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REACTION OF α,β,α',β'-DIEPOXYKETONES WITH METHANOL IN THE PRESENCE OF BORON TRIFLUORIDE ETHERATE

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The reaction of trans-diepoxyketones with methanol in the presence of boron trifluoride etherate leads to tetrahydropyran-4-ones and/or tetrahydrofuran-3-ones. The size of the heterocycle forming depends on the direction in which the alkylsubstituted epoxide ring opens and is determined by the relative configuration of the chiral centers of the epoxide rings.

It is known that the reaction of keto-epoxides with alcohols in an acidic medium occurs ambiguously and, depending on the structure of the substrate, leads to products of alcoholysis or isomerization [1-4]. Alcoholysis takes place primarily with the β-opening of the hydroxypyrane ring [1-4]. Moreover, we have shown previously that the generation of α- or β-hydroxypropionyl groups in the sidechain of a small ring (aziridine or oxirane) leads to intramolecular cyclization with formation of five or six-membered, oxygen-containing heterocycles [5, 6]. In order to study the stereochemical laws of the heterocyclization of diepoxyketones and the synthesis of functionally substituted compounds in the tetrahydropyran-4-one and tetrahydrofuran-3-one series, we have recently studied the reaction of arylaliphatic diepoxyketones with methanol in the presence of boron trifluoride etherate.

As objects of study, we chose α,β,α',β'-diepoxyketones Ia,b-IIIa,b, IVa, Vb, and VIb, prepared by the alkaline epoxidation of the β-arylacryloyloxiranes [5]. The a-group compounds differ from the b-group diastereometers in the relative configuration of the α-carbon atom of the alkylsubstituted epoxide ring in relation to the chiral centers of the trans-arylsubstituted ring.*

The reaction of diepoxyketones I-IVa with methanol in the presence of an equimolar amount of boron trifluoride etherate leads to a mixture of 3-hydroxy-5-methoxy-2-aryltetrahydropyran-

*Comparison of the results obtained with the data in [5, 6] assigns the diastereomers of the diepoxides and azirinylepoxyketones with the relative configurations RRR(SSS) to the a-group and the diastereometers with the relative configuration SRR(RSS), to the b-group.

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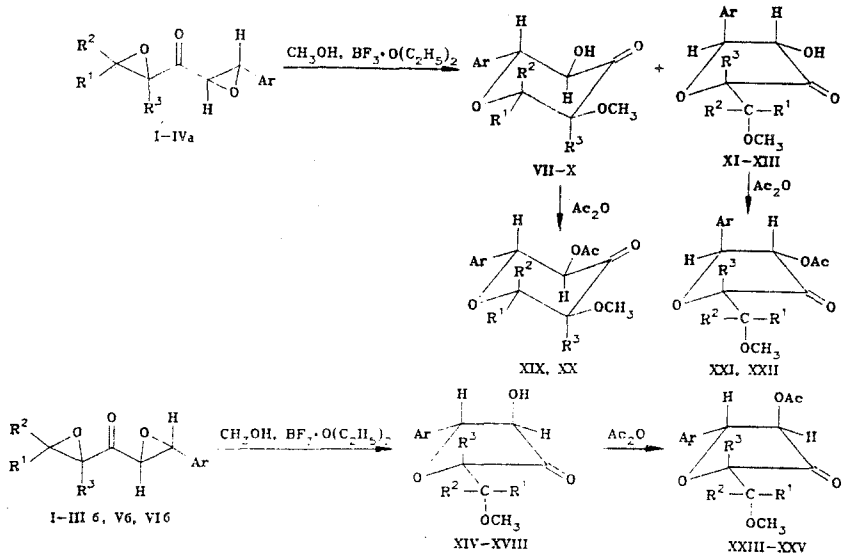
TABLE 1. Characteristics of the Compounds Synthesized

Compound	Empirical formula	mp, °C	Yield, %	Compound	Empirical formula	mp, °C	Yield, %
IIa	$C_{12}H_{11}BrO_3$	98...99	41	XVII	$C_{14}H_{18}O_5$	129...130	59
IIb		72...74	24	XVIII	$C_{12}H_{13}BrO_4$	Oil	43
IIIa	$C_{13}H_{13}BrO_3$	Oil	48	XIX	$C_{15}H_{18}O_5$	Oil	79
IIIb		86...88	27	XX	$C_{16}H_{19}BrO_5$	81...82	90
Vb	$C_{13}H_{14}O_4$	92...93	28	XXI	$C_{15}H_{18}O_5$	Oil	80
VIb	$C_{11}H_9BrO_3$	104...106	40	XXII	$C_{16}H_{19}BrO_5$	Oil	91
VII	$C_{13}H_{16}O_4$	127...128	49	XXIII	$C_{15}H_{18}O_5$	Oil	78
VIII	$C_{13}H_{15}BrO_4$	121...122	50	XXIV	$C_{16}H_{19}BrO_5$	82...83	95
IX	$C_{14}H_{17}BrO_4$	139...141	56	XXV	$C_{14}H_{15}BrO_5$	Oil	88
X	$C_{14}H_{18}O_4$	98...100	52	XXVIIa,b	$C_{14}H_{18}O_4$	Oil	88
XI	$C_{13}H_{16}O_4$	92...93	27	XXVIIIa,b	$C_{16}H_{20}O_5$	Oil	91
XII	$C_{13}H_{15}BrO_4$	Oil	25	XXIXa	$C_{12}H_{11}NO_5$	128...130	51
XIII	$C_{14}H_{17}BrO_4$	83...85	16	XXIXb		92...94	25
XIV	$C_{13}H_{16}O_4$	69...70	57	XXX	$C_{12}H_{13}NO_6$	138...139	20
XV	$C_{13}H_{15}BrO_4$	173...174	65	XXXI	$C_{16}H_{17}NO_8$	162...164	70
XVI	$C_{14}H_{17}BrO_4$	105...106	83				

4-ones (VII-X) and 4-hydroxy-2-methoxyalkyl-5-aryltetrahydrofuran-3-ones (XI-XIII). In the case of diepoxyketone IIIa, only tetrahydropyranone IX was isolated from the reaction and the formation of the tetrahydrofuranone was detected in the IR spectrum of the reaction mixture by the characteristic carbonyl stretching band. At the same time, the reaction of diepoxyketones I-IIIb, Vb, and VIb with methanol under analogous conditions forms primarily only the tetrahydrofuranones XIV-XVIII. Here, compounds XI-XIII differ from diastereomers XIV-XVI in the configuration at the $C_{(2)}$ atom.

The structure, composition, and configuration of compounds VII-XVIII were confirmed by elemental analysis, spectral data, and several chemical conversions (Tables 1, 2).

In the IR spectra of tetrahydropyrans VII-X, there is a C=O stretching band at 1715-1720 cm^{-1}; the absorption band from the OH group is found at 3480-3485 cm^{-1}. In the PMR spectra of compounds VII-X there are two AB-spin systems of lines from the vicinal and geminal protons. The observed HFCC of J = 9.7 Hz is characteristic of vicinal protons in a six-membered ring in the chair configuration and corresponds to the interaction of the axially oriented $C_{(2)}$-H proton with the axial $C_{(3)}$-H proton. The conformation of the $C_{(3)}$ atom in compounds VII-X was established with the aid of the nuclear Overhauser effect. Thus, irradiation of the protons of the $C_{(5)}$-CH_3 group in compounds VI and IX increases the $C_{(3)}$-H proton signal, indicating the axial disposition of the methyl group.



Ia,b VII, XI, XIV, XIX, XXI, XXIII $R^1=R^2=H$, $R^3=CH_3$, $Ar=C_6H_5$; IIa,b VIII, XII, XV $R^1=R^2=H$, $R^3=CH_3$, $Ar=4\text{-}BrC_6H_4$; IIIa, bIX, XIII, XVI, XX, XXII, XXIV $R^1=R^3=CH_3$, $R^2=H$, $Ar=4\text{-}BrC_6H_4$; IVa, X $R^1=R^3=CH_3$, $R^2=H$, $Ar=C_6H_5$; Vb XVII $R^1=R^2=H$, $R^3=CH_3$, $Ar=2\text{-}CH_3OC_6H_4$; VIb, XVIII, XXV $R^1=R^2=R^3=H$, $Ar=4\text{-}BrC_6H_4$

TABLE 2. PMR Spectra of Compounds II, III, and V-XXXI

Compound	PMR spectrum (in CCl_4)*, δ, ppm (J, Hz)
1	2
IIa	1,46 (3H, s, CH_3); 2,28; 2,96 (2H, AB-system J_{AB}=5,0 Hz, CH_2); 3,66; 3,76 (2H, AB-system, J_{AB}=1,5 Hz, CHCH); 7,00; 7,33 (4H, AB-system, J_{AB}=9,0 Hz, arom.)
IIb	1,46 (3H, s, CH_3); 2,83; 3,14 (2H, AB-system, J_{AB}=5,0 Hz, CH_2); 3,40; 3,60 (2H, AB-system, J_{AB}=1,5 Hz, CHCH); 7,00; 7,33 (4H, AB-system J_{AB}=9,0 Hz, arom.)
IIIa	1,25 (3H, d, J=6.0 Hz, CH_3CH); 1,34 (3H, s, CH_3); 3,05 (1H, q, J=6,0 Hz, $CHCH_3$); 3,52; 3,65 (2H, AB-system, J_{AB}=1,5 Hz, CHCH); 7,00; 7,30 (4H, AB-system J_{AB}=9,0 Hz, arom)
IIIb	1,33 (3H, d; J=6,0 Hz CH_3CH); 1,35 (3H, s, CH_3); 3,26 (1H, q, J=6,0 Hz, $CHCH_3$); 3,35; 3,76 (2H, AB-system, J_{AB}=1,5 Hz, CHCH); 7,04; 7,30 (4H, AB-system J_{AB}=9,0 Hz, arom.)
Vb	1,44 (3H, s, CH_3); 2,72; 3,04 (2H, AB-system, J_{AB}=5,0 Hz, CH_2); 3,26; 4,04 (2H, AB-system, J_{AB}=1,5 Hz, CHCH); 3,70 (3H, s OCH_3); 6,80 (4H, m, arom)
VIb	2,95 (1H, d.d J=6,0 Hz, J=2,4 Hz, epoxy ring); 3,09 (1H, d.d J=6,0 Hz, J=4,6 Hz); 3,94 (1H, d.d, J=4,6 Hz, J=2,4 Hz, epoxy ring); 3,55; 4,04 (2H, AB-system J_{AB}=1,5 Hz, CHCH); 7,02; 7,14 (4H, AB-system J_{AB}=9,0 Hz. arom.))
VII	1,46 (3H, s, CH_3); 3,34 (3H, s, OCH_3); 3,40 (1H, s, OH); 3,46; 3,70 (2H, AB-system, J_{AB}=11,0 Hz, CH_2); 3,90 (2H, s, CHCH); 7,15 (5H. s, arom.)
VIII	1,54 (3H, s, CH_3); 3,40 (3H, s, OCH_3); 3,54; 3,74 (2H, AB-system, J_{AB}=11,0 Hz, CH_2); 3,60 (1H, s, OH); 3,98 (2H, s, CHCH); 7,30 (4H, m, arom.)
IX	1,10 (3H, d, J=7.0 Hz CH_3CH); 1,22 (3H, s, CH_3); 3,30 (3H, s, OCH_3); 3,18 (1H, s OH); 3,36 (1H, q, J=7,0 Hz, $CHCH_3$); 4,08; 4,52 (2H, AB-system, J_{AB}=10,0 Hz, CHCH); 7,32 (4H, s, arom.)
X	1,16 (3H, d, J=7.0 Hz, CH_3CH); 1,42 (3H, s CH_3); 3,35 (3H, s OCH_3); 3,70 (1H, q, J=7.0 Hz, $CHCH_3$); 4,00 (1H, s, OH); 4,12 (2H, s, CHCH); 7,26 (5H, m. arom.)
XI	1,31 (3H, s CH_3); 3,18 (1H, s, OH); 3,30 (3H, s, OCH_3); 3,49; 3,71 (2H, AB-system J_{AB}=9.6 Hz, CH_2); 4,12; 5,08 (2H, AB-system, J_{AB}=9,8 Hz, CHCH); 7,35 (5H. arom.)
XII	1,21 (3H, s, CH_3); 3.24 (3H. s, OCH_3); 3.34; 3,57 (2H, AB system J_{AB}=9,8 Hz, CH_2); 3.60 (O, s, OH); 3,80; 4,90 (2H, AB-system, J_{AB}=9,6 Hz CHCH); 7,10; 7,25 (4H, AB-system J_{AB}=9,0 Hz, arom)
XIII	1,05 (3H, d J=7.0 Hz CH_3CH); 1,15 (3H, s, CH_3); 3,20 (3H, s, OCH_3); 3,24 (1H, q, J=7.0 Hz, $CHCH_3$); 3,60 (1H, s OH); 3,70; 4,80 (2H. AB-system J_{AB}=9,0 Hz CHCH); 7,12; 7,30 (4H, AB-system J_{AB}=9,0 Hz, arom)
XIV	1,06 (3H, s, CH_3); 3,16 (3H, s, OCH_3); 3.26 (2H, s, CH_2); 3,50 (1H, s OH); 3,82; 4,45 (2H. AB-system J_{AB}=9,8 Hz. CHCH); 7,15 (5H, m, arom.)
XV	1,12 (3H, s, CH_3); 3.24 (3H, s OCH_3); 3.34 (2H, s, CH_2); 3,60 (1H, s, OH); 3,90; 4.50 (2H. AB-system J_{AB}=9,8 Hz CHCH); 7,30 (4H, m. arom)
XVI	1,10 (3H, d J=7.0 Hz, CH_3CH); 1.20 (3H, s, CH_3); 3,16 (1H, s OH); 3,30 (3H, s, OCH_3); 3.33 (1H, q, J=7.0 Hz, $CHCH_3$); 4,06; 4,50 (2H. AB-system J_{AB}=9,5 Hz CHCH); 7,26; 7,36 (4H. AB-system, J_{AB}=9,0 m. arom.)
XVII	1,12 (3H, s CH_3); 3,25 (3H, s. OCH_3); 3.35 (2H, s CH_2); 3,72 (3H, s OCH_3); 4,14 (1H. d.d J=10.0 Hz, J=6.0 Hz, CHCH); 4,54 (1H, d.d J=6.0 Hz, HO—CH); 5,14 (1H, d.d J=10,0 Hz, CH—Ar); 7,10 (4H, m, arom)
XVIII	3,20 (3H, s, CH_3); 3.25 (1H, s, OH); 3,55 (2H, d, J=3,0 Hz CH_2CH); 3,90; 4,62 (2H, AB-system, J_{AB}=9,0 Hz, CHCH); 4.08 (1H, t, J=3,0 Hz, $CHCH_2$); 7,34 (4H. s, arom.)
XIX	1,56 (3H, s, CH_3); 1,86 (3H, s, CH_3COO); 3,36 (3H, s, OCH_3); 3,54; 3,70 (2H, AB-system, J_{AB}=11,0 Hz, CH_2); 4,26; 5.00 (2H, AB-system, J_{AB}=10,0 Hz, CHCH); 7,18 (5H, s, arom.)
XX	1,05 (3H, d, J=7.0 Hz, CH_3CH); 1,18 (3H, s, CH_3); 1,88 (3H, s, CH_3COO); 3,23 (3H, s, OCH_3); 3,23 (1H, q, J=7,0 Hz, $CHCH_3$); 4,72; 5,00 (2H, AB-system, J_{AB}=10.0 Hz, CHCH); 7,16; 7,30 (4H, AB-system, J_{AB}=9,0 Hz, arom.)
XXI	1,22 (3H, s. CH_3); 2,00 (3H, s, CH_3COO); 3,25 (3H, s, OCH_3); 3,38; 3,54 (2H, AB-system J_{AB}=9,6 Hz, CH_2); 5,10; 5,20 (2H, AB-system, J_{AB}=10,0 Hz, CHCH); 7.20 (5H, s, arom.)
XXII	1,18 (3H, d, J=7.0 Hz, CH_3CH); 1,26 (3H, s, CH_3); 2,00 (3H, s, CH_3COO); 3,28 (3H, s, OCH_3); 3.33 (1H, q, J=7.0 Hz, $CHCH_3$); 5,04 (2H, s, CH_2); 7,16; 7,35 (4H. AB-system, J_{AB}=9,0 Hz, arom.)
XXIII	1.17 (3H, s, CH_3); 1,92 (3H, s, CH_3COO); 3,22 (3H, s, OCH_3); 3,34 (2H, s, CH_2); 4,88; 5.02 (2H, AB-system J_{AB}=10,0 Hz, CHCH); 7,26 (5H, s, arom..)
XXIV	1,06 (3H, d, J=7.0 Hz CH_3CH); 1,16 (3H, s, CH_3); 1,94 (3H, s, CH_3); 3,25 (3H, s, OCH_3); 3,22 (1H, q, J=7,0 Hz, $CHCH_3$); 4,74; 5,00 (2H, AB-system,, J_{AB}=9,5 Hz, CHCH); 7,16; 7,34 (4H, AB-system, J_{AB}=9,0 Hz, arom..)
XXV	2.00 (3H, s, CH_3COO); 3,30 (3H, s, CH_3O); 3,60 (2H, d J=3,0 Hz, CH_2CH); 4,10 (1H. d.d J=3,0 Hz, $CHCH_2$); 4,80; 4,95 (2H, AB-system J_{AB}=9,0 Hz. CHCH); 7,25 (4H, m, arom.)
XXVIIa,b	0,93 (3H, s, CH_3); 1.30 (3H, s, CH_3); 3,19 (3H, s, OCH_3); 3,64 (1H, s, CH); 3,70 (1H, s, OH); 3,95; 4,95 (2H, AB-system, J_{AB}=1,5 Hz, CHCH); 7,14 (5H, m, arom..); 0,93 (3H, s, CH_3); 1,38 (3H, s, CH_3); 3,07 (3H, s, OCH_3); 3,35 (1H. s. CH); 3,66 (1H, s, OH); 3,80; 4,20 (2H, AB-system, J_{AB}=1,5 Hz, CHCH); 7,14 (5H, m, arom.)

TABLE 2 (Continued)

Compound	PMR spectrum (in CCl_4)*, δ, ppm (J, Hz)
1	2
XXVIIIa,b	0,95 (3H, s, CH_3); 1,20 (3H, s, CH_3); 1,92 (3H, s CH_3COO); 3,14 (3H, s, OCH_3); 3,90; 4,26 (2H, AB-system, J_{AB}=1,5 Hz, CHCH); 4,44 (1H, s, CH); 7,15 (5H, m, arom.) 1,16 (3H, s, CH_3); 1,32 (3H, s, CH_3); 1,96 (3H, s, CH_3COO); 3,03 (3H, s, OCH_3); 3,78; 4,18 (2H, AB-system, J_{AB}=1,5 Hz, CHCH); 5,02 (1H, s, CH); 7,15 (5H, m, arom.)
XXIX a	1,46 (3H, s, CH_3); 2,80; 2,96 (2H, AB-system, J_{AB}=5,0 Hz, CH_2); 3,66; 3,76 (2H, AB-system, J_{AB}=1,5 Hz CHCH); 7,00; 7,33 (4H, AB-system, J_{AB}=9,0 Hz, arom.)
XXIX b	1,46 (3Hz s, CH_3); 2,83; 3,14 (2H, AB-system, J_{AB}=5,0 Hz, CH_2); 3,40; 3,60 (2H, AB-system, J_{AB}=1,5 Hz, CHCH); 7,00; 7,33 (4H, AB-system, J_{AB}=9,0 Hz, arom.)
XXX	1,64 (3H, s, CH_3); 3,63; 4,05 (2H, AB-system, J_{AB}=10.8 Hz, CH_2); 4,43 (2H, s, CH_2); 4,51 (1H, sh.s OH); 4,58 (1H, s, OH); 7,80; 8,24 (4H, AB-system, J_{AB}=9,0 Hz, arom.)
XXXI	1,72 (3H, s CH_3); 1,92 (3H, s, CH_3COO); 2,04 (3H, s, CH_3COO); 4,02; 4,25 (2H, AB-system, J_{AB}=11,0 Hz, CH_2); 4,87; 5,32 (2H, AB-system, J_{AB}=9,0 Hz, CH_2); 7,72; 8,16 (4H, AB-system, J_{AB}=9,0 Hz, arom.)

*The PMR spectra of compounds IX, XI, XVI, XXV, and XXX were taken in $CDCl_3$, and of compounds X, XVII, and XVIII, in acetone-d_6.

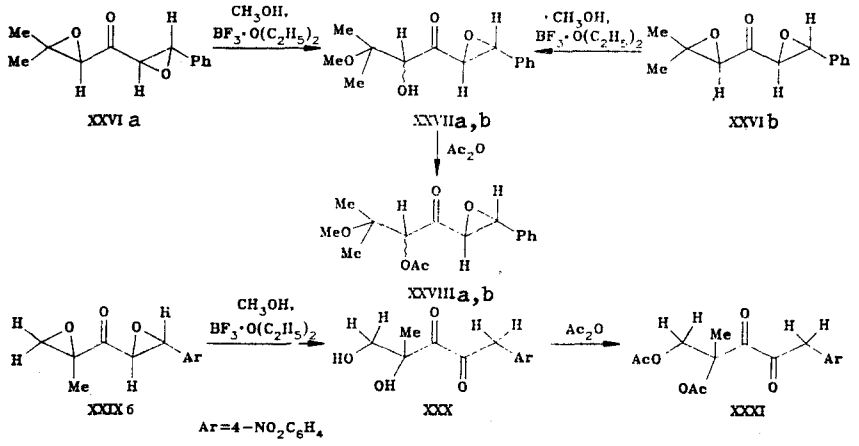
The location of the hydroxyl group on the $C_{(3)}$ atom and the methoxy group on $C_{(5)}$ (rather than the reverse) was shown by comparing the chemical shifts of the vicinal and geminal protons at $C_{(6)}$ in tetrahydropyrans VII and IX and their acetates, XIX and XX, prepared by boiling compounds VII and IX in acetic anhydride. The change in the chemical shifts of the $C_{(3)}$-H_a and $C_{(2)}$-H_a protons in the PMR spectra of acetates XIX and XX in comparison with alcohols VII and IX, is evidence of an equatorial hydroxyl group on the $C_{(3)}$ atom [7].

In the IR spectra of tetrahydrofuranones XI-XVIII, the C=O stretching band is located at 1765-1770 cm^{-1}, which is characteristic of such structures [8]. The hydroxyl stretching band is found at 3460-3480 cm^{-1}. The cisoid arrangement of the methyl and aryl groups in compounds XI-XIII and the transoid arrangement in diastereomers XIV-XVIII were shown with the help of the nuclear Overhauser effect. Irradiation of the $C_{(2)}$-CH_3 protons in diastereomer XI increases the $C_{(4)}$-H proton signal, whereas for tetrahydrofuranone XIV, an increase in the signal from the $C_{(5)}$-H proton is observed. This shows their relative disposition unambiguously. The position of the methoxy and hydroxyl groups in compounds XI-XVIII agrees with the structure presented, because, when ketoalcohols XI, XIII, XIV, XVII, and XVIII are converted to the corresponding acetates, the signals from the vicinal protons are found to be shifted to a weaker field by the anisotropic effect of the ester group while the chemical shifts of the methoxyalkyl group protons remain unchanged.

Analysis of the structures and configurations of the tetrahydropyran-4-ones and tetrahydrofuran-3-ones prepared shows that the size of the oxygen-containing, heterocyclic compound forming depends on the direction in which the alkylsubstituted epoxide ring opens. The subsequent stereospecific heterocyclization of the intermediate α-hydroxy-β-methoxy- or β-hydoxy-α-methoxyepoxyketones leads to five- or six-membered, heterocyclic hydroxyketones. The direction in which the alkylsubstituted epoxide ring opens with methanol in the presence of boron trifluoroide etherate depends on the relative configuration of the chiral centers of the initial diepoxyketones. For the diastereomers, the opening of the epoxy ring is predominately α, and for the b diastereomers, β. These results agree with data on the heterocyclization of aziridinylepoxyketones by methanol in the presence of boron trifluoride etherate [6]. They also confirm the fact that the size of the heterocycle forming is determined by the relative configurations of the centers of chirality coupled through the carbonyl group of the small rings, and does not depend on the nature of the heteroatom.

The presence of bulky substituents in the initial diepoxyketone molecule can prevent cyclization, and the reaction stops at the opening of the aliphatic epoxide ring. Thus, on reaction of 2-methyl-6-phenyl-2,3,5,6-diepoxyhexan-3-ones (XXVIKa,b) with methanol in the presence of boron trifluoride etherate, a mixture of α-hydroxy-β-methoxyketones, XXVIIa,b, is formed. The introduction of pure diastereometers XXVIa and XXVIb into the reaction leads to a diastereomeric mixture of ketones XXVIIa,b, due probably to epimerization of the latter under the reaction conditions.

The PMR spectra of compounds XXVIIa and b preserve an AB-spin system of lines from the vicinal protons of the oxirane ring, the HFCC being 1.5 Hz. On conversion of compounds XXVIIa and b to the corresponding acetates, XXVIIIa and b, the lines of the methine proton are found to be shifted to a lower field. Based on this, the ketones obtained are considered to be the products of β-opening [7].



Isomerization of the diepoxyketones to α-diketones under the effect of boron trifluoride etherate in methanol is the predominant process in the case of 2-methyl-5-(4-nitrophenyl)-1,2,4,5-diepoxypentan-3-one (XXIX). The epoxydiketone that forms undergoes hydrolysis to corresponding diol XXX during the course of the separation. This is confirmed by the conversion of the latter to diacetate XXXI by the action of acetic anhydride.

EXPERIMENTAL

The IR spectra of the substances in 10^{-1} M solutions in CCl_4 (0.01 cm thickness) were taken on a Specord 75 IR spectrophotometer. The PMR spectra of the compounds in CCl_4, $CDCl_3$, and acetone-d_6 solutions were measured on a Tesla BS-467A (60 MHz) and a Bruker WM-360 (360 MHz) spectrometer with HMDS as the internal standard.

Compounds Ia,b, IVa, and XXVIa,b were described in [5]. Diepoxyketones II, IIIa,b, Vb, VIa,b, and XXIXa,b were synthesized by the procedure in [5]. The C and H elemental analyses of the compounds correspond to the calculated values.

3-Hydroxy-2-aryl-5-methoxytetrahydropyran-4-ones (VII-X). 4r-Hydroxy-5t-aryl-2c-methoxyalkyltetrahydrofuran-3-ones (XI-XIII), and 4r-Hydroxy-5t-aryl-2t-methoxyalkyltetrahydrofuran-3-ones (XIV-XVIII). After the addition of 1.3 ml (0.01 mole) of boron trifluoride etherate in 10 ml of methanol to 0.01 mole of diepoxyketone I-Va or I-III, V, VIb in 50-70 ml of methanol the reaction mixture is held for 30-60 min at 18-20°C. The solution is concentrated to 1/3 of its volume and the remainder diluted with a tenfold volume of water. The solution is made alkaline to pH 8 with a sodium carbonate solution and extracted with ether (4 × 20 ml). The ether extract is dried over sodium sulfate, filtered, and evaporated to a volume to 10 ml. Pyranones VII-X crystallize from the ether solution. After removal of the crystalline product, the solution is evaporated down and the residue separated chromatographically on a 2 × 25 cm column with L40/100 silica gel and 1:1 ether/hexane as eluent. Compounds XI-XIII are crystallized from a 1:5 ether/hexane mixture. Tetrahydrofuran-3-ones XIV-XVII are crystallized from a 1:3 ether/hexane mixture. Compound XVIII is isolated with the help of column chromatography on silica gel with 1:1 ether/hexane as eluent.

3-Acetoxy-2-aryl-5-methoxytetrahydropyran-4-ones (XIX, XX) and 4-Acetoxy-5-acyl-2-methoxyalkyltetrahydrofuran-3-ones (XXI-XXV). Compounds VII, IX, XI, XIII, XIV, XVI, and XVIII (5 mmoles) are boiled for 2 h with 10-15 ml of acetic anhydride. The reaction mixture is cooled, diluted with a tenfold amount of water, made alkaline with a sodium carbonate solution to pH 8, and extracted with ether (5 × 30 ml). After the mixture has been dried over sodium sulfate, the solvent is removed in a rotary evaporator. Compounds XX and XXIV are crystallized from 1:10 ether/hexane; compounds XIX, XXI-XXIII appear as noncrystallizing oils.

3-Hydroxy-2-methyl-2-methoxy-6-phenyl-5,6-epoxyhexan-4-ones (XXVIIa,b). To 10.91 g (0.05 mole) of diepoxyketone XXVIa or XXVIb dissolved in 150 ml of methanol, 7.5 ml of boron

trifluoride etherate in 20 ml of methanol are added. After 5 min, the reaction mixture is concentrated to 30-50 ml and the remainder then diluted with three times the amount of water. The solution is made alkaline to pH 8 with sodium carbonate solution and extracted with ether (4 × 20 ml). After the ether solution has been dried over sodium sulfate and the solvent removed, the oily residue isolated is a diastereomeric mixture of XXVIIa and b.

3-Acetoxy-2-methyl-2-methoxy-6-phenyl-5,6-epoxyhexan-4-one (XXVIIIa,b). After 0.01 mole of compounds XXVIIa,b is boiled for 1 h with 7 ml of acetic anhydride, compounds XXVIIIa,b are isolated as described above for pyranone XIX.

1,2-Dihydroxy-2-methyl-5-(4-nitrophenyl)pentan-3,4-dione (XXX). After 1.3 ml (0.01 mole) of boron trifluoride etherate in 10 ml of methanol is added to 2.49 g (0.01 mole) of diepoxyketone XXIXa or XXIXb in 50 ml of methanol, the reaction mixture is treated as described above for compounds VII-IX. Compound XXX is crystallized from 1:2 ether/hexane.

1,2-Diacetoxy-2-methyl-5-(4-nitrophenyl)pentan-3,4-dione (XXXI). After 1.71 g (5 mmole) of diol XXX is dissolved in 10 ml of acetic anhydride, the solution is boiled for 2 h. Compound XXXI is then isolated as described for acetates XIX and XX. Diacetate XXXI is crystallized from ether.

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DETECTION OF NITROSOFURAN ANION RADICALS IN THE ELECTROCHEMICAL REDUCTION OF 5-NITROFURAN. EPR INVESTIGATIONS AND QUANTUM-CHEMICAL CALCULATIONS

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Previously unknown radicals that are associated with the 5-N-furylhydroxylamine–5-nitrosofuran redox system were detected by EPR spectroscopy in the electrochemical reduction of 5-nitrofuran. The electron structures of the free-radical products of the reduction of 5-nitrofuran were calculated by the INDO method. On the basis of the hyperfine structures (hfs) of the EPR spectra and the results of quantum-chemical calculations it was concluded that 5-nitrosofuran anion radicals and the nitrosofuran dimer were recorded.

The metabolic reduction of the nitro group is responsible for the high biological activity of compounds of the 5-nitrofuran series [1]. The study of the structures and properties of the unstable intermediate products of the reduction of nitrofurans, which, it is assumed, play a substantial role in the mechanisms of the carcinogenic, mutagenic, and cytotoxic action of nitrofurans [2], gives rise to particular interest. The structures and properties of the free-radical products of one-electron reduction – the anion radicals – for a large number of 5-nitrofuran derivatives that contain substituents with different chemical natures in the 2

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