3. The tertiary cyclopropylethynyl-substituted alcohols have been dehydrated at 220-250° in hempa medium to the corresponding enynes uncontaminated by isomerization products of the three-membered ring. Dihalomethylenation of these enynes proceeds at the double bond to form the corresponding dicyclopropylacetylenes.

4. We studied complete and partial reduction of the 1-cyclopropyl-2-(1-methyl-2, 2-dihalocyclopropyl)-acetylenes. By dehydrobromination of 1-cyclopropyl-2-(1-methyl-2-bromocyclopropyl)acetylene with potassium tert-butylate in DMSO we synthesized 1-cyclopropyl-2-(3-methylcyclopropen-3-yl)acetylene.

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REACTIONS OF 1-FLUORO-1-BROMO-2-ARYLCYCLOPROPANES IN SOLVOLYSIS CONDITIONS IN THE PRESENCE OF ELECTROPHILIC AND NUCLEOPHILIC AGENTS

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The reactions of compounds of the cyclopropane series in conditions of nucleophilic substitution, as a rule, lead to the formation of allylic derivatives and are accelerated by electrophilic or nucleophilic agents. Lewis bases are used as the electrophilic agents [1, 2] and organic and inorganic bases, as the nucleophilic agents [3]. The reaction rate in the presence of electrophilic agents depends on the nature of the group being cleaved and of the substituent on the cyclopropane ring [4] and on the relative position of the substituent on the three-membered ring and the group being cleaved [5, 6]. In the presence of nucleophilic agents, either ring opening of the cyclopropane ring [1, 3, 7, 8] or reactions with retention of the ring [9, 10] can occur, depending on the nature of the ring substituent. The behavior of unsymmetrical gem-dihalocyclopropanes in conditions of solvolysis has not yet been studied.

The aim of the present study is to establish the structure of the reaction products from 1-fluoro-1-bromo-2-arylcyclopropanes (I) with methanol in the presence of electrophilic and nucleophilic agents, to study the influence of substituents on the aromatic ring on the reaction rate, and to compare the reactivity of the syn and anti isomers.

The I are obtained as mixtures of both isomers [11] from the reaction of the corresponding substituted styrenes with fluorobromocarbene. Solvolysis in the presence of electrophilic agents was conducted by heat-

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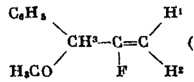
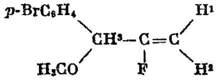
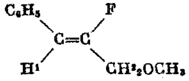
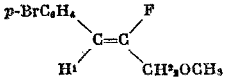
TABLE 1. Parameters of the NMR Spectra of the Solvolysis Products of anti-1-Fluoro-1-bromo-2-phenyl- and anti-1-Fluoro-1-bromo-2-(p-bromophenyl)cyclopropanes

Compound	Chemical shifts						J, Hz			
	τ, ppm					ppm				
	H^1	H^2	H^3	OMe	Ar	^{19}F *	J_{1-2}	J_{1-F}	J_{2-F}	J_{3-F}
 (II a)	5,54	5,50	5,58	6,88	2,95	54,8	3,0	50,0	17,0	11,0
 (II b)	5,50	5,48	5,58	6,77	2,80	54,0	3,0	49,0	18,0	12,0
 (III a)	4,42	6,15	–	6,75	2,95	51,8	0,5	39,0	15,0	–
 (III b)	4,48	6,12	–	6,72	2,80	51,3	0,5	39,0	16,0	–

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*From C_6F_6 in a weaker field.

TABLE 2. Rate Constants and Ratio of Methanolysis Products of anti-1-Fluoro-1-bromo-2-arylcyclopropanes in the Presence of $AgNO_3$ (50 ± 0.1°C; $AgNO_3$ concn. = 1.8 M)

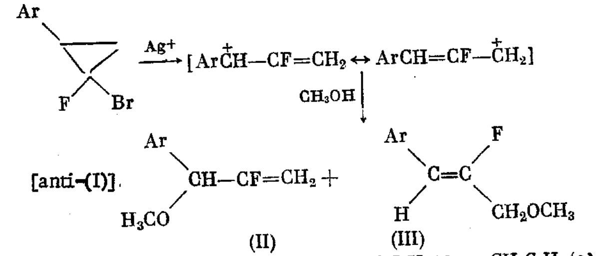
Ar in anti-I	$k \cdot 10^4$, sec^{-1}	k_{rel}	$\lg k_{rel}$	σ^+ [16]	(II) : (III)
p-$CH_3C_6H_4$	2,91±0,10	3,27	0,51	−0,311	4,0
m-$CH_3C_6H_4$	1,19±0,04	1,34	0,13	−0,066	3,0
C_6H_5	0,89±0,08	1	0	0	2,5
p-BrC_6H_4	0,38±0,06	0,43	−0,37	+0,150	2,0
m-BrC_6H_4	0,11±0,01	0,12	−0,92	+0,405	1,5

ing equimolar amounts of isomeric I and $AgNO_3$ in excess methanol at 50°C for 15 h. Investigation of the relative activity of the syn and anti isomers of I showed that in the conditions studied, only the anti isomer reacts; the syn isomer remains practically unchanged. Control experiments established that the starting compounds are not isomerized in the reaction conditions.

The methanolysis products from anti-I are the isomers 2-fluoro-3-methoxy-3-aryl-1-propene (II) and 2-fluoro-3-methoxy-1-aryl-1-propene (III). Gas — liquid chromatographic analysis of the reaction mixtures showed a predominance of II over III for all investigated I, with the ratio of the solvolysis products depending on the nature of the substituent on the aromatic ring. The absence of isomerization of the solvolysis products in the reaction conditions was established by control experiments. On studying the thermal stability of the single isomers IIa and IIIa (140°C, 7 h), partial isomerization of IIa to IIIa was observed. Solvolysis conducted in more severe conditions (140°C) leads primarily to the formation of the more thermodynamically stable III, which was used for obtaining preparative amounts of IIIa. The structure of II and III was established by NMR spectra of IIa, IIb, IIIa, and IIIb (Table 1).

The agreement between the spin — spin coupling constants for fluoro-substituted alkenes [12] confirms the structure for II and III. The high values of J_{1-F} for IIIa and IIIb indicate a trans configuration.

The formation of II and III in the methanolysis of anti-I in the presence of $AgNO_3$ can be represented by scheme:



Ar=C_6H_5 (a), p-BrC_6H_4 (b), m-BrC_6H_4 (c), p-$CH_3C_6H_4$ (d), m-$CH_3C_6H_4$ (e)

Cleavage of the bromine ion is accompanied by simultaneous opening of the thermodynamically unstable cyclopropyl cation to give an allylic cation. According to Woodward — Hoffmann rules, this ring opening occurs without rotamerism [13]. According to [14], during disrotatory opening of a cyclopropane ring, substituents located in a position anti to the group being cleaved rotate to the outside, whereas those located in a syn position rotate to the inside. Steric hindrance between the aryl group and the hydrogen atom prevents ring opening of syn-I. In the case of the anti isomers, there is a weaker interaction between the two hydrogen atoms. Considerable experimental data confirm a higher solvolysis rate for the anti isomers in comparison to the syn isomers in the presence of electrophilic agents [1, 2, 5, 6].

TABLE 3. Parameters of the NMR Spectra of the Reaction Products from 1-Fluoro-1-bromo-2-phenylcyclopropane with Methanol in the Presence of t-C_4H_9OK

Compound	Chemical shifts							Spin–spin coupling const, Hz					
	τ, ppm						ppm ^{19}F*						
	H^1	H^2	H^3	OMe	OMe	Ph		J_{1-2}	J_{1-3}	J_{2-3}	J_{1-F}	J_{2-F}	J_{3-F}
(VI)	8,90	8,75	7,78	7,00	6,75	2,95	—	5,5	7,4	10,1	—	—	—
(IV)							9,4				10	9	1,5
(V)							30,5				7	13	14
(VII)	5,1	4,6	4,6	6,9	6,9	3,0	—	0,5	0,5	1			

*From C_6F_6 in a weaker field.

TABLE 4. Degree of Conversion of 1-Fluoro-1-bromo-2-arylcyclopropanes During Methanolysis in the Presence of t-C_4H_9OK

Reaction time, min	Conversion, %					
	(Ia)		(Id)		(If)	
	syn	anti	syn	anti	syn	anti
10	35	17			100	100
20	60	28				
30			7	4		
60	80	40	17	8		
90			21	12		
120	92	56	29	15		

The arylallylic cation formed can react with methanol both at the α- and the γ-carbon atom, giving II and III, respectively. The distribution of the positive charge between the terminal atoms of the allylic system depends on the nature of the substitutents. Since a predominance of II over III is observed, it can be proposed that the positive charge in the arylallylic cation is concentrated mainly on the benzylic C atom. Disproportionation in charge distribution increases on introducing an electron-donor substituent on the aromatic ring and decreases on introducing an electron-acceptor substituent, which leads to a change in the II : III ratio, depending on substituent nature (Table 2). The structure and ratio of solvolysis products of anti-Ia agree with data in [15].

For finding the correlative dependence between the structure of I and their reactivity in the reaction with methanol in the presence of $AgNO_3$, the relative rate constants were calculated. Statistical analysis of the values for k_{rel} and various substituent constants (σ, σ^+, σ^0, σ^H) showed that log k_{rel} correlates best of all with the Brown σ^+ constants in accordance with the equation

$$\lg k_{\text{rel}} = (-2.0 \pm 0.1)\,\sigma^+ - 0.06 \pm 0.03,$$
$$(r = 0.995,\quad s_0 = 0.06)$$

The correlation of log k_{rel} with σ, σ^0, and σ^H was significantly poorer (r=0.986, 0.982, 0.968, respectively).

As can be seen from Table 2, the introduction of electron-donor substituents in the aromatic ring accelerates solvolysis, whereas electron-acceptor substituents slow the reaction. The high values for the rate constants with respect to absolute magnitude $|\rho| = 2.0$ indicates a transitory state, close to an ionic state. The correlation of log k_{rel} with σ^+ constants also indicates a transitory state in which the active center is positively charged and in direct polar conjugation with electron-donor substituents of the aromatic ring. The appearance of a positive charge on the benzyl C atom (and on the conjugated γ-C atom) support a simultaneous occurrence of bromine ion cleavage and cyclopropane ring opening in the solvolysis of anti-I.

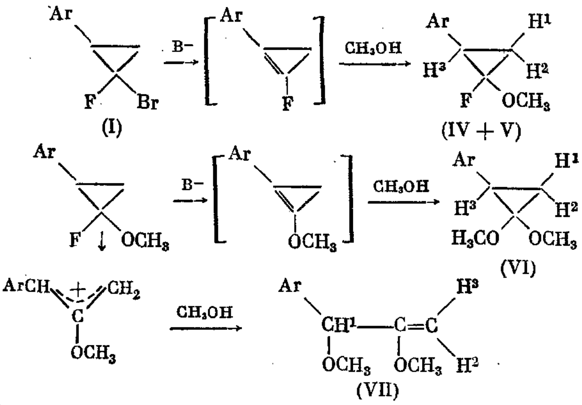
To investigate the behavior of isomeric I in solvolysis conditions in the presence of nucleophilic agents, the reaction was conducted in tenfold excess methanol at 50°C with fivefold excess K_2CO_3, NaOH, CH_3ONa, and t-C_4H_9OK (KTB). An acceleration of the reaction was observed with increasing basicity of the medium generated with methoxy anions. In the presence of K_2CO_3, no reaction products were observed and in the presence of NaOH, only trace amounts, but addition of CH_3ONa caused a significant increase in the reaction rate. The highest reaction rate was observed on adding KTB. Gas — liquid chromatographic analysis of the reaction mixtures showed identical reaction products; therefore, further investigation was conducted in the presence of KTB.

On heating mixtures of I isomers in methanol at 50°C with fivefold excess KTB, the starting syn isomers react faster than the anti isomers, in contrast to the solvolysis behavior in the presence of $AgNO_3$. The ratio of syn-Ia : anti-Ia rate **constant is 2.** The main reaction product is 1,1-dimethoxy-2-arylcyclopropane (VI). Since the I investigated contain aryl fragments which do not participate in the reaction, structure elucidation for the reaction products was conducted using the reaction products of Ia as an example. A comparison of GLC analysis for the reaction mixtures of all I investigated showed analogous reaction products. Parameters of the NMR spectra of VI are presented in Table 3.

Gas — liquid chromatographic data indicate that along with the main product VI, compounds IVa, Va and VIIa are formed in amounts of 10%, based on VIa. Compounds IVa and Va could not be isolated due to their instability. The structure for IVa and Va was established on the basis of ^{19}F NMR spectra of the fraction containing the starting syn- and anti-Ia in addition to the reaction products. The similarity of the spectra for IVa and anti-Ia and for Va and syn-Ia and the closeness in the J_{H-F} values for each pair suggest the structure of anti-1-fluoro-1-methoxy-2-phenylcyclopropane for IVa and of syn-1-fluoro-1-methoxy-2-phenylcyclopropane for Va. Proton magnetic resonance spectra of the fraction containing 70% VIIa suggest that this compound is 2,3-dimethoxy-3-phenyl-1-propene.

The rate of solvolysis depends essentially on the nature of substituents in I. A comparison of the degree of conversion of I during methanolysis at 50°C in the presence of fivefold excess KTB is presented in Table 4.

The data presented indicate an accelerating influence by the electron-acceptor substituents and an inhibiting influence by electron-donor substituents on the aromatic ring, in contrast to solvolysis in the presence of $AgNO_3$. The conversion of I in methanol in the presence of bases can be represented by the scheme below. The reaction apparently occurs via two sequential processes, the first of which consists in elimination of HX (X = halogen) under the influence of a base with the formation of the corresponding cyclopropenes. The higher reactivity of the syn isomers is probably associated with a preferred trans dehydrohalogenation. The elimination of HX in the presence of strong bases is used in the synthesis of cyclopropenes since aryl substituents on the three-membered ring promote dehydrohalogenation [17, 18]. The introduction of electron-acceptor substituents on the aromatic ring, leading to activation of the benzylic proton, should accelerate the reaction, which is borne out experimentally.



Ar: C_6H_5 (a), p-BrC_6H_4 (b), m-BrC_6H_4 (c), p-$CH_3C_6H_4$ (d), 2, 4, 6-$(CH_3)_3C_6H_2$ (e), C_6F_5 (f)

In the second stage of the reaction, addition of methanol to the cyclopropene double bond occurs. The IV-V mixture formed is again attacked by the base, with subsequent reaction with methanol to give VI. The formation of a product from the opening of the three-membered ring is not unexpected since substitution of the Br by a methoxy group in the arylcyclopropanes is conducive to heterolysis of the C–F bond.

In order to choose between two possible routes of VI formation, i.e., by substitution of X atoms by methoxy groups or by β-elimination of HX with subsequent addition of methanol to the cyclopropene, reaction of Ia with KTB in CD_3OD was carried out. A sharp decrease in the intensity of the signal for the benzylic proton in comparison to the methylenic protons of the cyclopropane ring in the PMR spectrum of VI confirm the elimination — addition nature of the process.

A study of the effect of electrophilic and nucleophilic agents on the solvolysis of I has shown that the nature of the additive exerts a decisive influence both on the direction of the reaction and on the reactivity of the initial syn and anti isomers. In the presence of $AgNO_3$, cleavage of the three-membered ring occurs and is accelerated by electron-donor substituents. Only the anti isomer is reactive in these conditions. The addition of bases, however, leads to conversion with retention of the cyclopropane structure and acceleration by electron-acceptor substituents. In these conditions, the syn isomer is more reactive.

EXPERIMENTAL

The IR spectra were recorded on a UR-20 instrument from thin layers. The PMR spectra were taken on a Tesla BS-487C spectrophotometer at solution concentration (CCl_4) 5-10%, using HMDS as the internal standard. The ^{19}F NMR were recorded on a Varian A 56/60 A instrument with C_6F_6 as the internal standard at frequency 56.4 MHz. Gas — liquid chromatographic analyses were conducted on an LKhM-8MD apparatus on columns filled with liquid phases (15% based on Chromaton N-AW) Apiezon L and Silicone XE-60.

2-Fluoro-3-methoxy-3-phenyl-1-propene (IIa). A mixture of 6.45 g (0.03 mole) of isomeric 1-fluoro-1-bromo-2-phenylcyclopropanes and 5.1 g (0.02 mole) of $AgNO_3$ in 15 ml of methanol was heated at 50°C with stirring for 15 h, after which the reaction mixture was cooled, diluted with water, extracted with ether, and dried with $MgSO_4$. After solvent removal, it was fractionated in vacuo. Yield of IIa, 2.1 g (75%, calculated on anti isomer), bp 71-72°C (14 mm); n_D^{20} 1.5032. Found: C 72.18; H 6.49%. $C_{10}H_{11}FO$. Calculated: C 72.29, H 6.63; F 11.44%. IR spectrum (ν, cm^{-1}): 875, 990 ($=CH_2$), 1050-1100 (C—O—C), (C—F), 1680 (C=C), 2840 (OCH_3). NMR data are given in Table 1.

2-Fluoro-3-methoxy-1-phenyl-1-propene (IIIa). Isomeric 1-fluoro-1-bromo-1-phenylcyclopropane (4.3 g, 0.02 mole) in methanol was heated in a steel ampul equipped with a valve for 10 h at 140°C. After cooling, water was added and the reaction mixture was extracted with ether. Compound IIIa was isolated by vacuum distillation at bp 120-121°C (14 mm). Yield of IIIa 2.3 g (70%); n_D^{20} 1.5320. Found: C 72.37; H 6.52%. $C_{10}H_{11}FO$. Calculated: C 72.29; H 6.63; F 11.44%. IR spectrum (ν, cm^{-1}): 1725 (C=C), 1100 (C—F), 2830 (OCH_3).

2-Fluoro-3-methoxy-3-(p-bromophenyl)prop-1-ene (IIb) and 2-Fluoro-3-methoxy-1-(p-bromophenyl)-prop-1-ene (IIIb). These compounds were obtained by the method described for IIa. Yield of IIb 20%, bp 102-104°C (14 mm). IR spectrum (ν, cm^{-1}): 1680 (C=C), 1080-1150 (C—O—C), (C—F), 2830 (OCH_3). Compound IIIb was not isolated. The NMR data (Table 1) are given for the fraction containing, according to GLC, 50% IIIb, 25% starting syn-Ib, and 25% IIb.

Method of Kinetic Measurements. Thermostatted isomeric 1-fluoro-1-bromo-2-arylcyclopropane (0.001 mole), internal standard (0.0001 mole), $AgNO_3$ (0.01 mole), and methanol (5 ml) were added rapidly to a three-necked flask equipped with a stirrer and a reflux condenser and placed in a thermostat (50 ± 0.1°C). At predetermined time intervals, samples were taken, cooled rapidly in an ice bath, and diluted with water, and slowly chromatographed.

1,1-Dimethoxy-2-phenylcyclopropane (VIa). A mixture of 0.02 mole of isomeric 1-fluoro-1-bromo-2-phenylcyclopropanes and 0.01 mole of $t-C_4H_9OK$ in 10 ml of methanol was heated at 50°C under stirring for 10 h, diluted with water, and extracted with ether. The ether extract was washed to neutral, dried, and vacuum distilled. Yield of VIa 1.2 g (67%), bp 83-84°C (12 mm); n_D^{20} 1.5222. Found: C 74.29; H 7.95%. $C_{11}H_{14}O_2$. Calculated: C 74.16; H 7.86%. NMR data are given in Table 3.

CONCLUSIONS

1. The reaction of 1-fluoro-1-bromo-2-arylcyclopropanes with methanol occurs predominately with retention of the three-membered ring in the presence of bases and exclusively via ring cleavage in the presence of $AgNO_3$.

2. syn-1-Fluoro-1-bromo-2-arylcyclopropanes do not react in the presence of $AgNO_3$ at 50°C, but are more reactive than the anti isomers in the presence of bases.

3. Electron-donor substituents on the aromatic ring of 1-fluoro-1-bromo-2-arylcyclopropanes accelerate the reaction in the presence of electrophilic agents and inhibit the reaction on addition of a base.

4. Logarithms of the relative rate constants for the reaction of 1-fluoro-1-bromo-2-arylcyclopropanes with methanol in the presence of $AgNO_3$ correlate with Brown's σ^* constants.

5. The reaction of 1-fluoro-1-bromo-2-arylcyclopropanes with alcohol in the presence of bases occurs via sequential elimination and addition.

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