SYNTHESIS AND SOME PROPERTIES OF CYCLIC ACETALS OF MALONALDEHYDE

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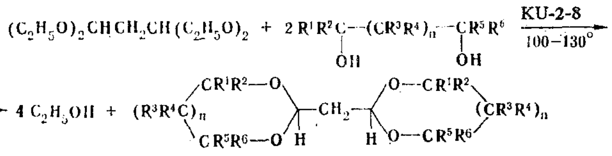
The Lewis acid-catalyzed addition of cyclic orthoformates to vinyl ethyl ether, which leads to the formation of malonaldehyde acetals, was studied. It is shown that of the linear-cyclic malonaldehyde acetals, 2-(2,2-diethoxyethyl)- and 5,5-dimethyl-2-(2,2-diethoxyethyl)-1,3-dioxanes are stable. The transacetalization of 1,1,3,3-tetraethoxypropane with 1,2- and 1,3-diols, which leads to the formation of cyclic malonaldehyde acetals, was studied. The physicochemical constants of the acetals were determined, and their ^{1}H and ^{13}C NMR spectra are described.

In a continuation of our systematic study of the reactivities and transformations of cyclic acetals [1] we directed our attention to derivatives of dialdehydes. The synthesis and properties of linear malonaldehyde acetals, which are of importance in synthetic organic chemistry [2], have been studied quite thoroughly [3, 4]. We were unable to find descriptions of the cyclic derivatives in the literature. We recently established the possibility of the smooth transacetalization of lower linear malonaldehyde acetals by means of some sterically unhindered diols [5]. In order to ascertain the applicability of the method to the synthesis of various bis(1,3-dioxa-2-cyclo-alkyl)-methanes and mixed linear-cyclic malonaldehyde acetals we studied the reaction of 1,1,3,3-tetraethoxypropane with various 1,2- and 1,3-diols in the presence of acidic agents. We found that KU-2-8 cation-exchange resin was the best catalyst for transacetalization; cyclic acetals I-IX were obtained by means of this catalyst:



I–IX

$n=0$ I $R^1=R^2=R^5=R^6=H$; II $R^1=CH_3$, $R^2=R^5=R^6=H$; III $R^1=R^5=CH_3$, $R^2=R^6=H$; IV $R^1=R^2=R^5=R^6=CH_3$; $n=1$ V $R^1=R^2=R^3=R^4=R^5=R^6=H$; VI $R^1=CH_3$, $R^2=R^3=R^4=R^5=R^6=H$; VII $R^1=R^2=CH_3$, $R^3=R^4=R^5=R^6=H$; VIII $R^1=R^2=R^5=R^6=H$, $R^3=R^4=CH_3$; IX $R^1=R^2=R^5=CH_3$, $R^3=R^4=R^6=H$

Products of partial transacetalization (linear-cyclic acetals) were not detected in the reaction mixtures.

The formation of bis(1,3-dioxepan-2-yl)methane from 1,4-butanediol and 1,1,3,3-tetraethoxypropane under the given conditions was not observed; N-ethyl- and N-butylethanolamines also did not react with the indicated linear acetals. A powdery inflammable polymer, which was insoluble in water, toluene, acetone, and ether and did not melt at up to 280-300°C, was obtained when the reaction of 1,1,3,3-tetraethoxypropane with pentaerythritol was carried out in refluxing toluene in the presence of $BF_3 \cdot O(C_2H_5)_2$.

The synthesized cyclic malonaldehyde acetals (I, IV, V, VII-IX) are colorless crystalline substances with a pleasant odor that are readily soluble in ordinary organic solvents. Those compounds that do not contain alkyl substituents in the ring are quite soluble in water but are extracted from aqueous solutions by means of diethyl ether.

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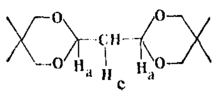
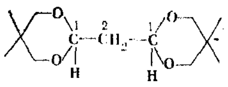
TABLE 1. Characteristics of Cyclic Malonaldehyde Acetals

Compound	bp, °C (hPa)	mp, °C	n_D^{20}	d_4^{20}	δ, ppm		J Hz	δ, ppm		J, Hz		Found, %		Empirical formula	Calc., %		Yield, %
												C	H		C	H	
					A	B	AB	$C_{(1)}$	$C_{(2)}$	$C_{(1)}H$	$C_{(2)}H$						
I	105—107 (19)	36	—	—	4,83	1,81	5,1	101,8	39,48	167	127,5	52,5	7,5	$C_7H_{12}O_4$	52,5	7,6	92
II^a	121—122 (41)	—	1,4396	1,088	4,80 4,82 4,94 4,96	1,72 1,78 1,82	5,5	101,2 102,0	40,78	167	129,3	57,7	8,6	$C_9H_{16}O_4$	57,4	8,6	93
III^a	110—112 (19)	—	1,4369	1,032	4,75 4,77 4,95 4,97 5,10 5,12	1,74 1,77 1,79	5,5	100,6	41,94	167	125	61,4	9,4	$C_{11}H_{20}O_4$	61,1	9,3	91
IV	—	79	—	—	4,93	1,66	5,5	98,45	44,98	165	127,5	66,1	10,3	$C_{15}H_{28}O_4$	66,1	10,4	90
V	130—133 (19)	42	—	—	4,53	1,67	5,7	99,36	41,94	160	128,1	57,5	8,6	$C_9H_{16}O_4$	57,4	8,6	89
VI^a	135—140 (20)	—	1,4528	1,059	4,46	1,66	5,5	99,1	42,07	162	128,1	60,9	9,4	$C_{11}H_{20}O_4$	61,1	9,3	95
VII	140—145 (20)	56	—	—	4,68	1,57	5,7	92,1	40,97	165	128	63,7	10,0	$C_{13}H_{24}O_4$	63,9	9,9	93
VIII	—	117—118	—	—	4,35	1,77	5,6	99,55	41,03	141	128,1	63,9	9,8	$C_{13}H_{24}O_4$	63,9	9,9	94
IX^a	145—150 (21)	75	—	—	4,67	1,59	5,7	—	—	—	—	66,0	10,3	$C_{15}H_{28}O_4$	66,1	10,4	94
X^b	119—120 (19)	—	1,4343	1,009	4,43 4,39	1,69	5,9	99,81 100,03^c	40,39	161	126	58,7	9,8	$C_{10}H_{20}O_4$	58,8	9,9	35

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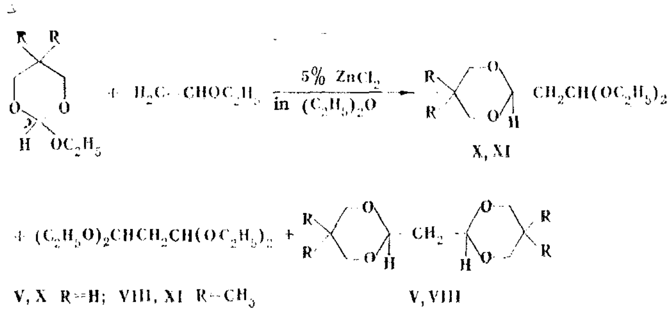
[a] From a mixture of stereoisomers of the glycols. [b] A mixed acetal, viz., 2-(2,2-diethoxyethyl)-1,3-dioxane.
[c] In the linear acetal fragment.

The mixed linear-cyclic malonaldehyde acetals were synthesized by the addition of cyclic orthoformates in the presence of Lewis acids [$ZnCl_2$, $BF_3 \cdot O(C_2H_5)_2$] to vinyl ethyl ether; symmetrical reaction products are formed in addition to the mixed acetals:



Thus 2-ethoxy-1,3-dioxane reacts with vinyl ethyl ether to give 1,1,3,3-tetraethoxypropane, bis(1,3-dioxan-2-yl)methane (V), and 2-(2,2-diethoxyethyl)-1,3-dioxane (X) in a ratio of 1:1:2 (the overall yield of the acetals at 40°C is 52%). The reaction of vinyl ether with 5,5-dimethyl-2-ethoxy-1,3-dioxane under similar conditions leads to a mixture of 1,1,3,3-tetraethoxypropane, bis(5,5-dimethyl-1,3-dioxan-2-yl)methane (VIII), and 5,5-dimethyl-2-(2,2-diethoxyethyl)-1,3-dioxane (XI) in a ratio of 5:5:1 [according to the results of gas-liquid chromatography (GLC), the overall yield of the acetals is 46%]. Only symmetrical acetals, viz., 1,1,3,3-tetraethoxypropane and bis(1,3-dioxolan-2-yl)methane (I) in a ratio of 1:1, are formed under similar conditions from 2-ethoxy-1,3-dioxolane and vinyl ethyl ether (the overall yield of the acetals at 40°C is 50%). The initially formed labile 2-(2,2-diethoxyethyl)-1,3-dioxolane is evidently rapidly converted under the reaction conditions to symmetrical products. This sort of symmetrization is well known in series of mixed acetals of aliphatic aldehydes [6].

The structures of the synthesized I-XI were proved by ^{1}H and ^{13}C NMR spectroscopy.

Thus the results show that of the unsymmetrical linear-cyclic malonaldehyde acetals that contain a 1,3-dioxycyclane fragment, the derivatives of 1,3-diols are stable under normal conditions.

EXPERIMENTAL

The PMR spectra of solutions of acetals I-XI in CCl_4 were recorded with a Tesla BS-467 spectrometer (60 MHz) with hexamethyldisiloxane as the internal standard. The ^{13}C NMR spectra were recorded with a Brucker H-90 spectrometer (22.63 MHz) at 303°K. In the case of crystalline acetals we used 40-60% solutions of the substances in CCl_4. The spectra were recorded under conditions of broad-band (total) suppression and without suppression of spin-spin coupling with the protons, which made it possible to make an unambiguous assignment of the signals of the carbon atoms. The assignment of the signals was made on the basis of an analysis of the spectra of the glycols that are included in the composition of the acetals, on the basis of literature data on the ^{13}C NMR spectra of a number of acetals [7, 8], and on the basis of concepts regarding the polarization of bonds as a result of the overall effect of substituents [9]. Gas-liquid chromatography was carried out with a Tsvet-101 chromatograph with a flame-ionization detector, a stainless steel column (3 m by 3 mm) packed with 10% Apiezon L/Chromaton N-AW-DMCS (0.200-0.250 mm), and nitrogen as the carrier gas.

The constants of I-X are presented in Table 1.

1,1,3,3-Tetraethoxypropane was obtained and purified by the method in [3], while 2-ethoxy-1,3-dioxane and 5,5-dimethyl-2-ethoxy-1,3-dioxane were obtained by a known method [10] and were distilled at atmospheric pressure prior to use.

Bis(1,3-dioxolan-2-yl)methane (I). A mixture of 22 g (0.1 mole) of freshly distilled 1,1,3,3-tetraethoxypropane, 12.4 g (0.2 mole) of ethylene glycol, and 1 g of KU-2-8 cation-exchange resin was heated in a flask equipped with a fractionating column on an oil bath at 110-120°C until alcohol liberation was complete. The warm reaction mixture was filtered rapidly to remove the catalyst, and the filtrate was distilled at reduced pressure with collection of the fraction with bp 105-107°C (19 hPa) to give 14.9 g of malonaldehyde bisethyleneacetal, which began to crystallize on standing. Redistillation gave 10 g of acetal I with a purity of 98% according to GLC. The product was quite soluble in water and organic solvents. PMR spectrum: 1.81 (2H, t, CH_2), 3.80 (8H, m, OCH_2), and 4.83 ppm (2H, t, CH).

Bis(4-methyl-1,3-dioxolan-2-yl)- and Bis(4,5-dimethyl-1,3-dioxolan-2-yl)methane (II, III). The similar reaction of 2.2 g (10 mmole) of 1,1,3,3-tetraethoxypropane, 0.1 g of KU-2-8 cation-exchange resin, and 20 mmole of the corresponding glycols (a commercial mixture of stereoisomers was used) gave liquid acetals II and III, which are mixtures of stereoisomers that are slightly soluble in water but quite soluble in acetone, ether, alcohols, and CCl_4.

Bis(4,4,5,5-tetramethyl-1,3-dioxolan-2-yl)methane (IV). A mixture of 14 g (62 mmole) of pinacol hydrate and 20 ml of benzene was heated in a flask equipped with a reflux condenser and a water separator. After 7 ml of water had been separated, 7 ml of 1,1,3,3-tetraethoxypropane and 0.3 g of KU-2-8 cation-exchange resin were added, and the alcohol and benzene were removed by distillation while the bath temperature was maintained at 120-130°C. The reaction mixture was filtered to remove the catalyst, and the filtrate was cooled, during which crystals began to form. The crude reaction product was washed with water and, where necessary, recrystallized from diethyl ether. The product was 95% pure (according to GLC) and was quite soluble in acetone, CCl_4, and alcohols but insoluble in water. PMR spectrum: 1.09 (24H, s, CH_3), 1.66 (2H, t, CH_2), and 4.93 ppm (2H, t, CH).

Bis(1,3-dioxan-2-yl)methane (V). The similar reaction of 22 g (0.1 mole) of 1,1,3,3-tetraethoxypropane, 15.2 g (0.2 mole) of 1,3-propanediol, and 1 g of KU-2-8 cation-exchange resin by heating on an oil bath to 120-130°C with subsequent separation of the catalyst and distillation at reduced pressure at 130-133°C (19 hPa) gave 16.8 g of malonaldehyde bistrimethyleneacetal, which began to crystallize on standing. Redistribution gave 14 g of acetal V with a purity of 99% (according to GLC); the product was quite soluble in water and organic solvents. PMR spectrum: 1.67 (2H, t, CH_2CH), 2.07 (4H, m, CH_2CH_2), 3.84 (8H, m, OCH_2), and 4.53 ppm (2H, t, CH).

Bis(4-methyl-1,3-dioxan-2-yl)- and Bis(4,4-dimethyl-1,3-dioxan-2-yl)methane (VI, VII). The similar reaction of 2.2 g (10 mmole) of 1,1,3,3-tetraethoxypropane, 0.1 g of KU-2-8 cation-exchange resin, and 20 mmole of the corresponding glycols gave liquid acetal VI and acetal VII; the latter began to crystallize on standing. The products were insoluble in water but quite soluble in acetone, ether, and CCl_4. Acetal VII can be recrystallized from CCl_4 to give a product with a purity of 95% (according to GLC). PMR spectrum: 1.14 (6H, s, eq-CH_3), 1.20 (6H, s, ax-CH_3), 1.57 (2H, t, CH_2), 1.68 (4H, m, ring CH_2), 3.74 (4H, m, OCH2), and 4.68 ppm (2H, t, CH).

Bis(5,5-dimethyl-1,3-dioxan-2-yl)- and Bis(4,4,6-trimethyl-1,3-dioxan-2-yl)methane (VIII, IX). These compounds were obtained by a method similar to that used to prepare acetals I-III. Crystalline product VIII was separated from the glycol by washing with water and, where necessary, was recrystallized; small amounts of the acetal can be distilled at reduced pressure. After separation from the glycol by washing with water and drying, crystalline acetal IX was distilled at reduced pressure at 145-150°C (21 hPa); the product began to crystallize on standing. According to GLC, acetals VIII and IX had purities of ∿99% and were insoluble in water but soluble in ether, acetone, and CCl_4. PMR spectrum of acetal VIII: 0.64 (6H, s, eq-CH_3), 1.08 (6H, s, ax-CH_3), 1.77 (2H, t, $CH\underline{H_2}CH$), 3.33 (8H, m, OCH_2), and 4.35 ppm (2H, t, CH). PMR spectrum of acetal IX: 1.08 (6H, d, $C\underline{H_3}CHO$), 1.14 (6H, s, eq-CH_3CO), 1.19 (6H, s, ax-CH_3CO), 1.24 (4H, d, ring CH_2), 1.59 (4H, t, $CH\underline{H_2}CH$), 3.70 (2H, m, $CH_3C\underline{H}O$), and 4.67 ppm (2H, t, CH).

2-(2,2-Diethoxyethyl)-1,3-dioxane (X). A 5% ether solution of $ZnCl_2$ in an amount comprising 30% of the initial volume was added with stirring to cooled freshly distilled 2-ethoxy-1,3-dioxane (0.1 mole), and 0.1 mole of vinyl ether was added from a dropping funnel to the mixture with cooling (the reaction mixture was not allowed to heat up above 30°C). The malonaldehyde acetals were isolated from the reactive mixture by a procedure similar to that described in [3]. Mixed acetal X can be purified by distillation at reduced pressure with a rectification column at 119-120°C (19 hPa) or can be isolated from the reaction mixture by means of preparative GLC. Liquid acetal X was only slightly soluble in water but quite soluble in organic solvents. PMR spectrum: 1.10 (6H, t, CH_3), 1.69 (2H, t, $CH\underline{H_2}CH$), 2.05 (2H, m, ring CH_2), 3.39 and 3.43 (2H and 2H, q and q, CH_3CH_2O), 3.85 (4H, m, ring OCH_2), 4.39 [1H, t, $(C_2H_5O)_2C\underline{H}CH_2$], and 4.43 ppm (1 H, t, $C\underline{H}CH_2$).

2-(2,2-Diethoxyethyl)-5,5-dimethyl-1,3-dioxane (XI). As in the preceding method, the reaction of freshly distilled 5,5-dimethyl-2-ethoxy-1,3-dioxane, an ether solution of $ZnCl_2$, and the freshly prepared ether gave a mixture of acetals containing VIII, XI, and 1,1,3,3-tetraethoxypropane. Yellow acetal XI (5%) was isolated from the mixture by preparative GLC; the product had a purity of 98% (GLC) and was insoluble in water but soluble in acetone, ether, and CCl_4. PMR spectrum: 0.64 (3H, s, eq-CH_3), 1.08 (3H, s, ax-CH_3), 1.08 (6H, t, $\underline{CH}_3CH_2O$), 1.74 (2H, t, $CH\underline{CH}_2CH$), 3.33 (4H, m, ring OCH_2), 3.88 and 3.43 (2H and 2H, q and q, $O\underline{CH}_2CH_3$), 4.27 (1H, t, ring CH), and 4.42 ppm (1H, t, CH).

^{13}C NMR spectrum (in CCl_4): 15.6 ($\underline{C}H_3CH_2$), 22.9 (ring eq-CH_3), 23.9 (ring ax-CH_3), 30.9 [ring $\underline{C}(CH_3)_2$], 39.7 ($CH\underline{C}H_2CH$), 60.84 (CH_2O), 77.44 (ring CH_2O), 99.70 (ring CH), and 100.2 ppm ($\underline{C}H$).

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