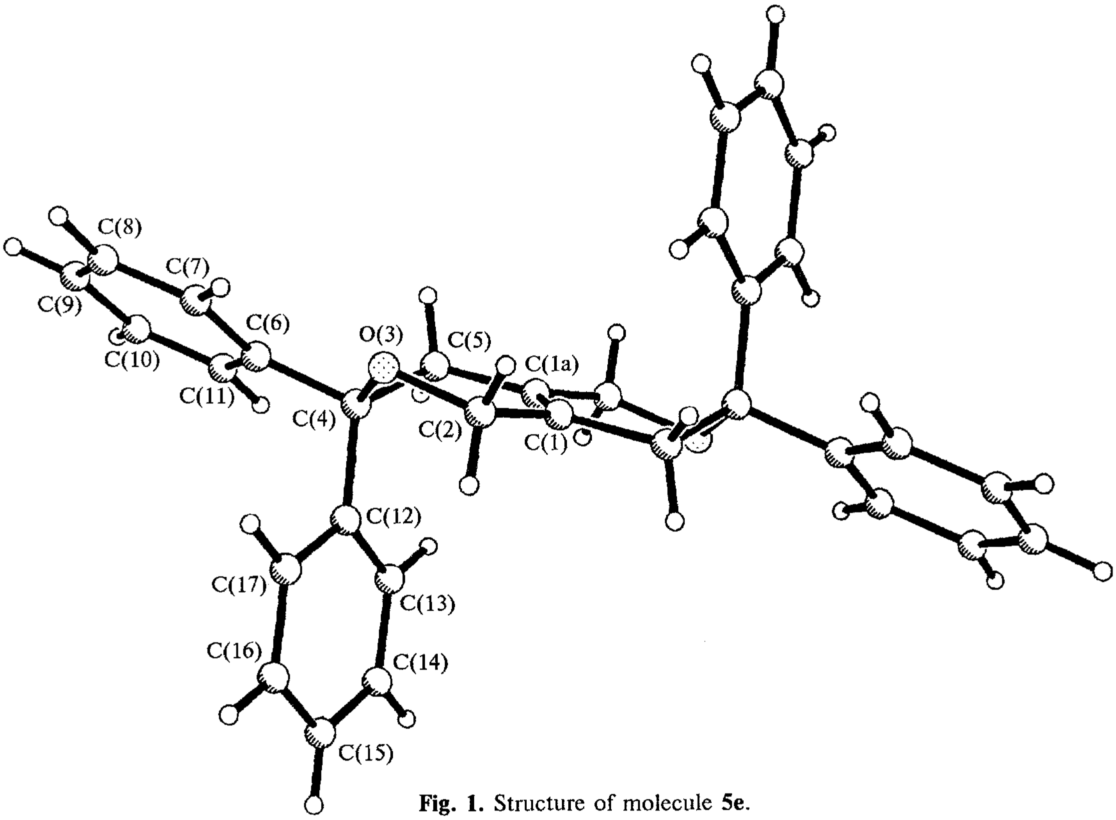


Fig. 1. Structure of molecule **5e**.

Table 2. Bond lengths in molecule **5e** (Å)

Bond	*d*/Å
C(1)*e*—C(2)*e*	1.502(2)
C(1)*e*—C(1*e*)*e*	1.326(2)
C(1)*e*—C(5*e*)*e*	1.505(2)
C(2)*e*—O(3)*e*	1.431(2)
O(3)*e*—C(4)*e*	1.443(1)
C(4)*e*—C(5)*e*	1.536(2)
C(4)*e*—C(6)*e*	1.526(2)
C(4)*e*—C(12)*e*	1.530(2)
C(5)*e*—C(1*e*)*e*	1.505(2)
C(6)*e*—C(7)*e*	1.395(2)
C(6)*e*—C(11)*e*	1.393(2)
C(7)*e*—C(8)*e*	1.392(2)
C(8)*e*—C(9)*e*	1.382(2)
C(9)*e*—C(10)*e*	1.384(2)
C(10)*e*—C(11)*e*	1.390(2)
C(12)*e*—C(13)*e*	1.392(2)
C(12)*e*—C(17)*e*	1.400(2)
C(13)*e*—C(14)*e*	1.387(2)
C(14)*e*—C(15)*e*	1.383(2)
C(15)*e*—C(16)*e*	1.392(2)
C(16)*e*—C(17)*e*	1.379(2)
C(1)*e*′—C(2)*e*′	1.497(2)
C(1)*e*′—C(1*e*′)*e*	1.330(2)
C(1)*e*′—C(5*e*′)*e*	1.503(2)
C(2)*e*′—O(3)*e*′	1.432(2)
O(3)*e*′—C(4)*e*′	1.444(1)
C(4)*e*′—C(5)*e*′	1.534(2)
C(4)*e*′—C(6)*e*′	1.526(2)
C(4)*e*′—C(12)*e*′	1.531(2)
C(5)*e*′—C(1*e*′)*e*	1.503(2)
C(6)*e*′—C(7)*e*′	1.382(2)
C(6)*e*′—C(11)*e*′	1.401(1)
C(7)*e*′—C(8)*e*′	1.393(2)
C(8)*e*′—C(9)*e*′	1.389(2)
C(9)*e*′—C(10)*e*′	1.383(2)
C(10)*e*′—C(11)*e*′	1.390(2)
C(12)*e*′—C(13)*e*′	1.386(2)
C(12)*e*′—C(17)*e*′	1.400(2)
C(13)*e*′—C(14)*e*′	1.390(2)
C(14)*e*′—C(15)*e*′	1.387(2)
C(15)*e*′—C(16)*e*′	1.383(2)
C(16)*e*′—C(17)*e*′	1.387(2)

5*e*′. The C—C and C—O bond lengths are close to the standard values.[9]

The formation of bicyclic unsaturated ethers **5** suggests that the reaction studied involves not only the "normal" process (Scheme 3), but also 1,4-iodocyclization to give dihydropyran **10**. The transformation of the latter into 3,8-dioxabicyclo[4.4.0]dec-1(6)-ene (**5**) probably occurs through intramolecular nucleophilic substitution of iodine and completes the bicyclization process.

Such a considerable contribution of cyclization according to Scheme 6 (see Table 1) can be attributed to steric hindrance in the transition state on the reaction

Scheme 6

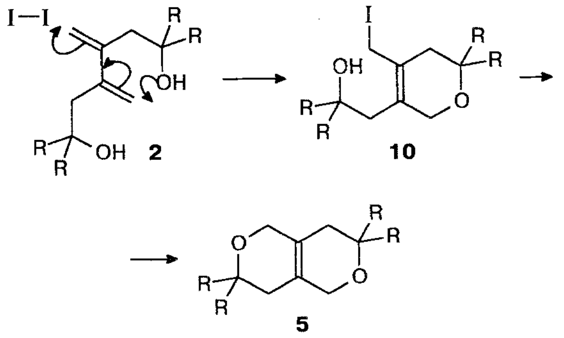
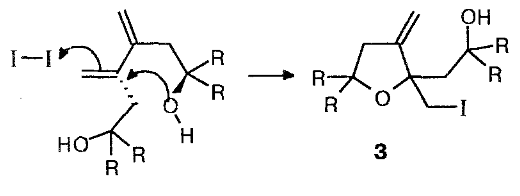


Table 3. Bond angles in molecule **5e** (deg)

Angle	ω/deg
C(2)*e*—C(1)*e*—C(1*e*)*e*	121.7(1)
C(2)*e*—C(1)*e*—C(5*e*)*e*	117.4(1)
C(1*e*)*e*—C(1)*e*—C(5*e*)*e*	120.9(1)
C(1)*e*—C(2)*e*—O(3)*e*	113.7(1)
C(2)*e*—O(3)*e*—C(4)*e*	113.3(1)
O(3)*e*—C(4)*e*—C(5)*e*	107.2(1)
O(3)*e*—C(4)*e*—C(6)*e*	106.7(1)
C(5)*e*—C(4)*e*—C(6)*e*	110.0(1)
O(3)*e*—C(4)*e*—C(12)*e*	109.4(1)
C(5)*e*—C(4)*e*—C(12)*e*	113.9(1)
C(6)*e*—C(4)*e*—C(12)*e*	109.5(1)
C(4)*e*—C(5)*e*—C(1*e*)*e*	110.9(1)
C(4)*e*—C(6)*e*—C(7)*e*	122.2(1)
C(4)*e*—C(6)*e*—C(11)*e*	119.4(1)
C(7)*e*—C(6)*e*—C(11)*e*	118.3(1)
C(6)*e*—C(7)*e*—C(8)*e*	120.5(1)
C(7)*e*—C(8)*e*—C(9)*e*	120.4(1)
C(8)*e*—C(9)*e*—C(10)*e*	119.5(1)
C(9)*e*—C(10)*e*—C(11)*e*	120.1(1)
C(6)*e*—C(11)*e*—C(10)*e*	121.0(1)
C(4)*e*—C(12)*e*—C(13)*e*	123.7(1)
C(4)*e*—C(12)*e*—C(17)*e*	118.2(1)
C(13)*e*—C(12)*e*—C(17)*e*	118.1(1)
C(12)*e*—C(13)*e*—C(14)*e*	120.8(1)
C(13)*e*—C(14)*e*—C(15)*e*	120.6(1)
C(14)*e*—C(15)*e*—C(16)*e*	119.2(1)
C(15)*e*—C(16)*e*—C(17)*e*	120.3(1)
C(12)*e*—C(17)*e*—C(16)*e*	121.0(1)
C(2)*e′*—C(1)*e′*—C(1*e′*)*e*	121.4(1)
C(2)*e′*—C(1)*e′*—C(5*e′*)*e*	117.2(1)
C(1*e′*)*e*—C(1)*e′*—C(5*e′*)*e*	121.5(1)
C(1)*e′*—C(2)*e′*—O(3)*e′*	113.4(1)
C(2)*e′*—O(3)*e′*—C(4)*e′*	113.1(1)
O(3)*e′*—C(4)*e′*—C(5)*e′*	108.0(1)
O(3)*e′*—C(4)*e′*—C(6)*e′*	106.3(1)
C(5)*e′*—C(4)*e′*—C(6)*e′*	109.7(1)
O(3)*e′*—C(4)*e′*—C(12)*e′*	109.2(1)
C(5)*e′*—C(4)*e′*—C(12)*e′*	113.9(1)
C(6)*e′*—C(4)*e′*—C(12)*e′*	109.5(1)
C(4)*e′*—C(5)*e′*—C(1*e′*)*e*	111.5(1)
C(4)*e′*—C(6)*e′*—C(7)*e′*	122.0(1)
C(4)*e′*—C(6)*e′*—C(11)*e′*	119.3(1)
C(7)*e′*—C(6)*e′*—C(11)*e′*	118.7(1)
C(6)*e′*—C(7)*e′*—C(8)*e′*	120.5(1)
C(7)*e′*—C(8)*e′*—C(9)*e′*	120.7(1)
C(8)*e′*—C(9)*e′*—C(10)*e′*	119.2(1)
C(9)*e′*—C(10)*e′*—C(11)*e′*	120.4(1)
C(6)*e′*—C(11)*e′*—C(10)*e′*	120.6(1)
C(4)*e′*—C(12)*e′*—C(13)*e′*	124.0(1)
C(4)*e′*—C(12)*e′*—C(17)*e′*	117.5(1)
C(13)*e′*—C(12)*e′*—C(17)*e′*	118.5(1)
C(12)*e′*—C(13)*e′*—C(14)*e′*	120.4(1)
C(13)*e′*—C(14)*e′*—C(15)*e′*	120.5(1)
C(14)*e′*—C(15)*e′*—C(16)*e′*	119.7(1)
C(15)*e′*—C(16)*e′*—C(17)*e′*	119.8(1)
C(12)*e′*—C(17)*e′*—C(16)*e′*	121.0(1)

pathway, which leads to the formation of five-membered rings (Scheme 7).

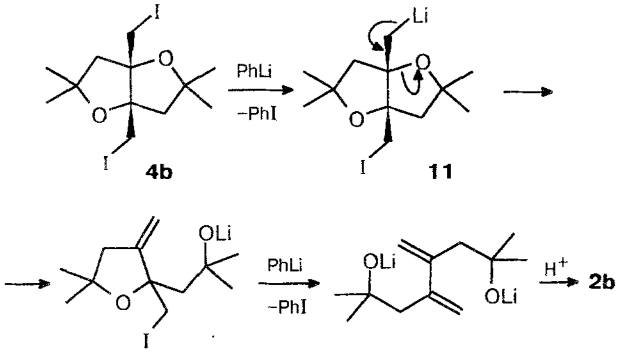
Scheme 7



This is confirmed by the fact that the reaction according to Scheme 6 predominates almost completely in the case of iodination of diene diol **2e** (R = Ph) containing four bulky phenyl groups, when we were unable to isolate the corresponding 2,6-dioxabicyclo[3.3.0]octane compound (**4e**) at all (See Table 1).

It is interesting that 2,6-dioxabicyclo[3.3.0]octane compounds **4** can be transformed back into diene diols **2** by treatment with phenyllithium (Scheme 8).

Scheme 8



The lithium derivatives **11** formed initially undergo β-elimination to give methylene compounds.

Experimental

All operations with organoboron compounds were carried out under dry argon. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker AC-200 spectrometer with working frequencies of 200 MHz for the ^{1}H nuclei and 50.29 MHz for the ^{13}C nuclei. IR spectra were recorded on a UR-20 spectrophotometer. High resolution mass spectra were obtained on a Varian MAT-311A mass spectrometer.

Single crystal of compound **5e** was grown by slow evaporation of its ethereal solution. Single crystals of **5e**: $C_{32}H_{28}O_2$, M = 444.6, triclinic, at −120 °C: a = 9.249(3), b = 10.288(3), c = 13.152(5) Å; α = 89.60(3), β = 71.07(3), γ = 87.03(3)°; V = 1183.1(9) Å^3, d_{calc} = 1.248 g cm^{-3}, space group $P\bar{1}$, Z = 2 (two crystallographically independent molecules **5e** and **5e′** in the centers of inversion). The cell parameters and intensities of 4910 reflections with $I \geq 3\sigma(I)$ were measured on a Siemens P3/PC diffractometer (λMoK_α, graphite monochromator, $\theta/2\theta$-scanning, $2\theta \leq 54°$). The structure was solved by the direct method and refined by the full-matrix least-squares method in the anisotropic approximation for the non-hydrogen atoms. All H atoms were revealed from a difference synthesis and refined isotropically. The final discrepancy factors were R = 0.038, R_w = 0.038. All calculations were performed using the SHELXTL PLUS program.[8] The atomic coordinates are presented in Table 4.

Diene diols **2b—d** were obtained according to the reported method.[6]

3,4-Dimethylene-1,6-hexanediol (2a). A mixture of borane **1** (3.23 g, 11.8 mmol) and paraformaldehyde (0.7 g, 23.6 mmol) in heptane (10 mL) was heated for 12 h at 98 °C. The reaction mixture was then treated with alkaline hydrogen peroxide and extracted with ether. The solvent was distilled off *in vacuo*, and the diol was purified by column chromatography on SiO_2 using ether as the eluent to give 0.18 g of diol **2a** (13 %) as a viscous oil. High resolution mass spectrum, m/z, ion: 142.09909, M$^+$. Calculated for $C_8H_{14}O_2$ 142.09937, M$^+$.

Table 4. Atomic coordinates ($\times 10^4$; for hydrogen atoms, $\times 10^3$) and their equivalent isotropic temperature factors

Atom	*x*	*y*	*z*	*U*
C(1)*e*	−41(1)	4786(1)	4536(1)	20(1)*
C(2)*e*	126(1)	3364(1)	4255(1)	22(1)*
O(3)*e*	625(1)	2573(1)	4984(1)	22(1)*
C(4)*e*	−143(1)	2906(1)	6098(1)	20(1)*
C(5)*e*	320(1)	4284(1)	6274(1)	21(1)*
C(6)*e*	449(1)	1932(1)	6763(1)	21(1)*
C(7)*e*	1382(2)	853(1)	6302(1)	31(1)*
C(8)*e*	1881(2)	−24(1)	6938(1)	36(1)*
C(9)*e*	1471(2)	168(1)	8036(1)	32(1)*
C(10)*e*	558(2)	1242(1)	8502(1)	33(1)*
C(11)*e*	51(2)	2115(1)	7869(1)	28(1)*
C(12)*e*	−1868(1)	2773(1)	6357(1)	20(1)*
C(13)*e*	−2952(1)	3725(1)	6890(1)	26(1)*
C(14)*e*	−4501(2)	3538(1)	7106(1)	33(1)*
C(15)*e*	−4997(2)	2410(1)	6781(1)	34(1)*
C(16)*e*	−3924(2)	1459(1)	6236(1)	32(1)*
C(17)*e*	−2384(2)	1633(1)	6035(1)	27(1)*
C(1)*e*′	4703(1)	9733(1)	10482(1)	18(1)*
C(2)*e*′	4061(1)	8404(1)	10606(1)	21(1)*
O(3)*e*′	3832(1)	7929(1)	9651(1)	21(1)*
C(4)*e*′	5130(1)	8106(1)	8697(1)	18(1)*
C(5)*e*′	5325(1)	9572(1)	8511(1)	19(1)*
C(6)*e*′	4728(1)	7498(1)	7772(1)	19(1)*
C(7)*e*′	3370(1)	6878(1)	7935(1)	22(1)*
C(8)*e*′	3023(1)	6362(1)	7069(1)	26(1)*
C(9)*e*′	4039(2)	6448(1)	6031(1)	28(1)*
C(10)*e*′	5407(2)	7054(1)	5864(1)	28(1)*
C(11)*e*′	5754(1)	7578(1)	6724(1)	25(1)*
C(12)*e*′	6535(1)	7386(1)	8831(1)	19(1)*
C(13)*e*′	7923(1)	7956(1)	8683(1)	25(1)*
C(14)*e*′	9149(2)	7232(1)	8813(1)	31(1)*
C(15)*e*′	8993(2)	5933(1)	9107(1)	32(1)*
C(16)*e*′	7610(2)	5356(1)	9268(1)	31(1)*
C(17)*e*′	6394(1)	6073(1)	9122(1)	25(1)*
H(21)*e*	91(2)	323(1)	354(1)	3(1)
H(22)*e*	−84(1)	304(1)	419(1)	2(1)
H(51)*e*	−26(2)	457(1)	701(1)	3(1)
H(52)*e*	141(2)	424(1)	621(1)	3(1)
H(7)*e*	170(2)	74(2)	553(1)	4(1)
H(8)*e*	257(2)	−77(2)	658(1)	5(1)
H(9)*e*	184(2)	−44(1)	848(1)	4(1)
H(10)*e*	29(2)	139(2)	929(1)	5(1)
H(11)*e*	−62(2)	285(1)	819(1)	4(1)
H(13)*e*	−260(2)	454(1)	712(1)	4(1)
H(14)*e*	−527(2)	421(2)	749(1)	4(1)
H(15)*e*	−606(2)	231(1)	693(1)	4(1)
H(16)*e*	−425(2)	66(2)	600(1)	4(1)
H(17)*e*	−160(2)	96(1)	566(1)	4(1)
H(21)*e*′	302(2)	841(1)	1117(1)	2(1)
H(22)*e*′	473(1)	779(1)	1086(1)	2(1)
H(51)*e*′	630(2)	975(1)	792(1)	2(1)
H(52)*e*′	447(2)	990(1)	826(1)	2(1)
H(7)*e*′	264(2)	681(1)	866(1)	3(1)
H(8)*e*′	206(2)	596(1)	719(1)	3(1)
H(9)*e*′	380(2)	609(1)	544(1)	3(1)
H(10)*e*′	614(2)	712(1)	516(1)	4(1)
H(11)*e*′	674(2)	799(1)	659(1)	3(1)
H(13)*e*′	806(2)	887(1)	849(1)	4(1)
H(14)*e*′	1011(2)	765(1)	869(1)	3(1)
H(15)*e*′	987(2)	545(2)	920(1)	4(1)
H(16)*e*′	748(2)	447(2)	949(1)	4(1)
H(17)*e*′	542(2)	568(1)	921(1)	3(1)

IR, ν/cm^{-1}: 1640 (C=C); 3080 (H_2C=C); 3316 (OH). ^{1}H NMR ($CDCl_3$), δ: 2.53 (t, *J* = 6.71 Hz, 4 H, CH_2); 3.50 (br.s, 2 H, OH); 3.69 (t, *J* = 6.71 Hz, 4 H, CH_2O); 5.06 and 5.16 (both br.s, 4 H, H_2C=). ^{13}C NMR ($CDCl_3$), δ: 37.3 (CH_2); 60.8 (CH_2O); 114.2 (H_2C=); 143.4 (C=).

1,1,6,6-Tetraphenyl-3,4-dimethylene-1,6-hexanediol (2e). A solution of benzophenone (1.24 g, 6.86 mmol) in ether (10 mL) was added at 0 °C to a solution of borane **1** (0.94 g, 3.43 mmol) in ether (10 mL). The reaction mixture was heated to 20 °C and stirred for 2 h. The diol was isolated as in the case of **2a** to give 1.26 g of compound **2e** (82 %). M.p. 128—129 °C (from ether). Found (%): C, 86.01; H, 7.04. $C_{32}H_{30}O_2$. Calculated (%): C, 86.06; H, 6.87. ^{1}H NMR ($CDCl_3$), δ: 2.75 (s, 2 H, OH); 3.1 (s, 4 H, CH_2); 4.4 and 4.8 (br.s, 4 H, H_2C=C); 7.1 and 7.3 (m, 20 H, Ph). ^{13}C NMR ($CDCl_3$), δ: 45.2 (CH_2); 78.0 (C—O); 118.1 (H_2C=); 125.9, 126.7, 128.0 and 146.7 (Ph); 145.4 (C=).

Iodocyclization of 3,4-dimethylene-1,6-hexanediol (2a). A solution of iodine (1.39 g, 5.47 mmol) in ether was added dropwise at 0—5 °C with vigorous stirring to a mixture of compound **2a** (0.26 g, 1.83 mmol) in ether (20 mL) and saturated aqueous $NaHCO_3$ (10 mL), and the mixture was stirred for 10 h. The excess iodine was removed by shaking with an aqueous solution of $Na_2S_2O_3$, the layers were separated, and the aqueous layer was extracted with ether (3 × 10 mL). The combined organic phase was dried with Na_2SO_4 and concentrated *in vacuo*. The residue was separated by column chromatography on SiO_2 using ether/hexane (1 : 5) as the eluent to give compounds **4a**, **3a**, and **5a**.

1) **1,5-*cis*-Bis(iodomethyl)-2,6-dioxabicyclo[3.3.0]octane (4a),** yield 0.08 g (11 %), m.p. 64—65 °C. High resolution mass spectrum, *m/z*, ion: 393.8926, M$^+$. Calculated for $C_8H_{12}O_2I_2$: 393.892614, M$^+$. ^{1}H NMR ($CDCl_3$), δ: 2.3 (m, 4 H, CH_2); 3.31 and 3.50 (both dm, $^2J_{AB}$ = 10.5 Hz, 4 H, CH_2); 3.95 (m, 4 H, CH_2O). ^{13}C NMR ($CDCl_3$), δ: 10.1 (CH_2I); 40.8 (C-4, C-8); 66.6 (C-3, C-7); 90.0 (C-1, C-5).

2) **2-(2-Hydroxyethyl)-2-iodomethyl-3-methylenetetrahydrofuran (3a),** yield 0.06 g (12 %). ^{1}H NMR ($CDCl_3$), δ: 1.92 and 2.26 (both dm, $^2J_{AB}$ = 14.0 Hz, 2 H, CH_2); 2.88 (m, 2 H, H_2C—C=C); 3.28 and 3.40 (both d, $^2J_{AB}$ = 10.5 Hz, 2 H, CH_2I); 3.72 (m, 2 H, CH_2OH); 3.96 (m, 2 H, CH_2O); 4.93 and 5.18 (both m, 2 H, CH_2=C). ^{13}C NMR ($CDCl_3$), δ: 15.4 (CH_2I); 33.3 and 39.9 (CH_2); 59.2 and 65.45 (CH_2O); 84.2 (C); 107.4 (H_2C=); 150.3 (C=).

3) **3,8-Dioxabicyclo[4.4.0]oct-1(6)-ene (5a),** yield 0.03 g (12 %), m.p. 56—57 °C. High resolution mass spectrum, *m/z*, ion: 140.08378, M$^+$. Calculated for $C_8H_{12}O_2$: 140.08366, M$^+$. ^{1}H NMR ($CDCl_3$), δ: 1.92 (s, 4 H, CH_2); 3.83 (t, *J* = 5.5 Hz, 4 H, CH_2O); 3.94 (s, 4 H, OCH_2—C=C). ^{13}C NMR ($CDCl_3$), δ: 24.9 (C-5, C-10); 64.4 (C-2, C-7); 67.7 (C-4, C-9); 125.4 (C-1, C-6).

Iodocyclization of 4,5-dimethylene-2,7-dimethyl-2,7-octanediol (2b). Similarly, the reaction of compound **2b** (0.68 g, 3.43 mmol) and iodine (2.61 g, 10.3 mmol) followed by chromatographic separation gave compounds **4b**, **3b**, and **5b**.

1) **1,5-*cis*-Di(iodomethyl)-3,3,7,7-tetramethyl-2,6-dioxabicyclo[3.3.0]octane (4b),** yield 0.24 g (15 %), m.p. 105—107 °C (from hexane). High resolution mass spectrum, *m/z*, ion: 434.92921, [M—CH_3]$^+$. Calculated for $C_{11}H_{17}O_2I_2$: 434.93170, [M—CH_3]$^+$. ^{1}H NMR ($CDCl_3$), δ: 1.29 and 1.40 (both s, 12 H, CH_3); 1.86 and 2.23 (both d, $^2J_{AB}$ = 13.8 Hz, 4 H, CH_2); 3.22 and 3.32 (both d, $^2J_{AB}$ = 10.4 Hz, 4 H, CH_2I). ^{13}C NMR ($CDCl_3$), δ: 11.9 (CH_2I); 29.8 (CH_3); 31.8 (CH_3); 51.3 (C-4, C-8); 80.6 (C-3, C-7); 92.1 (C-1, C-5).

2) **2-(2-Hydroxy-2-methylpropyl)-2-iodomethyl-5,5-dimethyl-3-methylenetetrahydrofuran (3b),** yield 0.03 g (3 %). ^{1}H NMR ($CDCl_3$), δ: 1.27, 1.29, 1.42 and 1.47 (all s, 12 H, CH_3); 1.96 and 2.12 (both d, $^2J_{AB}$ = 12.5 Hz, 2 H, CH_2); 2.46 (m, 2 H, $H_2C—C{=}C$); 3.80 and 3.93 (both d, $^2J_{AB}$ = 9.0 Hz, 2 H, CH_2I); 5.00 (m, 2 H, $CH_2{=}C$).

3) **4,4,9,9-Tetramethyl-3,8-dioxabicyclo[4.4.0]dec-1(6)-ene (5b),** yield 0.22 g (33 %), m.p. 54—55 °C (from hexane). High resolution mass spectrum, *m/z*, ion: 196.14646, M^+. Calculated for $C_{12}H_{20}O_2$: 196.14622, M^+. ^{1}H NMR ($CDCl_3$), δ: 1.22 (s, 12 H, CH_3); 1.80 (s, 4 H, CH_2); 3.95 (s, 4 H, CH_2O). ^{13}C NMR ($CDCl_3$), δ: 26.3 (CH_3); 35.5 (C-5, C-10); 63.8 (C-2, C-7); 70.3 (C-4, C-9); 122.7 (C-1, C-6).

Iodocyclization of 1,4-bis(1-hydroxycyclopentyl)-2,3-dimethylenebutane (2c). The reaction of diol **2c** (0.87 g, 3.47 mmol) and iodine (2.6 g, 10.42 mmol) according to the above procedure gave compounds **3c**, **4c**, and **5c**.

1) **1,5-*cis*-Bis(iodomethyl)-3,3,7,7-bis(tetramethylene)-2,6-dioxabicyclo[3.3.0]octane (4c),** yield 0.44 g (25 %), m.p. 42—43 °C (from hexane). High resolution mass spectrum, *m/z*, ion: 501.98325, M^+. Calculated for $C_{16}H_{24}O_2I_2$: 501.98644, M^+. ^{1}H NMR ($CDCl_3$), δ: 1.4—2.0 (m, 16 H, $(CH_2)_4$); 2.06 and 2.46 (both d, $^2J_{AB}$ = 13.8 Hz, 4 H, CH_2); 3.27 and 3.35 (both d, $^2J_{AB}$ = 10.3 Hz, 4 H, CH_2I). ^{13}C NMR ($CDCl_3$), δ: 11.5 (CH_2I); 23.3, 23.4, 40.0 and 41.5 ($(CH_2)_4$); 50.5 (C-4, C-8); 90.0 (C-3, C-7); 91.3 (C-1, C-5).

2) **2-(2-Hydroxy-2,2-tetramethyleneethyl)-2-iodomethyl-3-methylene-5,5-tetramethylenetetrahydrofuran (3c),** yield 0.06 g (45 %). ^{1}H NMR ($CDCl_3$), δ: 1.4—2.0 (m, 16 H, $(CH_2)_4$); 2.09 and 2.20 (both d, $^2J_{AB}$ = 12.5 Hz, 2 H, CH_2); 2.53 (m, 2 H, $H_2C—C{=}C$); 3.75 and 3.86 (both d, $^2J_{AB}$ = 9.4 Hz, 2 H, CH_2I); 4.96 (m, 2 H, $CH_2{=}C$).

3) **4,4,9,9-Bis(tetramethylene)-3,8-dioxabicyclo[4.4.0]dec-1(6)-ene (5c),** yield 0.21 g (24 %), m.p. 95—96 °C (from hexane). High resolution mass spectrum, *m/z*, ion: 248.17848, M^+. Calculated for $C_{16}H_{24}O_2$: 248.1775, M^+. ^{1}H NMR ($CDCl_3$), δ: 1.3—1.8 (m, 16 H, $(CH_2)_4$); 1.90 (s, 4 H, CH_2); 3.95 (s, 4 H, CH_2O). ^{13}C NMR ($CDCl_3$), δ: 23.8 and 36.5 ($(CH_2)_4$); 34.1 (C-5, C-10); 64.3 (C-2, C-7); 82.0 (C-4, C-9); 124.0 (C-1, C-6).

Iodocyclization of 1,4-bis(1-hydroxycyclohexyl)-2,3-dimethylenebutane (2d). The reaction of diol **2d** (1.1 g, 3.95 mmol) and iodine (3 g, 11.85 mmol) followed by column chromatography gave compounds **3d**, **4d**, and **5d**.

1) **1,5-*cis*-Bis(iodomethyl)-3,3,7,7-bis(pentamethylene)-2,6-dioxabicyclo[3.3.0]octane (4d),** yield 0.66 g (32 %), m.p. 79—80 °C (from hexane). High resolution mass spectrum, *m/z*, ion: 530.01932, M^+. Calculated for $C_{18}H_{28}O_2I_2$: 530.01772, M^+. ^{1}H NMR ($CDCl_3$), δ: 1.0—1.7 (m, 20 H, $(CH_2)_5$); 1.74 and 2.46 (both d, $^2J_{AB}$ = 13.5 Hz, 4 H, CH_2); 3.24 and 3.32 (both d, $^2J_{AB}$ = 10.4 Hz, 4 H, CH_2I). ^{13}C NMR ($CDCl_3$), δ: 12.8 (CH_2I); 23.4, 23.5, 24.6, 37.9, and 41.1 ($(CH_2)_5$); 48.8 (C-4, C-8); 82.4 (C-3, C-7); 90.37 (C-1, C-5).

2) **2-(2-Hydroxy-2,2-pentamethyleneethyl)-2-iodomethyl-3-methylene-5,5-tetramethylenetetrahydrofuran (3d),** yield 0.19 g (12 %). ^{1}H NMR ($CDCl_3$), δ: 1.0—1.7 (m, 20 H, $(CH_2)_5$); 1.83 and 2.10 (both d, $^2J_{AB}$ = 12.5 Hz, 2 H, CH_2); 2.42 (m, 2 H, $H_2C—C{=}C$); 3.75 and 3.88 (both d, $^2J_{AB}$ = 9.0 Hz, 2 H, CH_2I); 4.97 (m, 2 H, $CH_2{=}C$).

3) **4,4,9,9-Bis(pentamethylene)-3,8-dioxabicyclo[4.4.0]-dec-1(6)-ene (5d),** yield 0.49 g (45 %), m.p. 138—139 °C (from hexane). High resolution mass spectrum, *m/z*, ion: 276.20846, M^+. Calculated for $C_{18}H_{28}O_2$: 276.20878, M^+. ^{1}H NMR ($CDCl_3$), δ: 1.2—1.8 (m, 20 H, $(CH_2)_5$); 1.74 (s, 4 H, CH_2); 3.84 (s, 4 H, CH_2O). ^{13}C NMR ($CDCl_3$), δ: 21.8, 26.05, and 34.8 ($(CH_2)_5$); 34.8 (C-5, C-10); 62.9 (C-2, C-7); 71.1 (C-4, C-9); 122.25 (C-1, C-6).

Iodocyclization of 3,4-dimethylene-1,1,6,6-tetraphenyl-1,6-hexanediol (2e). The reaction of compound **2e** (0.2 g, 0.447 mmol) with iodine (0.34 g, 1.341 mmol) followed by chromatographic separation gave compounds **3e** and **5e**.

1) **2-(2-Hydroxy-2,2-diphenylethyl)-2-iodomethyl-3-methylene-5,5-diphenyltetrahydrofuran (3e),** yield 0.02 g (8 %). ^{1}H NMR ($CDCl_3$), δ: 2.71 and 3.05 (both d, $^2J_{AB}$ = 13.0 Hz, 2 H, CH_2); 3.32 (m, 2 H, $H_2C—C{=}C$); 3.85 and 4.10 (both d, $^2J_{AB}$ = 10.5 Hz, 2 H, CH_2I); 4.71 and 5.01 (both m, 2 H, $CH_2{=}C$); 7.1—7.8 (m, 20 H, Ph).

2) **4,4,9,9-Tetraphenyl-3,8-dioxabicyclo[4.4.0]dec-1(6)-ene (5e),** yield 0.15 g (75.5 %), m.p. 218—219 °C (from ether). High resolution mass spectrum, *m/z*, ion: 444.20676, M^+. Calculated for $C_{32}H_{28}O_2$: 444.20878, M^+. ^{1}H NMR ($CDCl_3$), δ: 2.5 (s, 4 H, CH_2); 4.00 (s, 4 H, CH_2O); 7.1—7.4 (m, 20 H, Ph). ^{13}C NMR ($CDCl_3$), δ: 33.9 (C-5, C-10); 63.7 (C-2, C-7); 78.4 (C-4, C-9); 124.6 (C-1, C-6); 126.3, 126.7, 128.0 and 144.9 (Ph).

4,4,9,9-Tetramethyl-3,8-dioxacyclodecane-1,6-dione (9). A solution of compound **5b** (0.19 g, 1 mmol) in CH_2Cl_2 (5 mL) was saturated with ozone at −78 °C until a weak blue color appeared. The reaction mixture was purged with a stream of oxygen until the solution discolored, and dimethylsulfide (0.5 mL) was cautiously added. When the temperature of the solution reached ~20 °C, the solvent was removed *in vacuo*, and residue was purified by column chromatography on SiO_2 using ether/hexane (1 : 10) as the eluent. Yield 0.17 g (76 %), m.p. 213—215 °C (from hexane). Found (%): C, 63.14; H, 8.80. $C_{12}H_{20}O_4$. Calculated (%): C, 63.13; H, 8.83. High resolution mass spectrum, *m/z*, ion: 228.13689, M^+. Calculated for $C_{12}H_{20}O_4$: 228.13604, M^+. IR, ν/cm^{-1}: 1700 (C=O). ^{1}H NMR ($CDCl_3$), δ: 1.23 (s, 12 H, CH_3); 2.76 (s, 4 H, CH_2); 4.00 (s, 4 H, CH_2O). ^{13}C NMR ($CDCl_3$), δ: 27.1 (CH_3); 45.8 (CH_2); 69.9 (CH_2O); 75.6 (C—O); 209.5 (C=O).

Reaction of 1,5-*cis*-bis(iodomethyl)-3,3,7,7-tetramethyl-2,6-dioxabicyclo[3.3.0]octane (4b) with PhLi. A solution of PhLi 11.3 mL, 0.6 M) in ether was added dropwise at 20 °C to a solution of compound **4b** (1.55 g, 3.44 mmol) in ether (20 mL). The mixture was stirred for 2 h; then 5 % HCl (20 mL) was added. The organic layer was separated, and the aqueous phase was extracted with ether (3 × 10 mL). The combined ethereal extracts were dried with Na_2SO_4, and the solvent was removed *in vacuo*. Recrystallization of the residue from hexane gave 0.5 g (75 %) of compound **2b**, m.p. 81—82 °C. The ^{1}H and ^{13}C NMR spectra were identical to those reported previously.[5]

This study was financially supported by the Russian Foundation for Basic Research (Grant No. 94-03-18193) and the International Science Foundation (Grant No. M3Y000).

References

1. D. J. Faulkner, *Nat. Prod. Rep.*, 1987, **4**, 539.
2. R. Kinnel, A. J. Duggan, T. Eisner, and J. Meinwald, *Tetrahedron Lett.*, 1977, 3913.
3. S. D. Rychnowsky and P. B. Bartlett, *J. Am. Chem. Soc.*, 1981, **103**, 3963.
4. T. L. B. Boivin, *Tetrahedron*, 1987, **43**, 3309.

5. M. E. Gurskii, S. B. Golovin, and Yu. N. Bubnov, *Izv. Akad. Nauk SSSR, Ser. Khim.*, 1990, 495 [*Bull. Acad. Sci. USSR, Div. Chem. Sci.*, 1990, **39**, 433 (Engl. Transl.)].
6. M. E. Gurskii, S. B. Golovin, and Yu. N. Bubnov, *Izv. Akad. Nauk, Ser. Khim.*, 1993, 155 [*Russ. Chem. Bull.*, 1993, **42**, 139 (Engl. Transl.)].
7. M. E. Gurskii, A. V. Geiderikh, S. B. Golovin, A. V. Ignatenko, and Yu. N. Bubnov, *Izv. Akad. Nauk, Ser. Khim.*, 1993, 236 [*Russ. Chem. Bull.*, 1993, **42**, 215 (Engl. Transl.)].
8. W. Robinson and G. M. Scheldrick, SHELX, in: *Crystallographic Computing Techniques and New Technologies,* Eds. N. W. Isaacs and M. R. Taylor, Oxford Univ. Press, 1988, 366.
9. F. H. Allen, O. Kennard, D. G. Watson, L. Brammer, M. G. Orpen, and R. Taylor., *J. Chem. Soc. Perkin Trans., II*, 1987, S1.

Received July 22, 1994