Reactions of α-Hydroxy Ketones with Glycerol, 1-Thioglycerol and *meso*-Erythritol

Inger Reidun Fjeldskaar, David Grace, Christian Rømming and Lars Skattebøl*

Department of Chemistry, University of Oslo, N-0315 Oslo 3, Norway

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The treatment of cyclic α-hydroxy ketones with glycerol in the presence of *p*-toluenesulfonic acid afforded tricyclic ethers stereospecifically in each case. Similar reactions using 1-thioglycerol afforded the corresponding sulfur analogues as mixtures of stereoisomers. Analogous results were obtained from reactions of 3-hydroxy-2-butanone with glycerol and 1-thioglycerol, respectively. The yields were high in all reactions. On the other hand, *meso*-erythritol and cyclic α-hydroxy ketones gave the corresponding bis(dihydrodioxin) derivatives in good yields. The mechanism of the reactions is discussed.

X-ray structure determinations were carried out for two compounds:

7,11,12-Trioxatricyclo[7.2.1.$0^{1,6}$]dodecane. Orthorhombic, space group $P\ c\ a\ 2_1$, a = 9.024(3), b = 12.105(4), c = 7.744(3) Å, Z = 4. Least-squares refinement of 109 parameters gave R = 0.070 for 553 observed [I > 2.5 σ (I)] reflections.

4,5-Dimethyl-6,8-dioxa-3-thiabicyclo[3.2.1]octane. Orthorhombic, space group $P\ b\ c\ a$, a = 10.731(1), b = 7.595(1), c = 19.074(2) Å, Z = 8. Least-squares refinement of 91 parameters gave R = 0.036 for 2602 observed [I > 2.5 σ (I)] reflections.

In a recent paper[1] we described a convenient method for the preparation of bicyclic dihydro-1,4-dioxins, dihydro-1,4-oxathiins, dihydro-1,4-dithiins and related compounds, comprising the acid-catalysed treatment of cyclic α-hydroxy ketones with diols, hydroxy thiols and dithiols, respectively. The reaction was originally described in 1959 by Summerbell and Berger[2] who obtained 2,3-diphenyldihydro-1,4-dioxin (**1**) from benzoin and ethylene glycol, and a few additional examples of aryl-substituted dihydrodioxins have since been prepared by the same procedure.[3] We have shown[4] that alkyl-substituted dihydrodioxins and their sulfur analogues can be prepared in excellent yields by the same procedure. In this paper reactions of polyhydric alcohols and thiols with α-hydroxy ketones are described.

The reactions were carried out as previously reported,[1] by heating benzene solutions of the reagents under reflux using *p*-toluenesulfonic acid as catalyst, and they were followed by gas chromatography (GLC). The products were purified by flash chromatography and in most cases characterised on the basis of spectroscopic data.

Treatment of the cyclic α-hydroxy ketones **2** with glycerol gave in each case a single product after heating for several hours under reflux. The product from **2a** was obtained as a low-melting solid in 89 % yield. The molecular mass was 170 and no absorption bands characteristic of hydroxyl groups, carbonyl groups or double bonds were present in the IR spectrum. In the ^{1}H NMR spectrum, eight protons exhibited a multiplet at δ 1.71 while six protons gave rise to absorption in the region δ 3.46–4.41, indicating them to be positioned on carbons adjacent to oxygen atoms. Two of these were tertiary while all the remaining protons were secondary according to the ^{13}C NMR DEPT spectrum. The latter also showed

*To whom correspondence should be addressed.

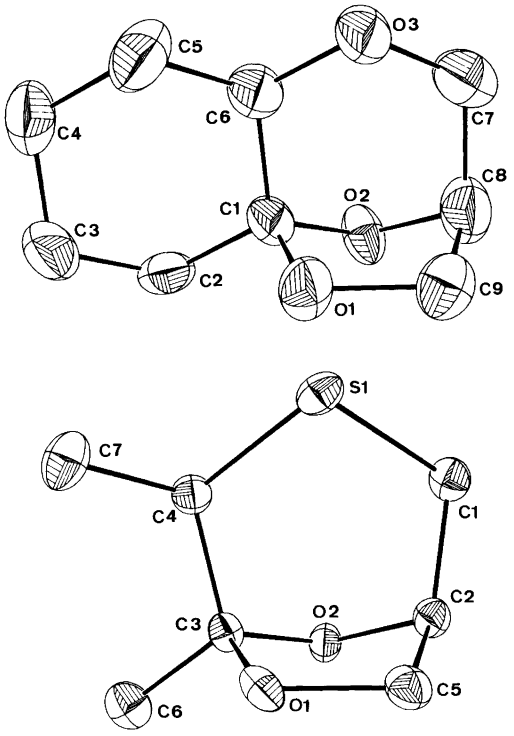


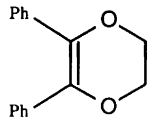
Fig. 1. ORTEP plot of the structures of $C_9H_{14}O_3$ (*3a*) and $C_7H_{12}O_2S$ (*9*). Hydrogen atoms are omitted for clarity.

the presence of one quaternary carbon (δ 105.9). This information is consistent with one of the stereoisomers of either **3a** or **4**. The spectroscopic data do not distinguish unequivocally between these alternatives, and a structure determination by X-ray diffraction was therefore undertaken. The compound proved to be the isomer **3a** with the two six-membered rings *trans*-annelated (Fig. 1).

Compounds **3b–d** were obtained in a similar way as sole products in better than 80 % yields. The spectroscopic data for these compounds are quite similar to those for **3a** and hence we assume that they incorporate the 1,3-dioxolane moiety and that the two remaining rings are fused in a *trans* configuration. Furthermore, the reaction of 3-hydroxy-2-butanone with glycerol gave a single product in 82 % yield to which we have assigned the structure **5**. Its spectral data correlate well with those of compound **3a**.

By following the reactions of the acyloins **2c** and **2d** by GLC we observed in both cases the initial formation of an intermediate with a considerably higher retention time than that of the product. Since the subsequent reaction to give the final product was quite slow, we could stop the reaction while the intermediate was still a major component and it could be easily isolated by flash chromatography on neutral alumina. Both compounds exhibited strong hydroxyl absorption in the IR spectra, and the NMR spectra were fully consistent with the hemiacetal structures **6c** and **6d**, respectively. An ion corresponding to the molecular mass was not recorded in the mass spectrum even under chemical ionisation conditions; the major ion corresponds to the loss of water from the molecular ion, which is not surprising considering the presence of the labile tertiary hydroxyl group of the hemiacetal moiety. Although compounds **6** appear to be homogeneous by GLC, the spectral data do not establish stereochemical purity.

The thiyl group is a significantly stronger nucleophile than the hydroxyl group. We therefore expected 3-mercapto-1,2-propanediol (thioglycerol) to react with an α-hydroxy ketone initially at the carbonyl function. If an intramolecular reaction similar to that observed with glycerol were to take place the anticipated product from **2** would be compound **7**, although formation of the isomer **8** could not *a priori* be excluded; however, the two structural isomers would be easily distinguishable spectroscopically by the presence of a tertiary proton adjacent to sulfur in the former, although ascertainment of stereochemistry would remain a problem. Treatment of 2-hydroxycyclohexanone (**2a**) with thioglycerol gave a liquid in 88 % yield consisting of two components in a ratio of 62:38 as shown by capillary GLC. The retention times were too close for successful separation of the compounds on a preparative scale. The ^1H and ^{13}C NMR spectra of the mixture were consistent with the presence of both stereoisomers of **7a**. The major component was identified as the isomer with the two six-membered rings *trans*-annelated. This assignment was based on the observation that C-8 in the major isomer was deshielded by 4.4 ppm as compared with the same carbon in the minor isomer. Models show that the only significant influence on the shift of C-8 will be due to the orientation of C-5; this is γ-gauche (hence shielding) in the *cis* isomer but γ-*trans* in the *trans* isomer.



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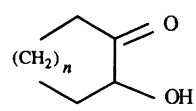

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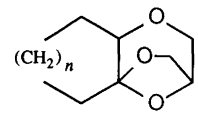

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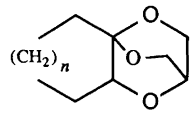

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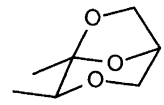

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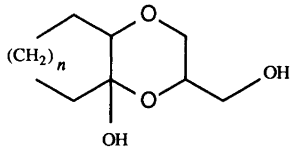

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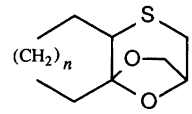

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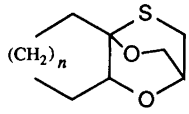

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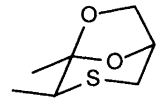

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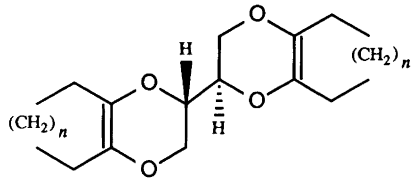

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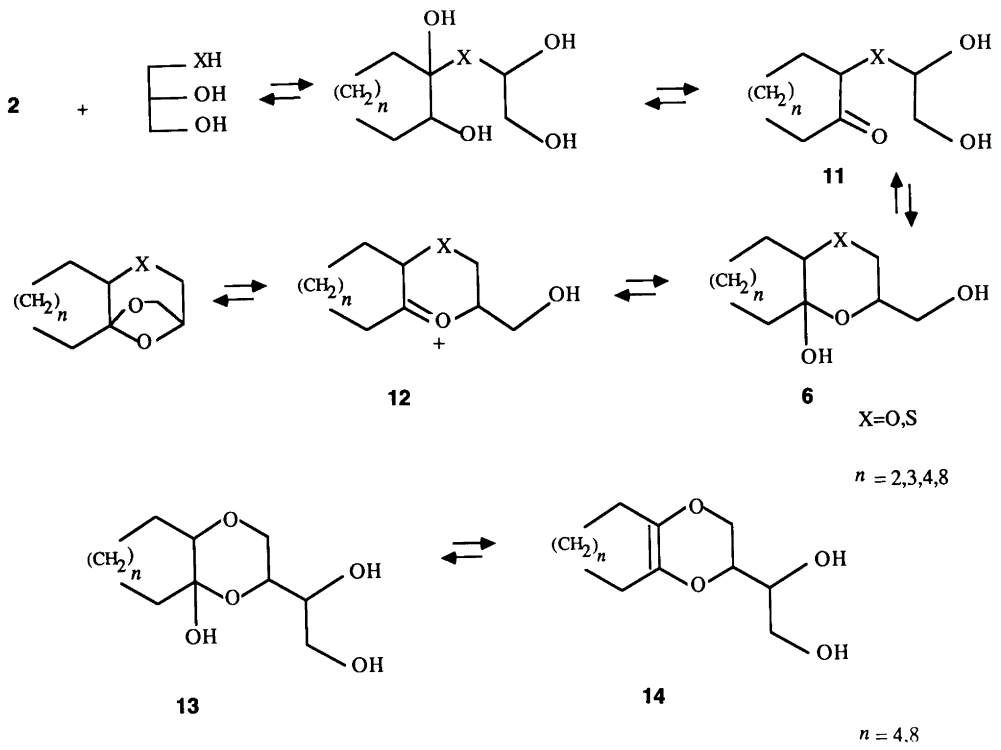
a: $n = 2$
b: $n = 3$
c: $n = 4$
d: $n = 8$

The assignments of the C-8 resonances were made by first identifying the H-8 resonances with the help of a homocorrelated 2D (COSY) spectrum and then performing a heterocorrelated 2D experiment. Further support for these stereochemical assignments was obtained from proton–proton N.O.E. measurements. Only in the case of the major component could an N.O.E. be detected at H-6 when H-8 protons were irradiated; the H-8 proton causing the N.O.E. was that giving a doublet resonance at δ 3.34. A similar result was obtained for reaction of the acyloin **2b** with the thioglycerol. The reaction produced an 89:11 mixture of the stereoisomers **7b** in 89 % yield. Also in this case separation of the isomers was not accomplished. However, reaction of 3-hydroxy-2-butanone with the thioglycerol gave an 82:18 mixture of isomers **9** in 78 % yield, from which the major component was separated as a crystalline compound, m.p. 44–46 °C; a structural determination by X-ray diffraction established the configuration as being that with the methyl groups *trans* (Fig. 1). We conclude that the major components of the above mixtures are the *trans*-fused stereoisomers.

The reaction of *meso*-erythritol with the acyloin **2c** took a course other than that in the examples given above. A viscous, homogenous liquid



Scheme 1.

was obtained in 75 % yield. Strong absorption at 1690 cm^{-1} indicated the presence of a dihydrodioxin component or a carbonyl group. The former was substantiated by the NMR spectra, which exhibited absorption characteristic of methylene groups adjacent to oxygen, a signal at δ 128.9 due to quaternary olefinic carbons, and the absence of signals for carbonyl carbons. A signal at δ 74.2 was assigned to a tertiary carbon adjacent to oxygen. This evidence and the appearance of a molecular ion at *m/z* 334 in the mass spectrum are in agreement with the dimeric dihydrodioxin structure **10c** for this product. The configuration should be that of the starting erythritol, viz. *meso*. A similar reaction of the acyloin **3d** gave the dimer **10d** as a viscous liquid in 77 % yield.

A rationalization of the above results is depicted in Scheme 1. A mechanism has been proposed[1] that explains the formation of dihydrodioxins from acyloins and ethylene glycol, embracing the sulfur analogs as well. On the reasonable assumption that reactions of glycerol and thioglycerol with acyloins follow a similar path, the initial reaction will lead to the ketone **11**, which by a non-stereospecific intramolecular cyclisation involving the secondary hydroxyl group gives rise to the hemiacetal **6**; formation of a six-membered ring is strongly preferred, and no reaction of the primary hydroxyl group was observed at this stage. The hemiacetal may eliminate water, forming the corresponding hydroxymethyldihydrodioxin, or undergo an intramolecular cyclisation to the observed tricyclic compounds. The last step may proceed via the stabilized carbenium ion **12** or by direct displacement. In either case a mixture of stereoisomers may result. The reactions are most probably thermodynamically controlled, and thermochemical data could explain why reactions with glycerol were apparently stereoselective while mixtures were obtained with thioglycerol. We had hoped that molecular mechanics calculations using the MM2 program should have been informative on this point, but the results were not conclusive. Formation of the bis(dihydrodioxin) compounds

Table 1. Crystal and experimental data.

Compound	$C_9H_{14}O_3$ (**3a**)	$C_7H_{12}O_2S$ (**9**)
Diffractometer	NICOLET *P3/F*	NICOLET *P3/F*
Crystal size/mm	0.1×0.1×0.4	0.13×0.4×0.5
Crystal system	Orthorhombic	Orthorhombic
a/Å	9.024(3)	10.731(1)
b/Å	12.105(4)	7.595(1)
c/Å	7.744(3)	19.074(2)
V/Å^3	845.2(5)	1554.4(3)
Temp./°C	−116	−116
Space group	$Pca2_1$ (No. 29)	*Pbca* (No. 61)
M	179.21	160.23
Z	4	8
F(000)	368	688
D_x/g cm^{-3}	1.337	1.369
μ(Mo*K*α)/cm^{-1}		3.47
Scan mode	θ/2θ	θ/2θ
Scan speed (2θ)/°min^{-1}	2–4	2–6
Scan range (2θ)/°	2.2	1.9
Maximum sinθ/λ/Å^{-1}	0.65	0.81
No. of indep. meas.	1357	2686
No. with $I > 3.0\sigma(I)$	553	2602
Correction for absorption	No	Empirical
$R = \Sigma\|F_o - F_c\|/\Sigma F_o$	0.070	0.036
$R_w = [\Sigma w(F_o - F_c)_2^2/\Sigma w F_o^2]^{\frac{1}{2}}$	0.054	0.042
$S = [\Sigma w(F_o - F_c)^2/(n-m)]^{\frac{1}{2}}$	2.2	2.06

10 shows that elimination of water from **13** to give the corresponding dihydrodioxin **14** may be the favoured process, leaving two hydroxyl groups available to react with a second molecule of acyloin to give the observed products.

Structural determination by X-ray diffraction. X-ray analyses proved the structures of compounds **3a** and **9** to be those depicted in Fig. 1.

In molecule **3a**, a cyclohexane ring is fused to a 1,4-dioxane ring in a *trans* configuration and a $-CH_2-O-$ bridge forms a 1,3-dioxolane ring. The former two rings are in the chair conformation; the 1,3-dioxolane ring has an envelope conformation with one oxygen atom out of the plane of the other four ring atoms. The torsion angle about the O1–C9 bond is 1.0°.

The bond lengths and angles (Table 3) are normal within the accuracy of the structure determination. The fairly low accuracy is due to a large thermal motion of the molecules in the crystal leading to a scarcity of intensity data. The thermal parameters given for **3a** in Table 2 correspond to r.m.s. amplitudes of 0.2–0.25 Å, which is unusually large when a data set is collected with a temperature of −116 °C at the crystal site. The reason is probably the spheroidal shape of the molecule, allowing large librational motions of the rather rigid molecule.

In molecule **9**, the 1,4-oxathiane ring is bridged by a $-CH_2-O-$ group forming a 1,3-dioxolane ring as in **3a**; the torsional angle about the O1–C5 bond is 4.0°. The two methyl substituents are both in equatorial positions.

The bond lengths and angles (Table 3) are normal, and since the thermal effect is not as large as that found for **3a**, the accuracy of the determination is correspondingly higher.

Experimental

General. The instruments employed have been described elsewhere.[1] Commercially available reagents and solvents were purified and dried when necessary by usual methods. The α-hydroxy ketones were prepared according to literature procedures.

Reactions of α-hydroxy ketones. General procedure. A solution of the α-hydroxy ketone **2** (1

Table 2. Fractional atomic coordinates and U_{eq} (mean value of U_{ij}).

Atom	*x*	*y*	*z*	U_{eq}
$C_9H_{14}O_3$ (**3a**)				
O1	.4871(5)	.2196(3)	.3080	.041
O2	.7023(4)	.3079(3)	.2230(8)	.039
O3	.4334(5)	.4002(3)	.0999(7)	.048
C1	.5835(7)	.2404(5)	.1582(9)	.040
C2	.6454(7)	.1325(5)	.0894(10)	.045
C3	.5188(10)	.0648(5)	.0082(9)	.056
C4	.4355(8)	.1266(5)	−.1256(10)	.055
C5	.3753(7)	.2360(6)	−.0518(10)	.057
C6	.4976(9)	.3027(5)	.0274(10)	.044
C7	.5381(8)	.4596(5)	.1992(11)	.058
C8	.6174(8)	.3873(5)	.3245(12)	.055
C9	.5059(8)	.3120(5)	.4220(8)	.040
$C_7H_{12}O_2S$ (**9**)				
S1	.12132(3)	.11730(4)	.17598(1)	.023
O1	−.16008(8)	.15456(10)	.15453(4)	.022
O2	−.08250(7)	−.05871(10)	.08363(4)	.020
C1	.06945(11)	−.11022(15)	.17512(6)	.023
C2	−.06650(11)	−.12403(14)	.15400(6)	.020
C3	−.09025(10)	.12706(14)	.09166(5)	.019
C4	.04175(10)	.20352(15)	.09855(6)	.021
C5	−.15351(11)	−.00451(15)	.19519(6)	.022
C6	−.16138(12)	.20133(18)	.02998(6)	.028
C7	.04390(14)	.40321(17)	.10550(7)	.030

equiv.), the glycerol derivative (1.3 equiv.) and *p*-toluenesulfonic acid (15 mg per mmol of **2**) in benzene (~15 ml per mmol of **2**) was heated under reflux while water was collected using a Dean-Stark trap. The reaction was monitored by GLC and the time required for completion is indicated below for each compound. The acid was neutralized with 10 % $NaHCO_3$ solution, and the organic phase was dried ($MgSO_4$) and evaporated to dryness under vacuum. The residue was purified by flash chromatography on neutral alumina (100–120 mesh) and recrystallized when appropriate.

7,11,12-Trioxatricyclo[7.2.1.0^{1,6}]dodecane (**3a**). The compound was obtained from 2-hydroxycyclohexanone (**2a**) and glycerol as a solid in 89 % yield, m.p. 26–27 °C (from pet. ether), after 10 h reaction time. IR(film): 1450, 1220, 1090, 1040, 650 cm^{-1}. ^1H HMR (300 MHz, $CDCl_3$): δ 1.71 (m, 'H), 3.46 (dd, 1H), 3.64 (dd, 1H), 3.86 (m, 1H), 3.98 (d, 1H), 4.21 (d, 1H), 4.41 (d, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 23.01, 23.64, 29.31, 32.08 (CH_2), 67.41, 69.81 (CH_2–O), 74.29, 78.86 (CH–O), 105.88 (O–C–O). GC/MS(CI): *m/z* 171 (100, M^+ + 1).

8,12,13-Trioxatricyclo[8.2.1.0^{1,7}]tridecane (**3b**). The compound was obtained from 2-hydroxycycloheptanone (**2b**) and glycerol as a viscous liquid in 81 % yield after 5 h reaction time. IR (film): 1450, 1215, 1115, 1020 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 1.62 (m, 10H), 3.50 (dd, 1H), 3.61 (d, 1H), 3.87 (m, 2H), 4.13 (d, 1H), 4.41 (d, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 20.83, 24.04, 27.75, 29.97, 34.88 (CH_2), 67.77, 69.45 (CH_2–O), 74.52, 82.49 (CH–O), 108.52 (O–C–O). GC/MS (CI): *m/z* 185 (100, M^++1).

9,13,14-Trioxatricyclo[9.2.1.0^{1,8}]tetradecane (**3c**). The compound was obtained from 2-hydroxycyclooctanone (**2c**) and glycerol as a viscous liquid in 87 % yield after 6 h reaction time. IR (film): 1435, 1195, 1100, 1015 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 1.62 (m, 11H), 1.98 (m, 1H), 3.62 (d, 1H), 3.72 (d, 1H), 3.87 (m, 2H), 4.15 (d, 1H),

Table 3. Bond lengths (Å), bond angles (°) and selected torsion angles (°).

$C_9H_{14}O_3$ (**3a**)

Bond		Bond	
O1 C1	1.47(1)	O1 C9	1.44(1)
O2 C1	1.44(1)	O2 C8	1.46(1)
O3 C6	1.43(1)	O3 C7	1.41(1)
C1 C2	1.52(1)	C1 C6	1.48(1)
C2 C3	1.54(1)	C3 C4	1.48(1)
C4 C5	1.54(1)	C5 C6	1.50(1)
C7 C8	1.49(1)	C8 C9	1.55(1)

Angle		Angle	
C1 O1 C9	106.4(5)	C1 O2 C8	99.9(5)
C6 O3 C7	111.3(5)	O1 C1 O2	105.2(6)
O1 C1 C2	110.3(5)	O1 C1 C6	108.4(6)
O2 C1 C2	109.8(5)	O2 C1 C6	109.8(5)
C2 C1 C6	113.0(6)	C1 C2 C3	109.2(6)
C2 C3 C4	113.1(6)	C3 C4 C5	110.7(6)
C4 C5 C6	110.8(6)	O3 C6 C1	111.3(6)
O3 C6 C5	107.9(6)	C1 C6 C5	113.0(6)
O3 C7 C8	112.1(6)	O2 C8 C7	106.8(7)
O2 C8 C9	102.5(5)	C7 C8 C9	110.5(6)
O1 C9 C8	103.6(6)		

Torsion angle		Torsion angle	
C1 O1 C9 C8	1.0(8)	C6 O3 C7 C8	−49.5(9)
O1 C9 C8 O2	−28.6(9)	O3 C7 C8 O2	64.2(8)
C9 C8 O2 C1	44.7(8)	C7 C8 O2 C1	−71.4(7)
C8 O2 C1 O1	−45.4(7)	C8 O2 C1 C6	71.1(8)
O2 C1 O1 C9	27.7(7)		

$C_7H_{12}O_2S$ (**9**)

Bond		Bond	
S1 C1	1.816(2)	S1 C4	1.827(2)
O1 C3	1.429(2)	O1 C5	1.437(2)
O2 C2	1.441(2)	O2 C3	1.422(2)
C1 C2	1.517(2)	C2 C5	1.521(2)
C3 C4	1.537(2)	C3 C6	1.512(2)
C4 C7	1.523(2)		

Angle		Angle	
C1 S1 C4	101.0(1)	C3 O1 C5	107.7(1)
C2 O2 C3	104.4(1)	S1 C1 C2	111.3(1)
O2 C2 C1	109.8(1)	O2 C2 C5	101.7(1)
C1 C2 C5	114.3(1)	O1 C3 O2	105.4(1)
O1 C3 C4	110.9(1)	O1 C3 C6	109.5(1)
O2 C3 C4	109.3(1)	O2 C3 C6	108.4(1)
C4 C3 C6	113.0(1)	S1 C4 C3	111.4(1)
S1 C4 C7	106.2(1)	C3 C4 C7	113.4(1)
O1 C5 C2	104.7(1)		

Torsion angle		Torsion angle	
C3 O1 C5 C2	4.0(1)	C4 S1 C1 C2	−39.3(1)
O1 C5 C2 O2	−26.4(1)	S1 C1 C2 O2	62.5(1)
C5 C2 O2 C3	39.3(1)	C1 C2 O2 C3	−82.1(1)
C2 O2 C3 O1	−38.1(1)	C2 O2 C3 C4	81.1(1)
O2 C3 O1 C5	20.6(1)	O2 C3 C4 S1	−61.7(1)
C3 C4 S1 C1	38.8(1)		

4.41 (d, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 21.21, 24.60, 25.83, 27.35, 30.69, 32.37 (CH_2), 68.11, 69.57 (CH_2–O), 74.35, 79.91 (CH–O), 108.80 (O–C–O). GC/MS (CI): *m/z* 199 (100, M^++1).

13,17,18-Trioxatricyclo[13.2.1.0^{1,12}]octadecane (**3d**). The compound was obtained from 2-hydroxycyclododecanone (**2d**) and glycerol as a crystalline compound, m.p. 86–87 °C (from pet.ether), in 87 % yield, after 10 h reaction time. IR(film): 1470, 1450, 1220, 1120, 1045, 1030, 710 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 1.35 (m, 19H), 1.60 (m, 1H), 3.62 (d, 1H), 3.75 (d, 1H), 3.87 (m, 2H), 4.17 (d, 1H), 4.41 (d, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 20.05, 22.22, 22.64, 22.82, 23.08, 23.23, 25.31, 26.41, 32.00 (CH_2), 67.90, 68.85 (CH_2–O), 74.05, 76.35 (CH–O), 109.20 (O–C–O). GS/MS (CI): *m/z* 225 (100, M^++1).

4,5-Dimethyl-3,6,8-trioxabicyclo[3.2.1]octane (**5**). The compound was obtained from 3-hydroxy-2-butanone and glycerol as a liquid in 82 % yield after 8 h reaction time. IR(film): 1445, 1380, 1228, 1112, 1012, 855, 645 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 1.09 (d, 3H), 1.32 (s, 3H), 3.60 (m, 2H), 3.89 (m, 2H), 4.15 (d, 1H), 4.40 (d, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 16.36, 19.51 (CH_3), 67.88, 69.43 (CH_2–O), 74.23, 76.68 (CH–O), 106.79 (O–C–O).

1-Hydroxy-11-hydroxymethyl-9,12-dioxabicyclo[6.4.0]dodecane (**6c**). When the reaction leading to **3c** was terminated after 2 h, the reaction mixture contained **2c** (18 %), **3c** (35 %) and **6c** (47 %). The latter was separated by flash chromatography on neutral alumina using hexane-ethyl acetate (1:9) as eluent. IR(film): 3500, 3300, 1460, 1260, 1190, 1090, 1020 cm^{-1}. ^1H NMR (300 MHz, DMSO): δ 1.55 (m, 12H), 3.37 (dd, 1H), 3.64 (m, 5H), 4.01 (m, 1H), 4.44 (d, 1H). ^{13}C NMR (75 MHz, DMSO): δ 20.32, 23.48, 25.76, 26.71, 28.87, 31.87 (CH_2), 63.40, 66.31 (CH_2–O), 74.04, 76.23 (CH–O), 107.90 (O–C–O).

1-Hydroxy-15-hydroxymethyl-13,16-dioxabicyclo[10.4.0]hexadecane (**6d**). When the reaction leading to **3d** was terminated after 4 h, the reaction mixture contained **2d** (29 %), **3d** (37 %) and **6d** (34 %). The latter was separated by flash chromatography on neutral alumina using hexane-ethyl acetate (1:4) as eluent. IR(film): 3500, 3300, 1440, 1280, 1170, 1100 cm^{-1}. ^1H NMR (300 MHz, DMSO): δ 1.39 (m, 22H), 3.30 (dd, 1H), 3.61 (d, 1H), 3.77 (m, 1H), 3.95 (d, 1H), 4.10 (d, 1H), 4.35 (d, 1H). ^{13}C NMR (75 MHz, DMSO): δ 21.55, 21.68, 22.43, 22.91, 24.56, 25.31, 31.14 (CH_2), 62.40, 66.02 (CH_2–O), 74.29, 74.88 (CH–O), 108.13 (O–C–O). GC/MS (CI): *m/z* 255, (M^++1)– H_2O.

11,12-Dioxa-7-thiatricyclo[7.2.1.0^{1,6}]dodecane(**7a**). The reaction of the acyloin **2a** and 1-thioglycerol for 5 h produced **7a** in 88 % yield as a liquid mixture of *trans* and *cis* isomers in a 62:38 ratio, respectively. They could not be separated, and the spectral data were obtained from the mixture. IR(film): 1330, 1210, 1180, 1070, 1005 cm^{-1}. *trans*-**7a**: ^1H NMR (300 MHz, $CDCl_3$): δ 1.1–2.1 (m, 8H), 2.25 (dd, 1H), 3.06 (dd, 1H), 3.34 (d, 1H), 3.97 (t, 1H), 4.33 (d, 1H), 4.71 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 23.69, 25.45, 30.09, 34.96 (CH_2), 31.59 (CH_2–S), 45.22 (CH–S), 68.91 (CH_2–O), 73.18 (CH–O), 106.59 (O–C–O). *cis*-**7a**: ^1H NMR (300 MHz, $CDCl_3$): δ 1.1–2.1 (m, 8H), 2.15 (dd, 1H), 2.37 (dd, 1H), 3.27 (d, 1H), 3.99 (t, 1H), 4.33 (d, 1H), 4.74 (d, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 23.47, 25.82, 33.44, 36.78 (CH_2), 27.11 (CH_2–S), 44.32 (CH–S), 68.23 (CH_2–O), 74.43 (CH–O), 106.59 (O–C–O).GC/MS (CI)) *m/z* 187 (100, M^++1).

12,13-Dioxa-8-thiatricyclo[8.2.1.0^{1,7}]tridecane (**7b**). The reaction of the acyloin **2b** and 1-thioglycerol for 5 h produced **7b** in 89 % yield as a liquid consisting of a 89:11 ratio of *trans* and *cis* isomers, respectively. They could not be separated, and the spectral data were obtained from the mixture. IR(film): 1455, 1329, 1258, 1165, 1040, 1000 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 1.24 (m, 1H), 1.51 (m, 4H), 1.78 (m, 3H), 1.92 (m, 2H), 2.20 (dd, 1H), 3.18 (m, 2H), 3.98 (t, 1H), 4.22 (d, 1H), 4.73 (m, 1H). *trans*-**7b**: ^{13}C NMR (75 MHz, $CDCl_3$): δ 21.09, 27.27, 28.00, 29.75, 31.77, 38.82 (CH_2), 48.42 (CH–S), 69.12 (CH_2–O), 73.79 (CH–O), 109.97 (O–C–O). *cis*-**7b**: ^{13}C NMR (75 MHz, $CDCl_3$): δ 20.43, 26.67, 26.87, 27.56, 33.45, 38.60 (CH_2), 47.58 (CH–S), 68.23 (CH_2–O), 74.55 (CH–O), 109.80 (O–C–O).

4,5-Dimethyl-6,8-dioxa-3-thiabicyclo[3.2.1]octane (**9**). Reaction of 3-hydroxy-2-butanone with 1-thioglycerol for 8 h gave **9** as a 82:18 mixture of stereoisomers in 78% yield. The major component was separated by flash-chromatography into a crystalline compound, m.p. 44–46 °C. The methyl groups were shown by X-ray diffraction to be *trans*-related (see above). IR(film): 1438, 1377, 1320, 1265, 1200, 1055, 1038, 1005 cm^{-1}. *trans*-**9**: ^1H NMR (300 MHz, $CDCl_3$): δ 1.11 (d, 3H), 1.44 (s, 3H), 2.24 (dd, 1H), 3.17 (q, 1H), 3.32 (m, 1H), 4.00 (t, 1H), 4.29 (d, 1H), 4.72 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 16.61, 22.34 (CH_3), 31.91 (CH_2–S), 42.04 (CH–S), 69.35 (CH_2–O), 73.49 (CH–O), 108.19 (O–C–O). *cis*-**9**: ^1H NMR (300 MHz, $CDCl_3$): δ 1.42 (s, 3H), 1.50 (d, 3H), 2.10 (dd, 1H), 2.55 (q, 1H), 3.29 (m, 1H), 3.98 (m, 1H), 4.29 (m, 1H), 4.74 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 19.46, 23.48 (CH_3), 26.67 (CH_2–S), 41.84 (CH–S), 68.64 (CH_2–O), 75.31 (CH–O), 108.40 (O–C–O). GC/MS(CI): *m/z* 161 (100, M^++1).

meso-*Bis-10,10'-{9,12-dioxabicyclo[6.4.0]dodec-1(8)-enyl}* (**10c**). A solution of 0.50 g (3.5 mmol) of the acyloin **2c** and 0.31 g (2.5 mmol) of *meso*-erythritol in 50 ml of benzene was heated under reflux for 4 h in the presence of *p*-toluenesulfonic acid. Work-up according to the general procedure gave 0.63 g (75%) of **10c** as a viscous liquid. IR(film): 1690, 1190, 710 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 1.75 (m, 10H), 2.18 (m, 2H), 3.68 (m, 1H), 3.97 (m, 1H), 4.35 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 26.51, 28.79, 28.99 (CH_2), 69.55 (CH_2–O), 72.09 (CH–O), 128.88 (=C–O). MS (EI); *m/z* 334 (M^+).

meso-*Bis-14,14'-{13,16-dioxabicyclo[10.4.0]hexadec-1(12)-enyl}* (**10d**). The compound was obtained, as described for **10c**, in 77% yield as a viscous liquid after 10 h reaction time. IR(film): 1690, 1205, 1095, 1040, 1010, 710 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ 1.35 (m, 14H), 1.58 (m, 4H), 2.15 (m, 2H), 3.80 (m, 1H), 4.00 (m, 1H), 4.36 (m, 1H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 22.32, 24.30, 24.40, 24.61, 26.01 (CH_2), 69.96 (CH_2–O), 72.43 (CH–O), 130.43 (=C–O). MS (EI); *m/z* 446 (M^+).

X-ray crystallography. Crystals were formed by sublimation; data for unit cell determination and intensity data were collected using a Nicolet *P3/F* diffractometer and graphite crystal monochromated Mo*K*α radiation (λ = 0.71069 Å). Crystal and experimental data are given in Table 1.

The atomic coordinates of all non-hydrogen atoms were determined by direct methods (MITHRIL).[5] Refinements were performed by least-squares calculations, and hydrogen atomic positions were calculated and included in the structure factor calculations but were not refined. An empirical absorption correction was applied to the data for **9**;[6] the minimum absorption correction was 0.686, and the maximum correction was 1.058. The computer programs employed have been described previously.[7]

Final figures of merit for both compounds are included in Table 1. Positional parameters are given in Table 2, and lists of anisotropic thermal parameters and structure factors may be obtained from the authors on request.

ORTEP plots of the molecules are presented in Fig. 1; bond lengths, bond angles and selected torsion angles are listed in Table 3.

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