RADIATION-INITIATED ADDITION OF ACETALDEHYDE TO ALLYL ALCOHOL AND CONVERSION OF THE 1 : 2-TELOMER INTO 1-METHYL-2,8-DIOXABICYCLO[4,2,1]NONANE

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Radiation-initiated addition of acetaldehyde to allyl alcohol gave a mixture of 5-hydroxy-2-pentanone (1 : 1-adduct *I*), 2-methyl-2-(4-oxopentyloxy)tetrahydrofuran (*II*), 7-hydroxy-4-hydroxymethyl-2-heptanone (1 : 2-telomer *III*) and 1,1-bis(4-oxopentyloxy)ethane (*IV*). The telomer *III* was dehydrated to afford 3-acetonyltetrahydropyran (*V*), 1-methyl-2,8-dioxabicyclo[4.2.1]nonane (*VI*) and 3,10-dimethyl-4,11,16,17-tetraoxatricyclo[8.4.2.2^{3,8}]octadecane (*VII*).

In our preceding paper we studied the photo- and radiation-initiated addition of acetaldehyde to allyl formate and acetate[1] in order to elaborate an alternative synthesis of 5-hydroxy-2-pentanone (*I*). Compound *I* is an important intermediate in organic synthesis and its preparation is based on hydrolysis of 2-acetyl-4-butanolide[2,3], partial hydrogenation of 2-methylfuran[4] or reduction of α-angelicalactone[5]. It also can be prepared in one step by radical addition of acetaldehyde to allyl alcohol; the reaction was so far initiated with oxygen in the presence of cobalt(II) acetate[6].

In our present paper we study the γ-^{60}Co-initiated addition of acetaldehyde to allyl alcohol. We followed the dependence of chemical yield of the reaction products on the radiation dose (Table I) and on the ratio of the reactants at constant radiation dose (Table II). After irradiation of the two components and evaporation of the excess acetaldehyde we detected (TLC-comparison with standards) the hydroxypentanone *I*, 2-methyl-2-(4-oxopentyloxy)tetrahydrofuran (*II*) and 7-hydroxy-4-hydroxymethyl-2-heptanone (1 : 2-telomer *III*). Distillation of the reaction mixture afforded a mixture of the 1 : 1-adduct *I* and tetrahydrofuran *II* which were identified by ^{1}H NMR spectroscopy (spectrum of the mixture was compared with those of pure standards[1]). Attempts to isolate the 1 : 2-telomer *III* by distillation resulted in fractions of varying composition, containing mainly 1,1-bis(4-oxopentyloxy)ethane (*IV*). Compound *IV* was probably formed during the distillation by reaction of acetaldehyde with the hydroxy ketone *I*. Therefore, we prepared the diol *III* by deacylation of the corresponding diacetate or diformate[1]. Already during distillation under

diminished pressure the diol *III* underwent an intramolecular dehydration to give 1-methyl-2,8-dioxabicyclo[4.2.1]nonane (*VI*), and probably also an intermolecular dehydration resulting in formation of 3,10-dimethyl-4,11,16,17-tetraoxatricyclo-[8.4.2.$2^{3,8}$]octadecane (*VII*). The acid-catalyzed dehydration of the diol *III* afforded 3-acetonyltetrahydropyran (*V*) in addition to the bicyclononane *VI*.

The only one hitherto described compound with the 2,8-dioxabicyclo[4.2.1]nonane skeleton is 6-ethyl-2,8-dioxabicyclo[4.2.1]nonan-7-one[10]; this lactone has been used as a chiral synthon in the enantioselective synthesis of eburnane alkaloids.

Three structural isomers of our compound *VI* have been described: 1-methyl- and 6-methyl-7,9-dioxabicyclo[4.2.1]nonane (ref.[7] and ref.[8], respectively) and 1-methyl-2,9-dioxabicyclo[4.2.1]nonane[9].

TABLE I

Radiation-initiated addition of acetaldehyde to allyl alcohol. Dependence of chemical yield of *I*, *II*, and *IV* on the radiation dose (*D*)

D	Allyl alcohol g (mol . 10^{-3})	MR[a]	*I* + *II*		*IV*		Distillation residue g
			g	%	g	%	
7·3	3·38(58·19)	40·8	0·86	14·5	—	—	0·27
15·5	3·40(58·5)	40·2	1·63	27·3	—	—	0·56
30·2	3·37(58·0)	41·2	2·33	39·4	0·58	8·7	0·83
57·3	3·43(59·0)	40·9	2·78	46·2	0·95	14·0	0·50
100·3	3·35(57·7)	41·8	3·05	51·8	1·53	23·0	0·47

[a] Molar ratio acetaldehyde : allyl alcohol.

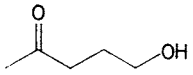
TABLE II

Dependence of chemical yield of *I* and *II* on the ratio of reagents at constant radiation dose *D* = 100 kGy

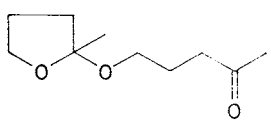
Allyl alcohol g (mol . 10^{-3})	MR[a]	*I* + *II*		Distillation residue[b] g
		g	%	
18·5(318·9)	6·26	3·16	11·5	7·22
10·05(172·35)	12·5	5·69	38·3	12·79
5·04(86·8)	25·3	2·06	27·5	8·01
3·36(57·9)	41·4	2·87	57·5	6·09

[a] Molar ratio acetaldehyde : allyl alcohol; [b] compound *IV* was not isolated.

Various other derivatives containing an x,y-dioxabicyclo[4.2.1]nonane skeleton are known, in which x,y = 2,7 (refs[11,12]), 3,4 (refs[13-15]), 3,9 (refs[16-18]), 7,8 (refs[19-21]) and 7,9 (refs[22-25]). Compounds with the mentioned skeletons have been found



I



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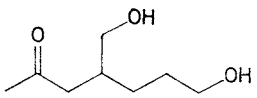

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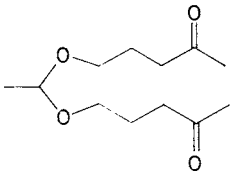

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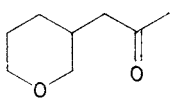
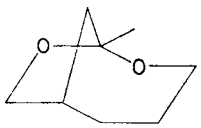
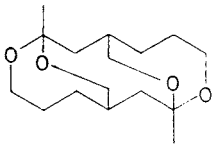


V



VI



VII

among natural compounds[11,12,16,24,25] or in the glycoside part in C-nucleosides[18]. They are also formed in ozonolysis of bicyclic alkenes[13-15], in photooxidation of cycloheptatriene[21] or in cyclization of 2,3-dibromocycloalkane hydroperoxides[19].

Structure of our compounds was determined by elemental analysis, infrared, mass ^{1}H NMR and ^{13}C NMR spectra. Using the ^{13}C NMR spectroscopy we have found that the dioxabicyclooctane *VI* on standing at room temperature turns into an equilibrium mixture of probably three stereoisomeric tetraoxatricyclooctadecanes *VII*. On the other hand, in deuteriochloroform solution the compound *VII* is gradually converted into the dioxabicyclooctane *VI*.

EXPERIMENTAL

The melting points are uncorrected. The proton and ^{13}C NMR spectra were measured on a Bruker AM 400 instrument (^{1}H at 400·13 MHz, ^{13}C at 100·62 MHz) in deuteriochloroform (unless stated otherwise) with tetramethylsilane as internal standard. Chemical shifts δ are given in ppm, coupling constants J in Hz, resolution 0·18 Hz for ^{1}H and 0·75 Hz for ^{13}C NMR spectra. Besides the usual shift rules, homonuclear as well as heteronuclear 2D-NMR correlations were also used for assignment of the signals. Mass spectra were obtained with a JEOL DX 303

or a Finigan instrument, IR spectra were recorded on a Perkin–Elmer 325 spectrometer in tetrachloromethane or chloroform; the wavenumbers are given in cm^{-1}. The addition reaction of acetaldehyde to allyl alcohol was initiated by ^{60}Co-γ-irradiation in a Gammacell 220 (AECL) equipment.

Radiation-initiated Addition of Acetaldehyde to Allyl Alcohol

Argon was introduced for 10 min at 0°C in a mild stream into a mixture of allyl alcohol (3·35 g, 0·057 mol) and acetaldehyde (135 ml, 106·08 g, 2·31 mol) in a 300 ml glass ampoule. After evacuation to about 5 kPa, the ampoule was cooled to −70°C and sealed. The molar ratio acetaldehyde : allyl alcohol was 41·75. The ampoule was irradiated with ^{60}Co-radiation, the total dose *D* being 100 kGy. After removal of the unreacted acetaldehyde and low-boiling fractions containing predominantly trimethyltrioxane, the reaction mixture was fractionated to give two fractions: 1. fraction (3·05 g), b.p. 70–115°C/2·26 kPa and 2. fraction (2·53 g), b.p. 120–170°C/2·0 kPa. According to TLC and ^{1}H NMR spectrum, the 1. fraction was a 3 : 2 mixture of hydroxypentanone *I* and 2-methyl-2-(4-oxopentyloxy)tetrahydrofuran (*II*), containing about 5% of 1-methyl-2,8-dioxabicyclo[4.2.1]nonane *VI*.

Hydroxypentanone I: ^{1}H NMR: 1·81 m, 2 H (C–CH_2–C); 2·18 s, 3 H (CH_3CO); 2·58 t, 2 H (CH_2CO, J = 7·2 Hz); 3·60 t, 2 H (CH_2O, J = 7·2 Hz).

Tetrahydrofuran II: ^{1}H NMR: 1·42 s, 3 H (CH_3–C); 1·65–2·1 complex, 6 H (C–CH_2–C); 2·13 s, 3 H (CH_3CO); 2·50 t, 2 H (CH_2CO, J = 7·2 Hz); 3·35–3·50 m, 2 H (CH_2O acyclic); 3·80–3·92 m, 2 H (CH_2O cyclic).

The 2. fraction was a mixture (TLC) in which (according to the ^{1}H NMR spectrum) 1,1-bis-(4-oxopentyloxy)ethane (*IV*) was the dominant component. ^{1}H NMR: 1·26 d, 3 H (CH_3–CH); 1·76–1·88 m, 4 H ($CH_2CH_2CH_2$); 2·15 s, 6 H (CH_3CO); 2·54 t, 4 H (CH_2CH_2CO, J = 7·2 Hz); 3·38–3·60 dm, 4 H (OCH_2CH_2); 4·63 q, 1 H (OCHO, J = 5·2 Hz). IR spectrum: ν(C=O) 1 710.

Dependence of Yield of Mixture of *I* and *II* on the Irradiation Dose

Five ampoules containing allyl alcohol and acetaldehyde in the molar ratio 1 : 40 were prepared. The individual ampoules were irradiated, the doses *D* being 7, 15, 30, 57 and 100 kGy. The yields are given in Table I.

Dependence of Yield of Mixture of *I* and *II* on Molar Ratio of Reacting Compounds

Mixtures of allyl alcohol and acetaldehyde (molar ratio 1 : 6, 1 : 12, 1 : 25 and 1 : 40) were irradiated (D = 100 kGy). The yields are given in Table II.

To simplify the calculation, for both experiments the whole first fraction, b.p. 70–115°C/2·26 kPa, was taken as the pure compound *I* whereas the whole second fraction, b.p. 120 to 170°C/2 kPa as the pure compound *IV*. No 1 : 2-telomer *III* has been found (^{1}H NMR spectrum) in the distillation fractions.

1-Methyl-2,8-dioxabicyclo[4.2.1]nonane (*VI*) and 3,10-Dimethyl-4,11,16,17-tetraoxatricyclo[8.4.2.$2^{3,8}$]octadecane (*VII*)

The 1 : 2-telomer *III* (0·534 g), obtained by deformylation according to reference[1], was distilled in vacuo, affording: b.p. 70–74°C/1·5 kPa (clear mobile liquid) and 2. fraction (0·048 g), b.p. 138–140°C/1·5 kPa (clear very viscous liquid). According to TLC (chloroform–methanol 95 : 5, silica gel G), both fractions consisted of two compounds in different ratio.

The principal component of the lower-boiling fraction (R_F 0·58) was found to be the bicyclononane *VI*. Mass spectrum (electron impact) *m/z* (rel. int., %): 142 (M^+, 4), 127 (M − CH_3, 2), 124 (M − H_2O, 5), 112 (M − CH_2O, 10), 97 (15), 84 (13), 83 (100), 82 (12), 71 (5), 69 (5), 67 (20), 58 (4), 55 (13), 54 (16), 43 (90), 41 (13), 38 (8). ^{1}H NMR: 1·50 s, 3 H (CH_3); 1·45—1·55 m, 1 H, 1·65—1·78 m, 2 H, 1·82—1·92 m, 1 H (H-4ab, H-5ab); 1·93 dd, 1 H (H-9a or 9b, ^2J = = 13·7 Hz, ^3J = 7 Hz); 2·11 d, 1 H (H-9a or H-9b, ^2J = 13·7 Hz); 2·49 m, 1 H (H-6); 3·6 to 3·73 m, 4 H (H-3ab, H-7ab). ^{13}C NMR: 26·41 (C-4); 27·59 (CH_3); 32·12 (C-5); 36·38 (C-6); 40·97 (C-9); 65·63 (C-3); 73·16 (C-7); 108·83 (C-1).

The higher-boiling fraction contained mainly the tricyclooctadecane *VII*, R_F 0·34. Mass spectrum (chemical ionization, methane), *m/z*: 299 (M + 15), 285 (M + 1), 269 (M − 15), 255 (M − 29), 239 (M − 45), 227, 213, 197, 185, 171, 157, 143 (100%), 125, 83, 43. ^{1}H NMR of the stereoisomeric mixture: 1·41, 1·43, 1·52 s (CH_3); 1·6—2·5 m (C-CH_2-C + CH); 3·3—4·0 m (CH_2O). ^{13}C NMR: 22·25; 22·91 and 23·09 (CH_3).

3-Acetonyltetrahydropyran (*V*)

Amberlite CG 120 AR (H^+-form, catalytic amount) was added to a solution of the 1 : 2-telomer *III* (1·894 g) in a mixture of benzene (50 ml) and ethanol (3 ml) and the mixture was allowed to stand at room temperature. The conversion of *III* to a mixture of *VI* and *VII* in the course of 24 h was followed by TLC. The reaction mixture was washed with water and dried over sodium sulfate. Evaporation of the solvent and distillation afforded: 1. fraction (0·16 g), b.p. 70°C/ /3·7 kPa, and 2. fraction (0·30 g), b.p. 121°C/3·7 kPa. As shown by gas–liquid chromatography (OV 225, 135°C), the 1. fraction contained more than 95% of *VI*. For $C_8H_{14}O_2$ (142·2) calculated: 67·57% C, 9·92% H; found: 66·97% C, 10·02% H. The 2. fraction was a 4 : 5 mixture of *VI* and *V* (gas-liquid chromatography, ^{1}H NMR, ^{13}C NMR and mass spectra).

Acetonyltetrahydropyran (*V*). ^{1}H NMR: 1·2 and 1·82 m, 2 H (H-4ab); 1·6 m, 2 H (H-5ab); 2·13 s, 3 H (CH_3); 2·32 m, 2 H (CH_2-CO), ^3J = 16·5 Hz); 3·12 and 3·82 m, 2 H (H-2ab, ^2J = = 9 Hz); 3·3—3·5 m and 3·78—3·9 m, 2 H (H-6ab). ^{13}C NMR: 25·2 (C-5); 29·7 (C-4); 30·0 (C-3); 31·74 (CH_3); 46·2 (CH_2-CO); 68·3 (C-6); 75·2 (C-2); 207·3 (C=O). Mass spectrum (electron impact), *m/z* (rel. int., %): 142 (M^+, 2), 127 (M − CH_3, 1), 124 (M − H_2O, 7), 112 (15), 97 (20), 83 (98), 71 (10), 69 (9), 67 (25), 58 (7), 55 (9), 54 (20), 43 (100), 41 (16), 38 (9).

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