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Functionalized α-Bromocyclopropylmagnesium Bromides: Generation and Some Reactions

I. G. Bolesov[a], V. A. Solov'eva[a], and M. S. Baird[b]

[a]*Lomonosov Moscow State University, Moscow, 119992 Russia*
e-mail: dr.vera.solovyeva@gmail.ru
[b]*Department of Chemistry, University of Wales Bangor, LL 57 2 UW Gwynedd, UK*

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Abstract—Functional derivatives of *gem*-dibromocyclopropanes (ethers and esters of *gem*-dibromocyclopropylmethanol, 2,2-dibromocyclopropanecarboxylic acids and their esters) undergo partial hydrodebromination at the treatment with isopropylmagnesium bromide (3–6 mol-equiv) in THF and then in methanol at –60°C affording the corresponding monobromides in 64–95% yields. The addition of nonsolvated magnesium bromide to the reaction mixture results in the considerable reduction of the amount of the Grignard reagent (from 6 to 3 mol-equiv). This allows achieving the partial hydrodebromination of 2,2-dibromocyclopropanecarboxylic acids.

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High synthetic potential of *gem*-dihalocyclopropanes provides a possibility to utilize them as initial compounds for the efficient and selective preparation of diverse compounds: derivatives of monohalocyclopropane, cyclopropene, benzocyclopropene, bicyclobutane, allene, cumulene, cyclopentane, cyclopentadiene, and many other hydrocarbon systems, both unsubstituted and containing functional groups [1]. The synthesis of *gem*-dihalocyclopropanes is underlain by the application of available initial compounds: alkenes, dienes, unsaturated ethers and esters, and haloforms [2].

The transformations of cyclopropylidene derivatives that can br easily generated from the corresponding *gem*-dihalocyclopropanes are attractive because of the opportunities to perform efficient and selective conversions with the help of simple organometallic reagents [3]. The versatile synthetic routes were found in the reactions of lithium and magnesium cyclopropane derivatives containing polar functional groups. The cyclopropylidenelithium derivatives enter into reactions of intra- and intermolecular [1+2]-cycloaddition [4], 1,3-, 1,4-, and 1,5-C–H-insertion, and insertion into the H–heteroatom bonds [5]. The intramolecular acyl transfer in the functional derivatives of *gem*-dibromocyclopropane occurs with a high diastereo- and enantioselectivity [6]. The hydrodebromination of chiral 2,2-dibromocyclopropanecarboxylic acids under the methyllithium treatment results in the formation of the second optical center and affords monobromo-substituted acids of the optical purity up to 98% [7]. In such selective transformations often just the polar functional groups govern the diastereoselectivity of the metallation of *gem*-dihalocyclopropanes.

Unlike the α-halocyclopropyllithium derivatives the α-halocyclopropylmagnesium halides are far less studied. In early publications the conditions of the generation of α-bromocyclopropylmagnesium bromides without functional groups were described: The treatment of 1,1-dibromo-2-methyl-2-phenylcyclopropane with Grignard reagents in THF at –60°C [8] of the reaction of 7,7-dibromobicyclo[4.1.0]heptane with isopropylmagnesium bromide (2.4 mol-equiv) [9]. The corresponding α-chlorocyclopropylmagnesium chlorides can be effectively obtained by the exchange reactions from α-halo-cyclopropyl sulfoxides with the aid of alkylmagnesium chlorides [10].

In keeping with [11–13] the intermolecular reactions of alkyl- and aryl-*gem*-dibromocyclopropanes with Grignard reagents (3–4 mol-equiv) in THF at –60°C followed by quenching of the reaction mixtures with electrophiles

are efficient for the preparation of the products of the halogen substitution by the corresponding electrophile. Therewith the *cis*- and *trans*-isomers were commonly obtained in the ~1 : 1 ratio.

In this study[1] we investigated the features of hydrodebromination reactions of *gem*-dibromocyclopropane functional derivatives under the treatment with organolithium and organomagnesium reagents. The selected objects of the research are readily available analogs of already known biologically active compounds or precursors [15, 16].

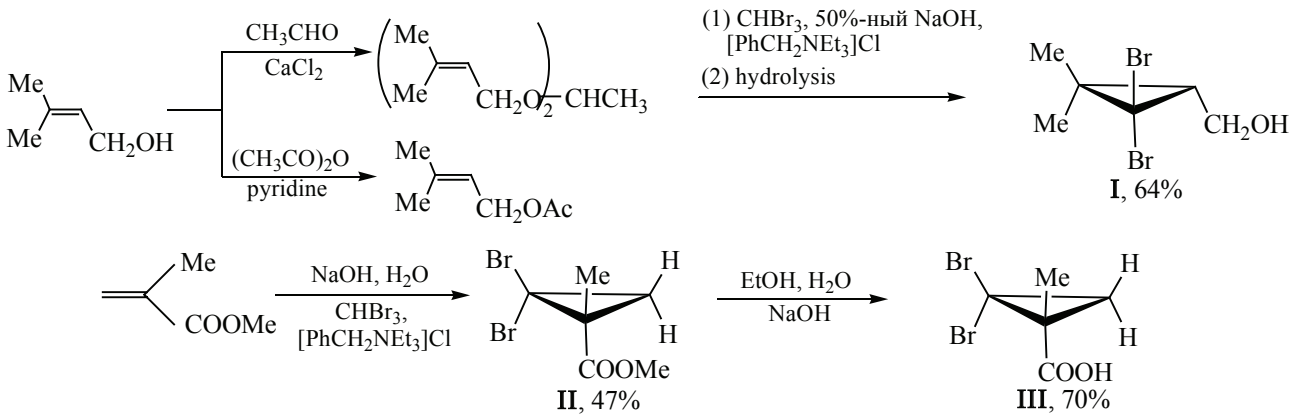
The protection of the hydroxy group and the cyclopropanation of acetaldehyde diprenyl acetal as well as methyl methacrylate and also the subsequent hydrolysis of the cyclopropanation products were carried out by the following established techniques [7, 17, 18] (Scheme 1). The obtained 2,2-dibromo-3,3-dimethylcyclopropylmethanol (**I**), methyl 1-methyl-2,2-dibromocyclopropanecarboxylate (**II**), and 1-methyl-2,2-dibromocyclopropanecarboxylic acid (**III**) were purified by vacuum distillation, recrystallization, or by silica gel column chromatography.

Ethers **IV, V** were obtained by alkylation of sodium alcoholates of alcohol **I** with methyl iodide or allyl bromide or via Williamson reaction in DMSO as solvent (Scheme 2). Acetate **VI** was prepared by treating the initial compound **I** with acetic anhydride in the presence of pyridine. The reaction products as a rule were isolated by vacuum distillation or by column chromatography on silica gel. The structure of compounds **I–VI** was confirmed by IR, ^{13}C and ^{1}H NMR spectra.

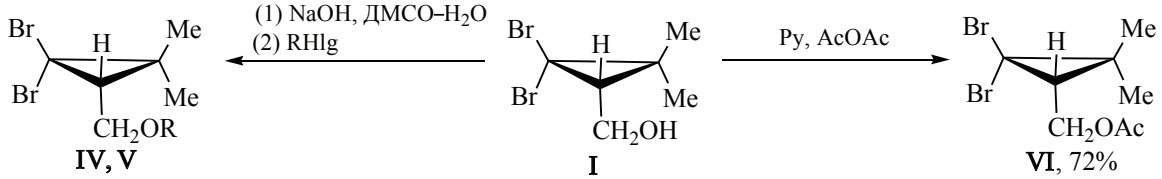
2,2-Dibromo-3,3-dimethylcyclopropanecarboxylic acid (**VII**) and *trans*-2,2-dibromo-3-phenylcyclopropanecarboxylic acid (**VIII**) were obtained by oxidation of 2,2-dibromo-3,3-dimethylcyclopropylmethanol and *trans*-2,2-dibromo-3-phenylcyclopropanecarbaldehyde with chromic anhydride in glacial acetic acid. Salts **IX, X** were prepared by neutralization of cyclopropanecarboxylic acid **VII** with potassium or lithium carbonates at boiling in methanol (Scheme 3).

Compounds **II, IV–VI** were treated with the solution of isopropylmagnesium bromide (1.1–3 mol-equiv) in THF at –60°C in an argon atmosphere, the reaction mixtures were quenched with methanol at the same tempera-

Scheme 1.



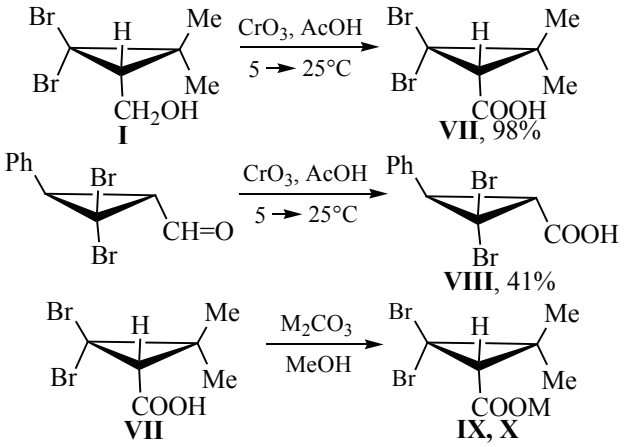
Scheme 2.



R = Me (77%, **IV**), All (82%, **V**).

[1] For preliminary communication, see [14].

Scheme 3.



M = K (85%, **IX**), Li (89%, **X**).

ture. The analysis of the ^{1}H NMR spectra of the reaction mixtures showed that as a result of the reaction stereoisomeric products of the partial hydrodebromination are formed in the ratio 1.2–1.7 (Table 1, Scheme 4). The ratio of the stereoisomeric monobromides was estimated from the integral intensities of the proton signals of the CHBr groups in the region 3.0–3.7 ppm, and the configuration of the formed *cis*- and *trans*-monobromo ethers was determined from the spin-spin coupling constants of the protons in groups CHBr and $CHCH_2OR$ of the small ring. The compounds having J 7–8 Hz were assigned to the *cis*-series, with J 4–5 Hz, to the *trans*-series [19].

The performed experiments demonstrated that the partial low-temperature hydrodebromination of ethers and esters of 2,2-dibromo-3,3-dimethylcyclopropylcarbinol in tetrahydrofuran at the treatment with alkylmagnesium halide and methanol made it possible to obtain the corresponding derivatives of monobromocyclopropane in 64–95% yields at the stereoisomers ratio 1.2 : 1.7.

The majority of the stereoisomeric reaction products were easily separated by the preparative chromatography on silica gel. However we failed to separate in this way stereoisomers **XVIIa, XVIIb**.

The complete hydrodebromination of compound **II** under the described conditions (THF, –60°C, 30 min) was achieved already at the use of 1.1 mol-equiv of isopropylmagnesium bromide, whereas compound **XII** was not completely metallated even with 2.5 mol-equiv of the Grignard reagent. The total conversion of compound **XII** was attained at the action of no less than 3 equiv of *i*-PrMgBr.

The treatment of acid **VII** with 1.5–2.5 mol-equiv of the Grignard reagent at –60°C and with hydrochloric acid at room temperature led only to the initial compound. In the ^{1}H NMR spectra of these reaction mixtures even traces of hydrodebromination product **XVIII**

Table 1. Low-temperature (–60°C) hydrodebromination of functional derivatives of *gem*-dibromocyclopropanes in THF with the use of *i*-PrMgBr and proton donors

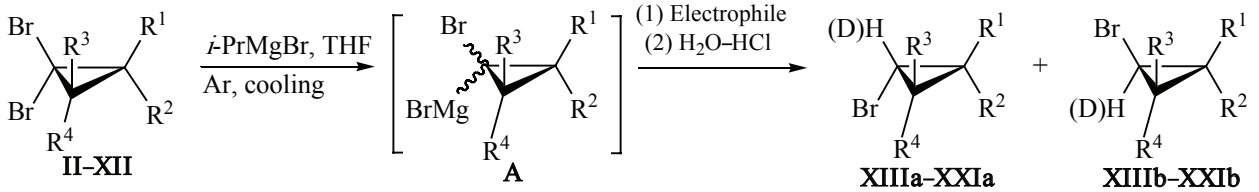
No. of initial compound	Quantity of *i*-PrMgBr, equiv	Time, min	Proton donor[a]	Reaction products (*cis*-/*trans*-, %)	Yield, %
II	1.1	30	MeOH	**XIII** (55/45)	72
III	6	30	MeOH, HCl	**XIV** (75/25)	85
IV	3	40	MeOH	**XV** (47/53)	64
V	3	30	MeOH	**XVI** (37/63)	79
VI	3	30	MeOH	**XVII** (45/55)	95
VII	6	30	MeOH, HCl	**XVIII** (78/22)	90
VII	6	30	$(CD_2)_3CO$, HCl	**XX** (75/25)	83[b]
VII	6	30	MeOD, HCl	**XX** (75/25)	83[b]
VIII[c]	7	30	MeOH, HCl	**XIX** (90/10)	88
XI	6	30	MeOH, HCl	**XVIII** (74/26)	86
XII	3	30	MeOH	**XXI** (47/53)	64

[a] 1 mL, 10 min.

[b] Products of deuterodebromination were formed, **XXa**, **XX**b.

[c] The reaction was carried out at –70°C, the workup with methanol, at ≤ –65°C.

Scheme 4.



$R^1 = R^2 = H$, $R^3 = Me$, $R^4 = COOMe$ (**II, XIII**), COOH (**III, XIV**); $R^1 = R^2 = Me$, $R^3 = H$, $R^4 = CH_2OMe$ (**IV, XV**), CH_2OAl (**V**, **XVI**), CH_2OAc (**VI, XVII**), COOH (**VII, XVIII**); $R^1 = Ph$, $R^2 = R^3 = H$, $R^4 = COOH$ (**VIII, XIX**); $R^1 = R^2 = Me$, $R^3 = H$, $R^4 = COOD$ (**XI**), COOH (**XX**, D); $R^1 = Me$, $R^2 = Ph$, $R^3 = R^4 = H$ (**XII, XXI**).

were not detected. Apparently under these conditions the α-bromocyclopropylmagnesium bromides **A** did not form, and the only reaction product was the bromomagnesium salt of *gem*-dibromocyclopropanecarboxylic acid (**VII**). The stereoisomeric monobromo-substituted acids **XVIIIa, XVIIIb** were found among the reaction products only at applying more than 3 equiv of the Grignard reagent. After the treatment of acid **VII** with 6 mol-equiv of the organomagnesium compound quantitative metallation of the *gem*-dibromocyclopropane fragment of the bromomagnesium salt of the carboxylic acid occurred quantitatively.

Taking into consideration the experimental results (Table 1) the quenching of magnesium carboxylates of α-bromocyclopropylmagnesium bromides with acetone or methanol led to the predominant formation of the *cis*-products of hydrodebromination. The ratio of stereoisomeric *cis*- and *trans*-monobromocyclopropanecarboxylic acids **XIVa, XIVb** and **XVIIIa, XVIIIb** was ~3 : 1. The analogous treatment of *trans*-3-phenyl-2,2-dibromocyclopropanecarboxylic acid (**VIII**) with the solution of isopropylmagnesium bromide in THF, further with methanol at –60°C and hydrochloric acid at room temperature afforded the mixture of monobromo-substituted acids **XIXa, XIXb** in the ratio 9 : 1.

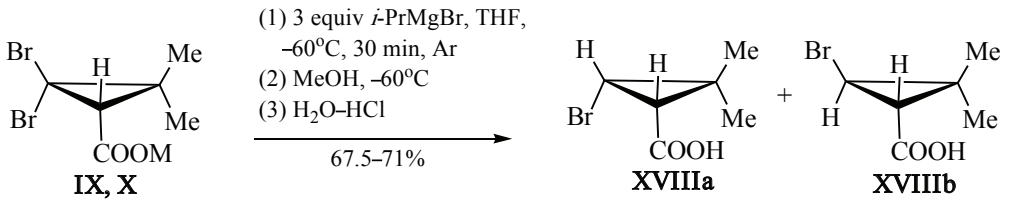
Probably the formed in the course of the reaction magnesium (or bromomagnesium) salts of the cyclopropanecarboxylic acids possess a complex structure which also may contain also isopropylmagnesium bromide. Presumably the bulky complex cation of the magnesium salt of cyclopropanecarboxylic acid hinders the attack of isopropylmagnesium bromide on the bromine atom in the *cis*-position with respect to the carboxy group, whereas the more remote bromine atom located in the *trans*-position may be more available for the reaction with the Grignard reagent. The treatment of these reaction mixtures with methanol and HCl resulted in stereoisomeric 2-bromocyclopropanecarboxylic acids with *cis*-form prevailing.

We also examined the behavior of *gem*-dibromocyclopropyl carboxylates of the other metals under the described conditions. To this end we treated potassium and lithium derivatives **IX, X** with isopropylmagnesium bromide (3 equiv) at –60°C in THF for 30 min, then with methanol at the same temperature and with hydrochloric acid at 20°C. The analysis of NMR spectra of the reaction mixtures showed that the conversion of lithium salt **X** reached 90% and of potassium salt **IX**, 100%. A complex mixture of substances was obtained in the reaction where 2-bromocyclopropanecarboxylic acid **XVIIIa, XVIIIb** prevailed. The ratio of *cis*- and *trans*-isomers depended on the nature of the cation of the cyclopropanecarboxylic acid[2] salt. The treatment of lithium derivative **X** with isopropylmagnesium bromide followed by the quenching of the reaction mixture with methanol and HCl led to the formation of the mixture of *cis*- and *trans*-2-bromocyclopropanecarboxylic acids **XVIIIa, XVIIIb** in the ratio 3 : 1. Potassium derivative **IX** reacted more actively and less selectively giving a mixture of equal amounts of *cis*- and *trans*-monoobromo derivatives **XVIII** (Scheme 5).

To clear the origin of the proton substituting the halogen atom we carried out experiments using methanol-d_1 and acetone-d_6 for quenching the reaction mixtures generated from acid **VII** and isopropylmagnesium bromide. In each of these cases products of deuterodebromination **XXa, XXb** were isolated as showed the appearance of singlet signals of CH group linked to the carboxy group at

[2] The diastereoselectivity of magnesium debromination of *gem*-dibromocyclopropanecarboxylic acid esters and nitriles with Grignard reagents depends on solvent. In ether the diastereomeric excess of *cis*-2-bromocyclopropane derivatives is up to 96–99% [12].

Scheme 5.



M = K (**IX**), Li (**X**).

1.79 and 1.82 ppm, respectively. The treatment of the deuterated 2,2-dibromo-3,3-dimethylcyclopropanecarboxylic acid-d_1 (**XI**) with isopylmagnesium bromide with the subsequent quenching of the reaction mixture with methanol afforded compounds **XVIIIa, XVIIIb** lacking deuterium. Consequently in the reactions of dibromocyclopropanecarboxylic acids with isopropylmagnesium bromide in THF the Grignard reagent primarily attacks the carboxy function and only afterwards the CBr_2 fragment of the small ring. The α-bromocyclopropylmagnesium bromides thus generated are further stabilized by the intermolecular transfer of a proton from the donor used for the quenching of the reaction mixture.

The features of the reaction mechanism of *gem*-dibromocyclopropanecarboxylic acids with methyllithium should be mentioned [3, 20]. The latter first attacks the bromine atom located in the *cis*-position with respect to the carboxy group; the intermediate thus generated [20] is stabilized due to the intramolecular transfer of a proton from the carboxy function to the carbanion center.

At the use of the hexadeuteroacetone for quenching the reaction mixture containing magnesium or bromomagnesium salts of α-bromocyclopropylmagnesium carboxylates the only reaction products isolated in the overall yield of 86% were the stereoisomeric deuterated acids **XXa, XXb**.[3] Even traces of addition products of α-bromocyclopropyl anionic intermediates to the carbonyl group of hexadeuteroacetone were not detected in the ^{1}H NMR spectrum of the reaction mixture.

Another fact that came for us as a surprise was a necessity to apply 6 equiv of isopropylmagnesium bromide for attaining the 100% conversion in the partial hydrodebromination of *gem*-dibromocyclopropanecarboxylic acids at low temperature. This event turned our attention to the structure of the Grignard reagent in THF.

The analysis of some structures of Grignard reagents **A–C** [22–24] available from the database of the Cambridge Crystallographic Data Center showed that the magnesium included in the organomagnesium compounds prepared in THF possessed the coordination number of 4 or 6 and frequently formed oligomeric, e.g., tetrameric structures where the carbanion sites of the Grignard reagents might be spatially blocked (see the figure, **B**, **C**).

In the solutions of alkylmagnesium halides in THF the Schlenk equilibrium is shifted to the side of species R_2Mg and $MgBr_2$ [25, 26].

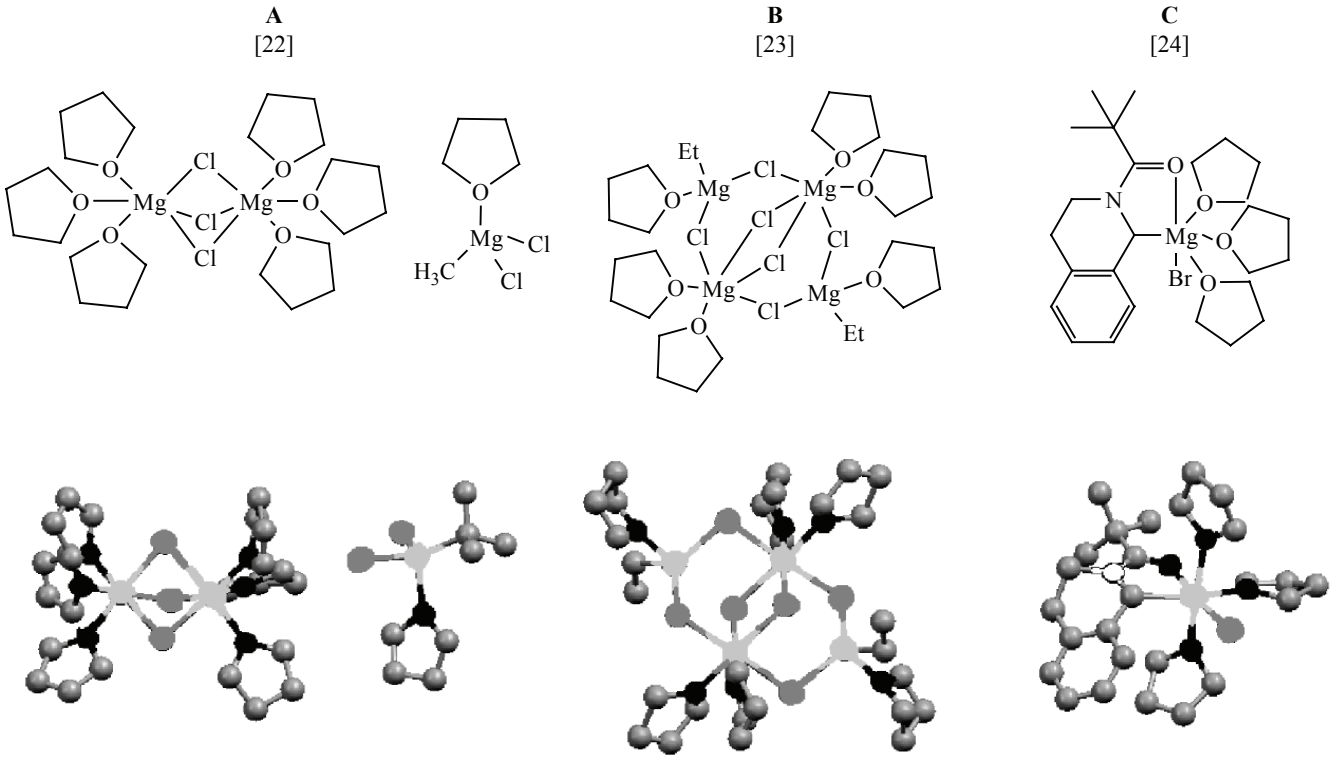
Assuming that the addition of nonsolvated magnesium bromide to the solution of the Grignard reagent in THF would shift the Schlenk equilibrium to the side of the formation of RMgBr species, probably, more active with respect to *gem*-dibromocyclopropanes. The introduction of the nonsolvated magnesium bromide may affect the solvate shell of the alkylmagnesium halide: The more polar species of $MgBr_2$ should be more efficiently solvated with THF molecules, and consequently the carbanion centers of the isopropylmagnesium bromide may become more accessible to the attack of the nucleophilic centers of the *gem*-dibromocyclopropane derivatives. In structures **A** and **B** (see the figure) the carbanion centers of methyl- and ethylmagnesium chloride in the presence of magnesium chloride are bound to a single THF molecule, whereas in the structure **C**, free of salt additives, the carbanion center is surrounded with three solvent molecules.

If the suggested hypothesis is valid, the addition of magnesium bromide to the solution of the Grignard reagent in THF would make it possible to reduce the amount of the isopropylmagnesium bromide necessary for the preparation of monobromocyclopropanecarboxylic acids.

We carried out a series of experiments where acid **VII** was treated with the solution of isopropylmagnesium

[3] It was shown in [17, 21] that in the reaction with acetone of α-bromocyclopropylmagnesium bromide generated from 1,1-dibromo-2,2-diphenylcyclopropane is formed 1-bromo-2,2-diphenylcyclopropane. The second compound isolated from the reaction mixture in 80% yield was the product of acetone condensation, 4-hydroxy-4-methylpentan-2-one.

The structure of Grignard reagents in crystals obtained from solutions in tetrahydrofuran.



bromide in THF containing 1–3 mol-equiv of magnesium bromide. The subsequent quenching of the reaction mixtures with methanol at –60°C followed by treating with hydrochloric acid at room temperature resulted in the formation of the corresponding stereoisomeric monobromocyclopropanecarboxylic acids. The ratio of the reaction products **XVIIIa, XVIIIb** remained unchanged. The results of the experiments (Table 2, Scheme 6) demonstrated that the addition to the reaction mixture of nonsolvated magnesium bromide significantly reduced the quantity of the Grignard reagent (from 6 to 3 mol-equiv) required for the partial hydrodebromination of 2,2-dibromocyclopropanecarboxylic acids.

The reaction of 2,2-dibromo- and 1-methyl-2,2-dibromocyclopropanecarboxylic acid with methyllithium in ether (1.5 mol-equiv) at 0°C in an argon atmosphere is known to furnish exclusively the product of the *trans*-hydrodebromination [18, 20, 27]. The reaction of 2,2-dibromo-3,3-dimethylcyclopropanecarboxylic acid (**VII**) with methyllithium under the above conditions led to a mixture of *trans*-2-bromocyclopropanecarboxylic acid (**XVIIIb**) and the corresponding allene **XXII** in 3 : 1 ratio. The main reaction product was isolated by absorption chromatograpgy on silica gel. The variation of the reaction temperature from –50 to 25°C showed that the yield of allene **XXII** from 27 to 35%. The ratio of the reaction products insignificantly varied with temperature. The reaction of *trans*-2,2-dibromo-3-phenyl-

Scheme 6.

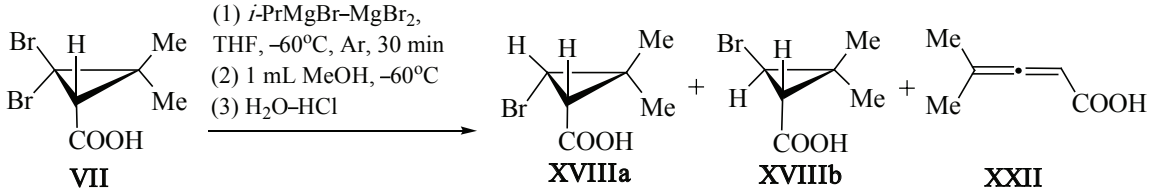


Table 2. Reactions of cyclopropanecarboxylic acid **VII** with isopropylmagnesium bromide in the presence of 1–3 mol-equiv of $MgBr_2$ at –60°C

Quantity of *i*-PrMgBr–$MgBr_2$, mol-equiv	Ratio of reaction products, %			Overall yield, %
	XVIIIa	**XVIIIb**	**XXII**	
4 :2	80	20	–	86
3 : 1	80	20	Traces	65
3 : 3	58	27	Traces	73

cyclopropanecarboxylic acid (**VIII**) with methyllithium in ether at 0°C afforded acid **XIX** in 85% yield without the formation of side products (Scheme 7).

Hence the partial low-temperature hydrodebromination of functional derivatives of *gem*-dibromocyclopropane with isopropylmagnesium bromide in THF can be used for the preparative synthesis of ethers and esters of 2-bromocyclopropylmethanol, 2-bromocyclopropanecarboxylic acids, and their esters.

Unlike methyllithium which provides with a high diastereoselectivity the *trans*-2-bromocyclopropanecarboxylic acids from the corresponding 2,2-dibromo-substituted acids, the isopropylmagnesium bromide utilized in this study fulfills the partial hydrodebromination of *gem*-dibromocyclopropanecarboxylic acid with the prevailing formation of *cis*-isomers. The greatest selectivity of the partial hydrodebromination was observed in the case of *trans*-2,2-dibromo-3-phenylcyclopropanecarboxylic acid (**VIII**).

Based on the findings obtained we suggested the scheme of the mechanism of hydrodebromination of *gem*-dibromocyclopropanecarboxylic acids with isopropylmagnesium bromide. The main steps of the mechanism are as follows: (a) The formation of magnesium salts of initial carboxylic acids; (b) metallation of the latter with isopropylmagnesium bromide resulting predominantly in the generation of the corresponding α-bromocyclopropylmagnesium bromides of bromomagnesium carboxylate with the *trans*-oriented substituents BrMg and COOMgBr; (c) treatment of the obtained intermediates with methanol or acetone and further with mineral acids leads to the formation of stereoisomeric 2-bromocyclopropanecarboxylic acids.

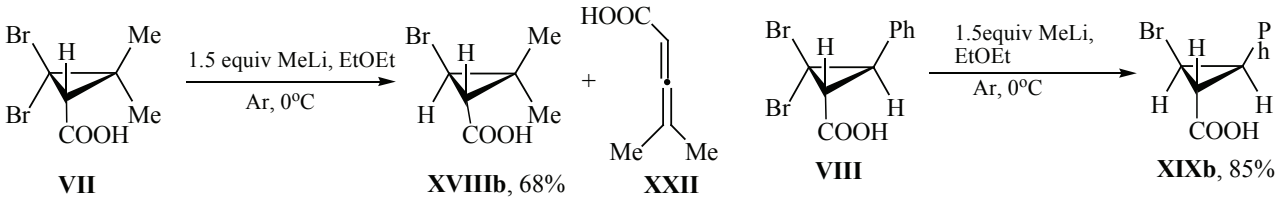
EXPERIMENTAL

^{1}H NMR spectra of compounds synthesized were registered on a spectrometer Varian VXR 400 (400 MHz), internal reference TMS. ^{13}C NMR spectra were obtained on a spectrometer Varian VXR 400 (100 MHz), solvent and internal reference deuterochloroform. IR spectra were recorded on a spectrophotometer UR-20 from thin film of pure oily substances, from mulls in mineral oil of crystalline compounds. GC-MS measurements were carried out on a GLC instrument Carlo Erba/Kratos Fractovap Series 4200, column HP Ultra-1, 25 m × 0.2 mm, stationary phase thickness 0.33 μm, carrier gas helium (1 mL/min), split ratio 1 : 10, vaporizer temperature 280°C, ramp from 150 to 280°C, heating rqate 5 deg/min). Mass spectral detector ITD-700 (Finnigan MAT), EI, 70 eV, mass range *m/z* 45–400.

The thin layer chromatography was performed on Silica gel plates on aluminium 20 Aldrich. The preparative separation and purification was carried out on silica gel Li-Chroprep Si 60 (25–40 μm) Merck, staining with the alcoholic solution of phosphomolybdic acid.

The syntheses with the use of Grignard reagents and methyllithium, and also all distillations applied to the separation and purification of obtained substances were performed under an atmosphere of argon of the "special

Scheme 7.



VII **XVIIIb**, 68% **XXII** **VIII** **XIXb**, 85%

purity" grade.

Reagents of the grades "chemically pure", "pure", and "pure for analysis" of Khimmed Co (hydrochloric acid, acetic acid, ethyl acetate, dichloromethane, benzene, toluene, chloroform, hexane, petroleum ether 40/70, potassium hydroxide and carbonate), and also reagents of Aldrich [methanol, bromoоформ, sodium hydroxide, nonsolvated magnesium bromide (purity 98%), magnesium (purity 98%), triethylbenzylammonium chloride (purity 99%)] and of Fluka [hexadecyltrimethylammonium bromide (purity 98%)] were used without additional purification.

Anhydrous ethyl ether was prepared by boiling with alkali (granulated KOH or NaOH) followed by distillation, then boiling with sodium in the presence of benzophenone and the subsequent distillation (procedure [28]), or by boiling with lithium aluminum hydride followed by distillation. Anhydrous pyridine was obtained by boiling with sodium followed by distillation [28]. Anhydrous tetrahydrofuran was prepared by boiling with sodium with subsequent addition of Grignard reagent with low concentration (0.6–0.8 M) stored more three days from the moment of preparation, followed by distillation; then boiling with sodium in the presence of benzophenone till the solution became of deep blue-violet color, and finally it was subjected to distillation [28].

Reagents of the grades "chemically pure", "pure", and "pure for analysis" (acetic anhydride, ethyl bromide, isopropyl bromide, allyl bromide) used in the preparation of organometallic and initial compounds were distilled prior to use.

Elemental analyses were carried out in the microanalysis laboratory of the Chair of Organic Chemistry of the Chemical Department of Lomonosov Moscow State University and in the microanalysis laboratories of Institute of Organic Chemistary and Institute of Organoelemental Compounds of the Russian Academy of Sciences.

Initial compounds (acetaldehyde diprenyl acetal, *trans*-2,2-dibromo-3-phenylcyclopropylcarbaldehyde) were synthesized from commercially available reagents: prenyl alcohol, methyl methacrylate, and cinnamic aldehyde, according to published procedures [7, 16–18, 29]. The compounds were purified by distillation or by preparative column chromatography.

Isopropylmagnesium bromide. Into a dried flask heated with dry air (to no less than 200°C) was charged 1.54 g (63 mmol) of magnesium turnings, 46 mL of THF, and gradually was added at stirring 1/6 part of the solution of 4.7 mL (6.16 g, 50 mmol) of isopropyl bromide in 4 mL of THF. After 3–5 min the reaction mixture strongly self-heated. As the reaction mixture cooled the remaining solution of isopropyl bromide was added to the flask with the rate preventing the boiling of the reaction mixture. The stirring was continued for 1 h, and the reaction mixture was left overnight. Then a sample of the Grignard reagent (1 mL) was poured into 20 mL of 0.1 m solution of hydrochloric acid followed by titration with 0.1 m solution of sodium hydroxide in the presence of methyl orange indicator. The concentration of obtained solutions varied in the range 0.80–1.03 mol L^{-1} (80–103%). The solution of isopropylmagnesium bromide was used in reactions within 3 days after the preparation [14, 17, 25].

Ethylmagnesium bromide. Into a dried flask heated with dry air (to no less than 200°C) was charged 1.54 g (63 mmol) of magnesium turnings and 43.7 mL of THF was added with a syringe. At stirring 1/6 part of the solution of 3.7 mL (5.45 g, 50 mmol) of ethyl bromide in 6.3 mL of THF was added. After 1–3 min the reaction mixture strongly self-heated. As the reaction mixture cooled the remaining solution of ethyl bromide was added to the flask with the rate preventing the boiling of the reaction mixture. The stirring was continued for 1 h, then a sample of the Grignard reagent (1 ml) using a syringe was poured into 20 mL of 0.1 m solution of hydrochloric acid followed by titration with 0.1 m solution of sodium hydroxide in the presence of methyl orange indicator. The concentration of obtained solution was 0.95 mol L^{-1} (95%). The solution of ethylmagnesium bromide was used within 3 days after the preparation [14, 17, 25].

Methyllithium. Into a dried flask heated with dry air (to no less than 200°C) was charged 1.22 g (0.174 mol) of lithium cut into small pieces, and 50 mL of ethyl ether was added with a syringe. At stirring into the flask was gradually added with a syringe by 2–3 mL portions of solution of methyl iodide (5.5 mL, 0.09 mol, 12.54 g) in 38 mL of ether maintaining the rate of addition so that the boiling of the ether was not too vigorous. On the completion of the addition the reaction mixture was heated to boiling for 1 h on a water bath. On cooling the reaction mixture to room temperature the flask was sealed from the air access with paraffin wax. The concentration of the methyllithium solutions in ether was measured directly before the use along procedure [18, 30]. The concentration of solutions was 0.8–1.04 mol l^{-1}.

2,2-Dibromo-3,3-dimethylcyclopropylmethanol

(I) [16, 17, 31]. To a solution of 12.9 g (65 mmol) of acetaldehyde diprenyl acetal and 2.4 g (10 mol%) of hexadecyltrimethylammonium bromide in 36 mL of dichloromethane and 23 mL (65.8 g, 0.26 mol) bromoform was added 32.4 g (0.81 mol) of 50% aqueous solution of sodium hydroxide at 10°C. The formed mixture was vigorously stirred for 5 h at room temperature and poured into 150 mL of water, the reaction products were extracted into dichloromethane (3 × 30 ml), the extract was dried with magnesium sulfate. The solvent and bromoform excess were distilled off in a vacuum, the residue was filtered through a bed of silica gel, the sorbent was washed with petroleum ether, the solvent was distilled off. The obtained yellowish oily substance was dissolved in 20 mL of THF and at cooling to 10°C with a water bath this solution was added to a solution of 0.6 g (2.8 mmol, 10 mol%) of *p*-toluenesulfonic acid hydrate in 15 mL of water and 30 mL of THF. The reaction mixture was stirred for 2.5 h at 50°C and poured into 100 mL of water, the reaction products were extracted into dichloromethane (3×30 mL), the extract was washed with 10% water solution of potassium carbonate (3 × 20 mL), with water, and dried with magnesium sulfate. The solvent was removed in a vacuum, the residue was distilled in a vacuum. Yield 25.1 g (64%), bp 79–81°C (1 mm Hg). At storage in the argon atmosphere in a refrigerator at 3°C the oily substance crystallized into colorless crystals. R_f 0.29 (hexane–ether, 4 : 1). IR spectrum, cm^{-1}: 3600–3100 s, 3000 s, 2970 s, 2945 s, 2880 s, 1730 w, 1630 w, 1465 s, 1405 s, 1380 s, 1330 w, 1285 w, 1250 w, 1210 w, 1150, 1120 w, 1080 s, 1045 s, 1050 s, 1000 m, 920 w, 830 w, 780 s, 760 s, 730 w. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm:1.28 s (3H), 1.43 s (3H), 1.61 t (1H, *J* 7.3 Hz), 1.66 s (1H), 3.76 d (2H, *J* 7.3 Hz).

Methyl 1-methyl-2,2-dibromocyclopropanecarboxylate (II) [18, 29] was obtained from 21.2 mL (20 g, 0.2 mol) of methyl methacrylate, 100 mL of dichloromethane, 35 mL of bromoform, 3.64 g (5 mol%) of hexadecyltriethylammonium bromide, and 120 mL (80 g, 2 mol) of 50% aqueous solution of sodium hydroxide. After distillation yield 25.6 g (47%). Colorless fluid, bp 100–103°C (10 mm Hg). ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.55 s (3H), 1.67 d (1H, *J* 7.1 Hz), 2.33 d (1H, *J* 7.1 Hz), 3.75 s (3H).

1-Methyl-2,2-dibromocyclopropanecarboxylic acid (III) [18, 29]. To a solution of 4.88 g (0.122 mol) of sodium hydroxide in 45 mL of ethanol and 15 mL of water was added a solution of 25 g (92 mmol) of ester **II** in 15 mL of ethanol, the mixture was stirred for 18 h at room temperature. The mixture was evaporated, the residue in the flask was dissolved in 70 mL of water, nonpolar impurities were extracted with dichloromethane (3 × 15 mL), the water layer was acidified with conc. HCl to pH 1, the reaction product was extracted into chloroform (4 × 15 mL). The combined extracts were washed with water and dried with magnesium sulfate. The solvent was distilled off, the precipitated yellowish crystals were recrystallized from a mixture hexane–benzene, 2 : 1, and dried in Fischer's drying pistol. Yield 16.68 g (70%). Colorless crystalline powder, mp 112.5–114°C. IR spectrum, cm^{-1}: 3070 m, 2970 s, 2870 s, 1910 w, 1715 s, 1470 s, 1450 s, 1380 m, 1359 w, 1305 w, 1250 s, 1225 m, 1120 s, 1030 w, 980 m, 945 m, 930 m, 840 w, 825 m, 750 w, 697 s. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.63 d (1H, *J* 7.9 Hz), 1.64 s (3H), 2.43 d (1H, *J* 7.9 Hz), 7.20 s (1H).

1,1-Dibromo-2,2-dimethyl-3-methoxymethylcyclopropane (IV). To a solution of 1.5 g (5.8 mmol) of alcohol **I** in 12 mL of dimethyl sulfoxide was added a solution of 0.53 g (13.3 mol) of sodium hydroxide in 1 mL of water, the mixture was stirred for 30 min at 20°C, then a solution was added of 0.66 mL (1.5 g, 10.2 mmol) of methyl iodide in 1 mL of DMSO at 20°C. After 3 h the mixture was poured into 50 mL of water, the reaction product was extracted into ether (3×15 ml), the extract was dried with magnesium sulfate. After the purification by preparative absorption chromatography ether **IV** was isolated as colorless fluid. Yield 1.3 g (77%), R_f 0.45 (petroleum ether–ethyl acetate, 20:1). IR spectrum, cm^{-1}: 3500–3250 s, 3000 s, 2970 s, 2940, 2910, 2890, 2840 s, 1715 w, 1460 s, 1410 m, 1390 m, 1380 m, 1290 w, 1255 w, 1230 w, 1200 m, 1160 m, 1120 s, 1115 s, 1080 m, 1050 m, 1005 m, 1005 m, 980 w, 970 w, 930 w, 910 w, 825 w, 780 m, 760 m. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.24 s (3H), 1.42 s (3H), 1.56 t (1H, *J* 6.7 Hz), 3.39 s (3H), 3.42 d.d (1H, *J* 10.9, 6.7 Hz), 3.57 d.d (1H, *J* 10.9, 6.7 Hz). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 19.42, 27.13, 38.17, 44.49, 58.52, 71.55, 111.56. Found, %: C 31.16; H 4.58. $C_7H_{12}Br_2O$. Calculated, %: C 30.91; H 4.44.

1-(Allyloxymethyl)-2,2-dibromo-3,3-dimethylcyclopropane (V) [17]. To a solution of 2 g (7.75 mmol) of compound **I** in 20 mL of anhydrous DMSO at 10–15°C was added a solution of 0.87 g of NaOH in 1.2 mL of water, the mixture was stirred for 20 min at 20°C, and a solution was added of 1.8 mL (16 mmol) of allyl bromide in 1.5 mL of DMSO. After keeping the mixture for 2.5 h

at 20°C it was poured into 50 mL of water, the reaction product was extracted into ether (3×15 mL), the extract was dried with magnesium sulfate. Ether **V** was isolated by distillation. Yield 1.45 g (82%). Colorlessая fluid, bp 121–123°C (12 mm Hg), R_f 0.92 (petroleum ether–ethyl acetate, 4 : 1). IR spectrum, cm^{-1}: 3500–3200 s, 3090 w, 3000 m, 2970 m, 2940 s, 2880 s, 2870 s, 1710 w, 1650 w, 1535 w, 1460 s, 1410 m, 1380 s, 1350 w, 1295 w, 1270 w, 1260 w, 1230 w, 1145 s, 1105 s, 1090 s, 1000 s, 930 s, 825 m, 780 s, 765 s, 730 w. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.25 s (3H), 1.43 s (3H), 1.59 d.d (1H, *J* 6.8, 6.6 Hz), 3.45 d.d (1H, *J* 6.8, 10.85 Hz), 3.63 d.d (1H, *J* 6.6, 10.85 Hz), 3.99 d.d (1H, *J* 5.6, 12.8 Hz), 5.19 d (1H, *J* 10.4 Hz), 5.29 (1H, *J* 17.2 Hz), 5.91 d.d.t (1H, *J* 17.2, 10.4, 5.6 Hz). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 19.47, 27.14, 28.33, 38.31, 44.58, 68.50, 71.75, 117.28, 134.55. Found, %: C 35.90; H 4.97. $C_9H_{14}Br_2O$. Calculated, %: C 36.27; H 4.73.

2,2-Dibromo-3,3-dimethylcyclopropan-1-ylmethyl acetate (VI) [14, 16, 32]. To a solution of 1.43 g (5.5 mmol) of compound **I** in 0.9 mL (0.9 g, 11.2 mmol) of pyridine was added 0.85 mL (0.92 g, 8.4 mmol) of acetic anhydride. The formed mixture was stirred for 3 h at room temperature. Acetate **VI** was isolated by preparative chromatography on silica gel (eluent hexane–ethyl acetate, 4 : 1, R_f 0.35) as a colorless fluid. Yield 1.2 g (72%), bp 101–102°C (3 mm Hg). IR spectrum, cm^{-1}: 3470 w, 3000 s, 2970 s, 2940 s, 2910, 2880 s, 1745 s, 1650 w, 1465 s, 1390 m, 1375 s, 1280 s, 1240 s, 1160 s, 1120 w, 1090 m, 1045 s, 1010 m, 980 w, 905 w, 855 w, 820 w, 780 s. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.26 s (3H), 1.41 s (3H), 1.64 d.d (1H, *J* 7.7, 7.4 Hz), 2.10 s (3H), 4.19 d.d (1H, *J* 7.7, 11.9 Hz), 4.14 d.d (1H, *J* 7.4, 11.9 Hz). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 19.48, 20.82, 27.01, 28.74, 36.84, 43.29, 63.24, 170.73.

2,2-Dibromo-3,3-dimethylcyclopropanecarboxylic acid (VII) [16, 31]. To a solution of 6.84 g (6.84 mmol) of chromic anhydride in a mixture of 57.2 mL (60 g) of acetic acid and 6.8 mL of water at vigorous stirring and cooling to 0°C by an ice bath was added a solution of 4.5 g (20 mmol) of alcohol **I** in 5.7 mL (5.98 g, 0.1 mol) of acetic acid. The mixture was stirred for 24 h at room temperature and then poured into 100 mL of water. The separated oxidation products were extracted with dichloromethane (4×30 mL), the combined extracts were washed with water (2×15 mL), then with the saturated K_2CO_3 solution (3×30 mL). The combined alkaline extracts were washed with dichloromethane (1×20 mL), acidified with conc. HCl to pH 1, acid **VII** was extracted with dichloromethane (4×20 mL). The extract was dried with magnesium sulfate. The drying agent was separated, the solvent was distilled off to give 4.49 g of crude acid **VII**. Ater recrystallization from a mixture heptane–toluene, 4 : 1, and drying in Fischer's drying pistol yield 4.16 g (98%). Colorless needle crystals, mp 146–147°C. IR spectrum, cm^{-1}: 3075 w, 2980–2850 s, 1715 s, 1685 s, 1470 s, 1380 s, 1355 m, 1305 m, 1250 s, 1225 s, 1120 s, 1110 m, 1030 m, 990 m, 955 m, 930 m, 840 w, 760 w, 710 s. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.51 s (3H), 1.54 s (3H), 2.26 s (1H), 14.0 s (1H). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 19.50, 27.34, 34.44, 38.90, 40.39, 173.25. Found, %: C 26.67; H 2.96. $C_6H_8Br_2O_2$. Calculated, %: C 26.50; H 2.96.

***trans*-3-Phenyl-2,2-dibromocyclopropanecarboxylic acid (VIII)** [33]. To a solution of 10 g (0.1 mmol) of chromic anhydride in 52 mL (55 g, 0.9 mol) of acetic acid and 8 mL of water at vigorous stirring and cooling to 0°C by an ice bath was added a solution of 12 g (40 mmol) of *trans*-2,2-dibromo-3-phenylcyclopropylcarbaldehyde in 10 mL of acetic acid. The mixture was stirred for 20 h at room temperature After the standard workup of the reaction mixture and the recrystallization of the product from a mixture toluene–petroleum ether, 1 : 1, yield 3.9 g (31%). Colorless crystals, mp 142–143°C. IR spectrum, cm^{-1}: 3070 w, 2950 s, 2870 s, 1715 s, 1690 s, 1500 w, 1470 s, 1460 s, 1380 s, 1340 m, 1330 m, 1315 m, 1300, 1240 m, 1215 m, 1175 m, 1110 w, 1085, m, 1050 m, 1035 w, 980 m, 950 m, 910 m, 870 m, 850 w, 780 w, 765 m, 730 w, 715 m, 700 s. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 2.94 d (1H, *J* 8.4 Hz), 3.46 d (1H, *J* 8.4 Hz), 7.26–7.41 m (5H).

Potassium 2,2-dibromo-3,3-dimethylcyclopropanecarboxylate (IX). To a solution of 1.99 g (7.32 mmol) of acid **VII** in 17 mL of methanol was added 1.04 g (1.02 equiv, 7.46 mmol) of powdered potassium carbonate, the mixture was boiled on a water bath for 4 h and then it was stirred for 4 h at room temperature. The precipitate was filtered off, washed with methanol (4×20 mL). To the residue 10 mL of toluene was added, the solvent was distilled off in a vacuum on a rotary evaporator, and this procedurewas repeated 4 times. After drying the residue in Fischer's pistol for 8 h at 60°C over calcium chloride and paraffin wax the yield was 1.93 g (85%). Colorless powder. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 1.27 s (3H), 1.32 s (3H), 2.98 s (1H). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 20.17, 25.62, 27.49, 28.17, 49.62, 167.47.

Lithium 2,2-dibromo-3,3-dimethylcyclopropanecarboxylate (X). To a solution of 1.97 g (7.25 mmol) of acid **VII** in 17 mL of methanol was added 0.55 g (1.02 equiv, 7.40 mmol) of lithium carbonate. The mixture was boiled on a water bath for 4 h and then it was stirred for 4 h at room temperature. The precipitate was filtered off, washed with methanol (4×20 mL). To the residue 10 mL of toluene was added, the solvent was distilled off in a vacuum on a rotary evaporator, and this procedure was repeated 4 times. After drying the residue in Fischer's pistol for 8 h at 60°C over calcium chloride and paraffin wax the yield was 2.0 g (89%), colorless powder. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 1.32 s (3H), 1.38 s (3H), 3.01 s (1H). ^{13}C NMR spectrum (DMSO-d_6), δ, ppm: 20.07, 20.85, 25.93, 27.30, 50.51, 168.29.

2,2-Dibromo-3,3-dimethylcyclopropanecarboxylic acid-d_1 (XI). Acid **VII** (1 g, 3.7 mmol) was boiled with 1 mL of methanol-d_1 for 1 h, the residue of solvent was distilled off on a rotary evaporator. The procedure was repeated thrice. After removal of the solvent yield 0.998 g (98%). Colorless crystals. ^{1}H NMR spectrum (CCl_4), δ, ppm: 1.50 s (3H), 1.51 s (3H), 2.26 s (1H). ^{13}C NMR spectrum (CCl_4), δ, ppm: 19.5, 27.34, 34.44, 38.90, 40.39, 73.25. Found, %: C 26.68; H 2.87. $C_6H_7Br_2DO_2$. Calculated, %: C 26.40; H 3.31.

Functionalized α-bromocyclopropylmagnesium bromides. In a dry three-neck flask filled with argon was charged 1–3 mmol of dibromocyclopropane **II–XII**, and 9 mL of THF was charged with a syringe. The solution was cooled to the temperature in the range from –65 to –80°C (with a mixture alcohol–liquid nitrogen). At vigorous stirring with a magnetic stirrer to the cooled solution was added dropwise 1.1–7 mol-equiv of a solution of isopropylmagnesium bromide or ethylmagnesium bromide in THF. The rate of addition was chosen so that the temperature of the reaction mixture did not exceed from–60 to –75°C. The stirring at this temperature continued for 30–45 min, then the mixture was cooled to –70°C and 1 mL of hydrogen donor (Table 1) was added dropwise maintaining the temperature between –75 and –60°C. After warming the mixture to 0°C 1 mL of water was added and the reaction mixture was left to warm to room temperature.

Isolation of compounds without a carboxy group. To the reaction mixture obtained as above described was added 20 mL of petroleum ether, the organic layer was decanted, the water slurry of magnesium salts was dissolved in 4 M solution of HCl, the reaction products were extracted with petroleum ether, the combined organic extracts were washed with water and dried with magnesium sulfate. The solvent was distilled off in a vacuum, the mixture was filtered through 1.5 g of silica gel, the sorbent was washed with petroleum ether, then the solvent was distilled off and the corresponding *cis*- and *trans*-derivatives of monobromocyclopropane were isolated.

Isolation of acids. To the reaction mixture 20 mL of chloroform was poured, the organic layer was washed with a solution of 10 mL of conc. HCl in 50 mL of water, from the water layer the acids were extracted with chloroform, the combined organic extracts were treated with the saturated solution of potassium carbonate, the water fraction was washed with chloroform and acidified with conc. HCl to pH 1. The obtained acid was extracted from the water phase with chloroform, and the extract was dried with magnesium sulfate. After the solvent was distilled off the corresponding *cis*- and *trans*-monobromocyclopropanecarboxylic acid were isolated.

Methyl *cis*-2-bromo-1-methylcyclopropanecarboxylate (XIIIa) [29, 34]. Colorless oily substance. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.02 t (1H, *J* 5.5 Hz), 1.48 s (3H), 1.84 d.d (1H, *J* 8.4, 5.5 Hz), 3.52 d.d (1H, *J* 5.5, 8.4 Hz), 3.76 s (3H).

Methyl *trans*-2-bromo-1-methylcyclopropanecarboxylate (XIIIb) [29, 34]. Colorless oily substance. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.24 d.d (1H, *J* 7.7, 6.4 Hz), 1.38 s (3H), 1.80 d.d (1H, *J* 5.4, 6.4 Hz), 2.94 d.d (1H, *J* 5.4, 6.4 Hz), 3.68 s (3H).

***cis*-2-Bromo-1-methylcyclopropanecarboxylic acid (XIVa)** [18, 29]. Colorless crystals. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.32 d.d (1H, *J* 7.6, 6.7 Hz), 1.41 s (3H), 1.81 d.d (1H, *J* 6.7, 5.8 Hz), 3.02 d.d (1H, *J* 7.6, 5.8 Hz), 10.6 s (1H).

***trans*-2-Bromo-1-methylcyclopropanecarboxylic acid (XIVb)** [18, 29, 35]. Colorless crystals. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.09 d.d (1H, *J* 5.5, 5.8 Hz), 1.63 s (3H), 1.92 d.d (1H, *J* 8.2, 5.8 Hz), 3.57 d.d (1H, *J* 5.5, 8.2 Hz), 10.6 s (1H).

***cis*-1-Bromo-2,2-dimethyl-3-methoxymethylcyclopropane (XVa).** Colorless oily substance. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.15 s (3H), 1.16 s (3H), 1.21 m (1H, *J* 7.9, 6.9 Hz), 2.99 d (1H, *J* 7.9 Hz), 3.37 s (3H), 3.45–3.55 m (2H, *J* 6.9, 10.4 Hz). Found, %: C 43.72; H 6.92. $C_7H_{13}BrO$. Calculated, %: C 43.56; H 6.78.

***trans*-1-Bromo-2,2-dimethyl-3-(methoxymethyl) cyclopropane (XVb).** Colorless oily substance. ^{1}H

($CDCl_3$), δ, ppm: 1.15 s (3H), 1.21 m (1H, *J* 4.2, 6.2 Hz), 1.29 s (3H), 2.71 d (1H, *J* 4.2 Hz), 3.34 s (3H), 3.45–3.55 m (2H, *J* 6.2, 10.6 Hz). Found, %: C 43.57; H 6.90. $C_7H_{13}BrO$. Calculated, %: C 43.56; H 6.78.

***cis*-1-(Allyloxymethyl)-2-bromo-3,3-dimethylcyclopropane (XVIa)** [17]. Colorlessoe oily substance. IR spectrum, cm^{-1}: 3090 w, 3000 m, 2965 s, 2935 s, 2865 s, 1730 w, 1650 w, 1470 m, 1450 m, 1420 m, 1380 m, 1350 w, 1275 m, 1210 w, 1160–1140 m, 1100 m, 1030 w, 1000 w, 930 m, 680 m. ^1H NMR spectrum ($CDCl_3$), δ, ppm: 1.07 d.d (1H, *J* 6.8, 7.1 Hz), 1.14 s (3H), 1.16 s (3H), 2.99 d (1H, *J* 7.5 Hz), 3.5 d.d (1H, *J* 6.8, 10.6 Hz), 3.54 d.d (1H, *J* 10.6, 7.1 Hz), 4.0 m (2H, *J* 1.5, 5.8, 17.2, 10.4 Hz), 5.18 d.q (1H, *J* 1.5, 10.4 Hz), 5.29 d.q (1H, *J* 1.5, 17.2 Hz), 5.93 m (1H, *J* 10.4, 5.8, 17.2 Hz). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 17.14, 26.19, 26.86, 29.67, 34.99, 68.31, 71.79, 117.05, 134.89. Mass spectrum, *m/z* ($I_{rel.}$, %): $[M]^+$ 218, 220 (0.016), $[M - C_3H_7]^+$ 175, 177 (0.11), $[M - C_3H_5O]^+$ 161, 163 (1.7), $[M - C_4H_7O]^+$ 147, 149 (5), $[M - Br]^+$ 139 (9.6). Found, %: C 49.47; H 6.95. $C_9H_{15}BrO$. Calculated, %: C 49.33; H 6.89.

***trans*-1-(Allyloxymethyl)-2-bromo-3,3-dimethylcyclopropane (XVIb)** [17]. Colorless oily substance. IR spectrum, cm^{-1}: 3085 w, 2985 m, 2965 s, 2930 s, 2870 s, 1740 m, 1650 w, 1460 m, 1420 m, 1380 m, 1300 w, 1270 m, 1250 m, 1205 m, 1145 m, 1100 s, 1090 s, 1000 m, 935 m, 820 w, 680 m. ^1H NMR spectrum ($CDCl_3$), δ, ppm: 1.14 s (3H), 1.28 s (3H), 1.25 m (1H, *J* 4.3 Hz), 2.71 d (1H, *J* 4.3 Hz), 3.36 d.d (1H, *J* 8.1, 10.9 Hz), 3.58 d.d (1H, *J* 5.9, 10.9 Hz), 3.98 m (2H, *J* 1.5, 5.8, 5.5 Hz), 5.19 d.d (1H, *J* 1.5, 10.5 Hz), 5.28 d.d (1H, *J* 1.5, 17.2 Hz), 5.91 m (1H, *J* 10.5, 17.2, 5.8, 5.5 Hz). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 19.43, 21.81, 24.45, 33.15, 33.71, 68.52, 71.46, 117.08, 134.73. Found, %: C 49.51; H 7.02. $C_9H_{15}BrO$. Calculated, %: C 49.33; H 6.89.

***cis*-2-Bromo-3,3-dimethylcyclopropan-1-yl-methyl acetate (XVIIa).** Colorless oily substance. ^1H NMR spectrum ($CDCl_3$), δ, ppm: 1.12 m (1H, *J* 7.6 Hz), 1.16 s (3H), 1.17 s (3H), 2.07 s (3H), 3.0 d (1H, *J* 7.6 Hz), 4.12–4.21 m (2H). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 19.95, 22.19, 22.62, 24.88, 29.63, 34.35, 63.36, 170.99.

***trans*-2-Bromo-3,3-dimethylcyclopropan-1-ylmethyl acetate (XVIIb).** Colorless oily substance. ^1H NMR spectrum ($CDCl_3$), δ, ppm: 1.16 s (3H), 1.28 s (3H), 1.30 m (1H, *J* 4.3, 4.5, 8.1 Hz), 2.07 s (3H), 2.75 d (1H, *J* 4.3 Hz), 3.98 d.d (1H, *J* 11.9, 8.1 Hz), 4.12–4.21 m (1H, *J* 11.9, 4.5 Hz). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 19.55, 20.85, 24.27, 26.74, 31.97, 33.22, 63.40, 170.88.

Mixture of XVIIa, XVIIb. IR spectrum, cm^{-1}: 2965 s, 2935 s, 2880 m, 2745 w, 1740 s, 1460 m, 1380 s, 1240 s, 1150 w, 1125 w, 1050 s, 1000 w, 990 w, 930–920 w, 905 w, 850 w, 810 w, 710 w, 695 w. Mass spectrum, *m/z* (I_{rel}, %): $[M]^+$ 222, 220 (0.02), $[M - C_2H_3O_2]^+$ 163, 161 (0.11), $[M - C_3H_5O_2]^+$ 147, 149 (2.7), $[M - Br]^+$ 141 (10). Found, %: C 43.47; H 6.14. $C_8H_{13}BrO_2$. Calculated, %: C 43.46; H 5.92.

***cis*-2-Bromo-3,3-dimethylcyclopropanecarboxylic acid (XVIIIa).** Colorless crystals. ^1H NMR spectrum ($CDCl_3$), δ, ppm: 1.27 s (3H), 1.38 s (3H), 1.79 d (1H, *J* 7.9 Hz), 3.22 d (1H, *J* 7.9 Hz). Found, %: C 37.30; H 4.54. $C_6H_9BrO_2$. Calculated, %: C 37.33; H 4.69.

***trans*-2-Bromo-3,3-dimethylcyclopropanecarboxylic acid (XVIIIb).** Colorless crystals. ^1H NMR spectrum ($CDCl_3$), δ, ppm: 1.32 s (3H), 1.38 s (3H), 1.82 d (1H, *J* 4.2 Hz), 3.22 d (1H, *J* 4.2 Hz). Found, %: C 37.35; H 4.53. $C_6H_9BrO_2$. Calculated, %: C 37.33; H 4.69.

***cis*-2-Bromo-3-phenylcyclopropanecarboxylic acid (XIXa).** Colorless crystals. ^1H NMR spectrum ($CDCl_3$), δ, ppm: 2.42 d.d (1H, *J* 6.0, 8.4 Hz), 3.06 d.d (1H, *J* 6.0, 5.5 Hz), 3.49 d.d (1H, *J* 8.4, 5.5 Hz), 7.25–7.5 m (5H). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 25.33, 29.01, 33.70, 126.38, 127.53, 128.81, 136.63, 174.61. Found, %: C 50.13; H 3.90. $C_{10}H_9BrO_2$. Calculated, %: C 49.82; H 3.76.

***trans*-2-Bromo-3-phenylcyclopropanecarboxylic acid (XIXb).** Colorless crystals. IR spectrum, cm^{-1}: 3000 w, 2970, 2935 s, 2860 s, 1680 m, 1610 w, 1500 w, 1450 m, 1380 w, 1270 w, 1205 w, 1090 w, 1040 w, 1050 w, 960 w, 765 w, 730 w, 710 w. ^1H NMR spectrum ($CDCl_3$), δ, ppm: 2.44 d.d (1H, *J* 5.9, 3.8 Hz), 2.96 d.d (1H, *J* 5.9, 8.3 Hz), 3.72 d.d (1H, *J* 3.8, 8.3 Hz), 7.25–7.38 m (5H). ^{13}C NMR spectrum ($CDCl_3$), δ, ppm: 27.92, 29.67, 32.43, 127.53, 128.27, 129.01, 136.63, 174.61. Found, %: C 49.86; H 3.78. $C_{10}H_9BrO_2$. Calculated, %: C 49.82; H 3.76.

***cis*-2-Bromo-2-deutero-3,3-dimethylcyclopropanecarboxylic acid (XXa).** Colorlessые crystals. ^1H NMR spectrum ($CDCl_3$), δ, ppm: 1.28 s (3H), 1.39 s (3H), 1.79 s (1H). Found, %: C 37.01; H 4.38. $C_6H_8BrDO_2$. Calculated, %: C 37.11; H 5.15.

***trans*-2-Bromo-2-deutero-3,3-dimethylcyclopropanecarboxylic acid (XXb).** Colorlessые crystals. ^1H NMR spectrum ($CDCl_3$), δ, ppm: 1.33 s

(3H), 1.39 s (3H), 1.82 s (1H). Found %: C 37.38; H 4.38. $C_6H_8BrDO_2$. Calculated, %: C 37.11; H 5.15.

***cis*-1-Bromo-2-methyl-2-phenylcyclopropane (XXIa)** [17, 18, 21]. Colorless oily substance. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.34–1.40 m (2H, *J* 4.6, 7.3 Hz), 1.45 s (3H), 3.08 d.d (1H, *J* 4.6, 7.3 Hz), 7.18–7.37 m (5H).

***trans*-1-Bromo-2-methyl-2-phenylcyclopropane (XXIb)** [17, 18, 21]. Colorlessoe oily substance. ^{1}H NMR spectrum ($CDCl_3$), δ, ppm: 1.06 d.d (1H, *J* 4.8, 6.3 Hz), 1.61 s (3H), 1.64 d.d (1H, *J* 6.3, 8.0 Hz), 3.21 d.d (1H, *J* 4.8, 8.0 Hz), 7.18–7.37 m (5H).

Reactions of 2,2-dibromo-3,3-dimethylcyclopropanecarboxylic acid (VII) with isopropylmagnesium bromide in the presence of magnesium bromide (Table 2). Into a dried three-neck flask heated for 30 min in a vacuum of an oil pump (1 mm Hg) with the help of heat gun (to no less than 200°C) was charged 3 mmol of acid **VII**. Two necks of the flask were closed with septa, and into the third neck a thermometer was placed with a scale from –90 to 20°C. The flask was filled with argon, and 9 mL of THF was added with a syringe.

To an Erlenmeyer flask dried with a hot air ($T > 200$°C) and filled with argon was charged 2–4 mol-equiv of magnesium bromide, the flask was again flushed with argon, and 20–40 mL of THF was added with a syringe. At heating and stirring the salt dissolved completely. To the obtained yellow solution was added with a syringe 2–4 mol-equiv of isopropylmagnesium bromide solution in THF. In the course of the addition the solution turned colorless; the mixture was stirred for 15 min.

At stirring with a magnetic stirrer to the solution of acid **VII** cooled to –65°C with a bath of ethanol–liquid nitrogen was added dropwise the solution in THF of the mixture of isopropylmagnesium bromide with magnesium bromide. The rate of addition was chosen so that the temperature of the reaction mixture did not exceed –60°C. The stirring at this temperature continued for 45 min, then the mixture was cooled to –70°C and 1 mL of methanol was added maintaining the temperature between–70 and –61°C. At continuous stirring the reaction mixture was warmed to 0°C, 1 mL of water was added, and the reaction mixture was left to warm to room temperature.

To the reaction mixture 20 mL of chloroform was poured, the organic layer was washed with a solution of 10 mL of conc. HCl in 50 mL of water, from the water layer the reaction products were extracted with chloroform, the combined organic extracts were neutralized with the saturated solution of potassium carbonate, the water fraction was washed with chloroform and acidified with conc. HCl to pH 1. The obtained acid **XVIII** was extracted from the water phase with chloroform, and the extract was dried with magnesium sulfate. The drying agent was separated, after the solvent was distilled off we isolated the mixture of *cis*- and *trans*-isomers of carboxylic acids **XVIIIa, XVIIIb**.

Reaction of 2,2-dibromo-3,3-dimethylcyclopropanecarboxylic acid (VII) with methyllithium [7, 18, 20, 28, 35, 36]. Into a dry flask filled with argon was charged 0.5 g (1.84 mmol) of acid **VII**, and 5 mL of anhydrous ether was added with a syringe. If needed, the solution was cooled with a bath of ethanol–liquid nitrogen to the desired temperature (–50, –25, 0°C) or the synthesis was carried out at room temperature. To the solution obtained vigorously stirred with a magnetic stirrer was added at the required temperature within 10 min 1.5 mol-equiv (2.76 mmol) of ether solution of methyllithium. The mixture was stirred for 15 min under the same conditions, then the reaction mixture was warmed to room temperature within 2 h. To the reaction mixture was added carefully, first dropwise, 10 mL of water. The water fraction was separated, the organic fraction was washed with water. The combined water phases were washed with ether, acidified with 20% hydrochloric acid solution to pH 1, the organic acids were extracted with dichloromethane, the extract was dried with magnesium sulfate. The solvent was distilled off, the corresponding acids **XVIIIb** and **XXII** were isolated. Compound **XVIIIb** was isolated by preparative chromatography on silica gel (eluent petroleum–ethyl ether, 3 : 1); acid **XXII** decomposed under the chromatography conditions.

4-Methylpenta-2,3-dienoic acid (XXII). ^{1}H NMR spectrum, δ, ppm: 1.82 d (6H, *J* 2.7 Hz), 5.46 m (1H, *J* 2.7 Hz).

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