Russian Journal of Organic Chemistry, Vol. 40, No. 2, 2004, pp. 178–187. Translated from Zhurnal Organicheskoi Khimii, Vol. 40, No. 2, 2004, pp. 204–214.

Reactions of Heterocumulenes with Organometallic Reagents IX.* Synthesis and Rearrangements of *N*-Allyl- and *N*-[2-(Vinyloxy)ethyl]-3-butenethioamides and -1-(methylsulfanyl)-3-buten-1-imines

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Received March 27, 2003

Abstract—Reactions of allyl and 2-(vinyloxy)ethyl isothiocyanates with alyylmagnesium bromide (THF–Et_2O, 20–30°C, 1–3 h) after hydrolysis or alkylation of adducts afforded respectively *N*-allyl- and *N*-[2-(vinyloxy)ethyl]-3-butenethioamides or *N*-allyl- and *N*-[2-(vinyloxy)ethyl]-1-(methylmercapto)-3-buten-1-imines The reaction carried out in ethyl ether yielded instead of *N*-allyl-3-butenethioamide its isomer *N*-allyl-2-butenethioamide that cleanly isomerized in the system KOH–DMSO–H_2O into *N*-(1-propenyl)-2-butenethioamide. *N*-[2-(vinyloxy)ethyl]-3-butenethioamide suffers a prototropic rearrangement into *N*-[2-(vinyloxy)ethyl]-2-butenethioamide only in the system *t*-BuOK–DMSO.

Reactions of isothiocyanates with organometallic compounds, in particular, with Grignard reagents, were considered prior to our studies [2–4] mainly as one procedure among preparation methods for thioamides. The latter are an important class of organic compounds finding extensive and versatile application in industry (elastomers, curing accelerators, corrosion inhibitors, additives to lubricating oils, artificial fibers, auxiliary substances in textile industry, and chelating agents), in agriculture (insecticides and fungicides), and in medicine (drugs and physiologically active substances) [5–10]. Involving into reactions with isothiocyanates metallated alkynes and dienes not only resulted in discovery of fundamentally new general approaches to the synthesis of the most important nitrogen- and sulfur-containing heterocycles but also in development of quite a number of new reactions [2–4]. In its turn the variations in the character and structure of the isothiocyanate provide a possibility besides the extension of the set of the corresponding derivatives (among them thioamides [1, 10, 11] and imines [1, 11–13]) to affect significantly the reaction route and the structure of products obtained [2–4, 14–23], and also to perform additional functionalization of the products, for instance, to introduce highly active vinyl and allyl groups [1, 11–15, 19, 22–24]. In this respect as very promising substrates for organometallic compounds should be regarded available allyl **I** (commercial product) and 2-(vinyloxy)ethyl **II** [2, 25] isothiocyanates. The synthetic potential [26–31] and biological importance of these compounds (first of all, of allyl isothiocyanate [32]) is hard to overestimate. It should also be mentioned that the nature of organometallic reagent is here especially important, in particular, with allyl isothiocyanate as show the examples presented further.

We demonstrated formerly [13] that the reaction between allyl isothiocyanate and 1-MgBr-1-ethoxyethylene readily and in a high yield (81%) afforded (after alkylation of the adduct with methyl iodide) *N*-allyl-1-(methylmercapto)-2-ethoxy-2-propen-1-imine (as a mixture of *syn*- and *anti*-isomers). Yet the ethoxyethylene carbanions with lithium and potassium counterions [CH_2=C(OEt)M, M = Li, K] reacted with allyl isothiocyanate not as adding nucleophiles but as deprotonating bases (the superbase attacked the methylene group at the nitrogen atom CH_2N activated by the neighboring isothiocyanate group). As a result formed a previously unknown *N*-allyl-*N*-methyl-4-vinyl-2-(methylmercapto)-1,3-thiazol-5-amine [13, 14]. The same thiazole forms in reaction of allyl isothiocyanate with lithium diisopropylamide [15]. However potassium

* For communication VIII see [1].

diisopropylamide effected conversion of allyl isothiocyanate into 2-(R-mercapto)pyrrole [32–34]. The reaction of potassium derivative of ethoxyethylene with 2-(vinyloxy)ethyl isothiocyanate **II** occurs on the contrary in a usual way and after alkylation of the intermediate with methyl iodide furnished N-[2-(vinyloxy)ethyl]-1-(methylmercapto)-2-ethoxy-2-propen-1-imine, the first representative of promising 1,3-azadienes with vinyloxy groups [12, 13].

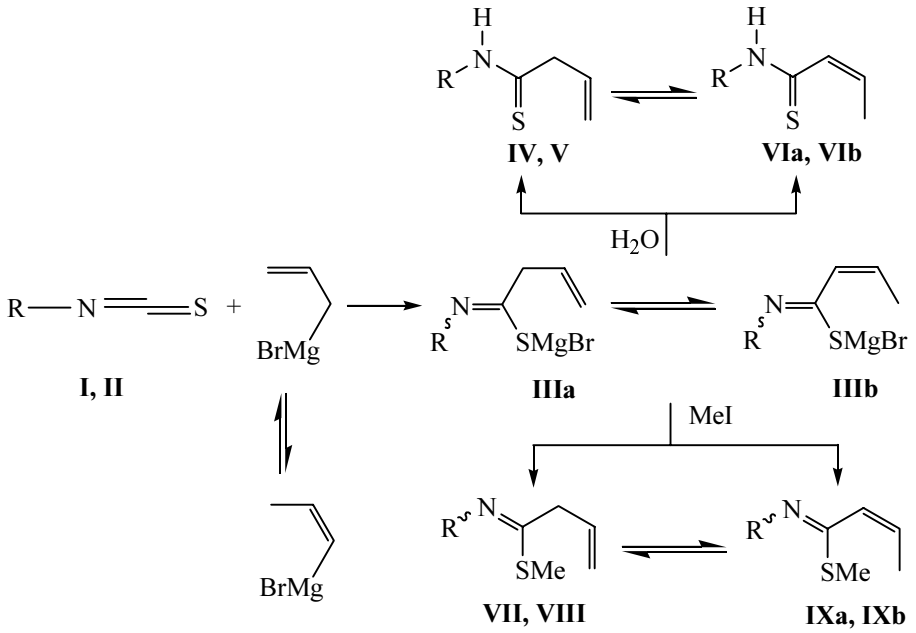
We also established [11] that allyl and 2-(vinyloxy)-ethyl isothiocyanates relatively easily take up the simplest organomagnesium compounds (EtMgBr, PhMgBr, PhMgI) affording on hydrolysis with diluted HCl or on alkylation with EtI adducts, respectively *N*-allyl- and *N*-[2-(vinyloxy)ethyl]thioamides (50–91%) or 1-(alkylmercapto)-1-imines (40–91%), promising monomers and semiproducts for various organic syntheses, including the preparation of biologically active and useful for practice compounds and materials..

In extension of our research in the field of isothiocyanates reactions with organometallic reagents [2, 28, 35], in particular, with Grignard reagents [11], we studied reactions between allyl and 2-(vinyloxy)ethyl isothiocyanates **I** and **II** with allylmagnesium bromide aiming at preparation of new families of highly active polyunsaturated thioamides **IV–VI** and imines **VII–IX** (Scheme 1) containing C=C-bonds of different chemical character: a vinyloxy group and nonequivalent N- and C-allyl substituents. These compounds could be useful as monomers, synthons, promising precursors of heterodiene and heterotriene systems capable of heterocyclization, and also as convenient models for investigation of rearrangements involving the double bond shift. Data on isomerisations of this type in such systems (unsaturated thioamides and imines) either are lacking or strongly limited. At least we did not find the corresponding published information, probably, because compounds of the type **IV–VI** and **VII–IX** were not known up till now. Moreover, before our investigations [2] polyunsaturated thioimidates [compounds containing a key fragment $(R^1S)C=NR^2$] were virtually unknown and therefore poorly studied imines derivatives (only few examples of this class compounds were described in the literature).

The isothiocyanate was added dropwise to a solution of allylmagnesium bromide (taken in ~1.35-fold excess with respect to isothiocyanate) in an appropriate solvent at cooling to –10°C. As solvents served ethyl ether, THF, and a binary mixture Et_2O–THF, 1:1.

The reaction progress was monitored by IR spectra of the reaction mixtures; namely, consumption of isothiocyanate was followed by decrease in the intensity of absorption bands at 2100–2200 cm^{-1} (N=C=S) till their complete disappearance.

Scheme 1.



R = CH_2=$CHCH_2$ (**I, IV, VIa, VII, IXa**), CH_2=$CHOCH_2CH_2$ (**II, V, VIb, VII, IXb**).

Reaction conditions and yields of thioamides **IV–VI** are compiled in Table 1. As seen from the data of Table 1, not only the yield but also the structure of reaction products (reaction regioselectivity) are strongly influenced by the character of the solvent and substituents R attached to the nitrogen atom. Grignard reagents including allylmagnesium bromide [36] are usually prepared in ethyl ether and more seldom in THF [5]. Ethyl ether proved to be the best solvent also for reactions of isothiocyanates **I** and **II** with ethylmagnesium and phenylmagnesium halides as we showed previously [11]. However the synthesis of thioamides **IV** and V occurred in the most efficient way in a binary system ethyl ether–THF. The reaction between isothiocyanates **I** and **II** with allylmagnesium bromide proceeded in these conditions regio-specifically and resulted exclusively in thioamides **IV** and **V** in 40 and 90% yield respectively at conversion of the isothiocyanates 52–53% (Table1, runs nos. *2* and *9*).

It is known [5, 13, 37, 38] that the reaction of Grignard reagents with electrophiles, among them also with heterocumulenes (RN=C=O, RN=C=S, CO_2, CS_2), is sometimes activated with catalysts, usually salts of copper(I) (CuX, X = Cl, Br, I). Actually, the reaction of allyl-magnesium bromide with isothiocyanate **I** in the binary system Et_2O–THF in the presence of 4 wt% of CuBr resulted in increase of the thioamide **IV** yield from 35 to 88%, and simultaneously the isothiocyanate conversion grew from 47 to 60% (Table. 1, runs nos. *4* and *5*).

In reaction of allylmagnesium bromide with allyl isothiocyanate in pure THF the expected thioamide **IV** formed in ~40% yield at isothiocyanate conversion attaining only ~18% (Table 1, run no. *1*). One of the reasons of the low isothiocyanate **I** conversion in this case is probably worse yield of allylmagnesium bromide in THF than at its preparation in ethyl ether (in the reaction carried out in THF always remains unreacted magnesium turnings).

It turned out unexpectedly that reaction of allylmagnesium bromide with allyl isothiocyanate in ethyl ether (20°C, 1 h) instead of *N*-allyl-3-butenethioamide **IV** furnished its isomer, N-allyl-2-butenethioamide **VIa** in 30% yield (isothiocyanate conversion 40%) (Table 1, run no. *6*). Interestingly, the reaction time increased to 18 h resulted in the same isothiocyanate **I** conversion and the same yield of thioamide (no increse in either yield of conversion was observed). The process regioselectivity also was retained: the only reaction product as in the run no. *6* was thioamide **VIa** (Table1, run no. *7*). However when to the reaction mixture is added even a little THF, more polar solvent, the rearrangement of structure **A** into **B** is totally prevented, and only thioamide **IV i**s obtained.

A **B**

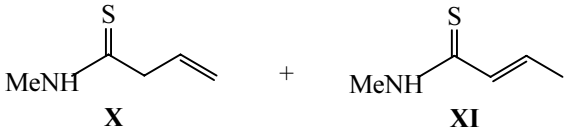
Reaction of the 2-(vinyloxy)ethyl isothiocyanate with allylmagnesium bromide in Et_2O in contrast to allyl isothiocyanate proceeded considerably slower (20–34°C, 3 h) and afforded nonisomerized thioamide **V** in a low

Table 1. Conditions of reaction between allyl **I** and 2-(vinyloxy)ethyl **II** isothiocyanates and allylmagnesium bromide (molar ratio isothiocyanate **I** or **II**–Grignard reagent 1:1.35, 0.037:0.05 mol), and yields of thioamides **IV**–**VI**

Run no.	Compd. no.	Solvent	Temperature, °C	Time, h	Conversion, %	Thioamide no.	Yield, %[a]
1	**I**	THF	20	1	18	**IV**	40
2	**I**	THF–Et_2O[b]	20	1	53	**IV**	40
3	**I**	THF–Et_2O[b]	20	2	50	**IV**	40
4	**I**	THF–Et_2O[b]	30	1.5	47	**IV**	35
5	**I**	THF–Et_2O[b]	30	1.5	60[c]	**IV**	88
6	**I**	Et_2O	20	1	40	**VIa**	30
7	**I**	Et_2O	20	18	39	**VIa**	25
8	**II**	THF–Et_2O[b]	30	3	48	**V**	44
9	**II**	THF–Et_2O[b]	3020	1.52.5	52	**V**	90
10	**II**	Et_2O	20	3	28	**V**	14
11	**II**	Et_2O	34	3	37	**V**	15

[a] Preparative yield calculated on reacted isothiocyanate. [b] In 1:1 ratio (by volume). [c] In the presence of 4 wt% of CuBr.

yield (14–15%) (Table 1, runs nos. *10*, *11*). No 2-butenethioamide **VIb** was detected in the reaction product. Note that the reaction of isothiocyanate **II** with ethyl- and phenylmagnesium bromides under similar conditions (Et_2O, ~30°C, 0.5–2 h) afforded the corresponding thioamides in 50 and 91% yields (at isothiocyanate conversion 100 and 62% respectively) [11]. Therewith the opposite dependence of thioamide yield from the isothiocyanate structure was observed: in reaction with RMgX (R = Et, Ph; X = Br, I) isothiocyanate **II** was somewhat more active than isothiocyanate **I** [11]. Nonetheless the yields of ethyl- and phenythioamides prepared from allyl isothiocyanate in all cases (without catalyst, in different solvents : Et_2O, THF–Et_2O, benzene–Et_2O, 30–42°C, 2–3 h) were also considerably higher than the yields of 3-butenethioamide **IV** (59–77% at conversion 50–100%) [11].



X **XI**

In order to clear up the cause of this considerable difference in the result of reaction of allylmagnesium bromide with allyl and 2-(vinyloxy)ethyl isothiocyanates in ethyl ether, namely, to find out whether unexpectedly ready formation of 2-butenethioamide **VIa** was inherent to some specific effect of the N-allyl group we carried out the reaction of allylmagnesium bromide with methyl isothiocyanate under identical conditions (Et_2O, 20°C, 1 h). It proved that the process afforded a mixture of *N*-methyl-3-butenethioamide **X** and *N*-methyl-2-butenethioamide **XI** in a ratio ~1:6 respectively (according to ^1H NMR data) in ~30% yield.

The formation of 2-butenyl derivative **XI** as prevailing isomer is well consistent with result of the similar reaction with allyl isothiocyanate. Adding THF and CuBr (4 wt%) and raising the temperature to 30°C (1.5 h) also led to a mixture of 3- **X** and 2- **XI** butenethioamides but in the ratio ~1:2 respectively (methyl isothiocyanate conversion 50%, yield 90%). The reaction of allylmagnesium bromide with allyl isothiocyanate under identical conditions gave exclusively 3-butenethioamide **IV** (Table 1, run no. *5*).

In keeping with the above it is clear that in treating the results of reactions in ethyl ether a specific effect of N-[2-(vinyloxy)ethyl} group should be taken into consideration and not of N-allyl group or of isothiocyanate **II**. Inasmuch as the reaction of allylmagnesium bromide with isothiocyanates proved to be very sensitive to the character of solvent, the influence of isothiocyanate **II** on the outcome of the reaction is probably due mainly (or among other causes) to its effect on the parameters of the medium (as a "cosolvent"). The presence in its structure of a polar vinyloxy group and its relatively high molecular weight (*M* 129) compared to those of methyl and allyl isothiocyanates might result in a perceptible contribution into the cooperative effects of the medium.

Thus the above data reveal that variying the isothiocyanate structure and the reaction conditions (solvent, catalyst) can efficiently control both the yield and regioselectivity of the process.

Adducts **III** alkylation with methyl iodide give rise to N-allyl- **VII** and N-[2-(vinyloxy)ethyl]- **VIII** 1-(methyl-mercapto)-3-buten-1-imines whose preparation conditions and yields are compiled in Table 2. It was established however that in ethyl ether (in the presence of 2–4 wt% of CuBr) and also in the binary system Et_2O–benzene (1:1) intermediate **III** with R = CH_2=$CHCH_2$ did not virtually undergo alkylation, and the main reaction products after workup were thioamides **IV** and **VIa** respectively (Table, runs nos. *8* and *9*). The expected imine **VII** was identified by ^1H and ^{13}C NMR spectra in trace amount. Similar results we had obtained formerly at the attempt to alkylate by EtI the adduct of 2-(vinyloxy)ethyl isothiocyanate **II** with phenylmagnesium bromide in Et_2O or a mixture Et_2O–benzene (2:1) [11]. The only reaction product obtained in this process was the corresponding thioamide (yield 61–72%). Yet the methylation of intermediate **III** prepared from isothiocyanate **II** and allylmagnesium bromide occurred in the ethyl ether although with low efficiency and gave imine **VIII** in 31% yield (Table 2, run no. *10*).

THF proved to be the most suitable solvent for alkylation with EtI of adduct from ethylmagnesium bromide and allyl isothiocyanate; here the imine yield reached 74% at quantitative conversion of isothiocyanate **II** [11]. However the reaction of adduct **III** with R = CH_2=$CHCH_2$ and MeI in THF afforded imine **VII** only in 32% yield (Table 2, run no. *1*). The intermediate **III** virtually was not alkylated with butyl iodide under identical conditions. The corresponding imine formed in ~2% yield, and the main reaction product was thioamide **IV** (Table 2, run no. *2*).

The alkylation carried out in the mixed solvent (Et_2O–THF) in the presence of copper(I) salts (CuBr, CuI) or LiBr (Table 2, runs nos.*3*, *4*, *6, 7*) gave higher yield of compound **VII** (43–50%) but in this case the ^1H NMR spectra of the reaction mixtures contain the signals from trace amounts of N-allyl-1-(methylmercapto)-

Table 2. Methylation conditions (molar ratio adduct **III** –MeI , 1:2.7, 0.037:0.10 mol) and yields of imines **VII–IX**

Run no.	Solvent	Temperature, °C	Time, h	Conversion, %	Reaction product			
					imine no.	yield, %[a]	thioamide no.	yield, %[a]
1	THF	20	18	50	**VII**	32[b]	–	–
2	THF	20	18	58	[c]	2	**IV**	24[b]
3	THF–Et_2O[d]	40	0.5	50[e]	**VIIf**	43	–	–
4	THF–Et_2O[d]	40	0.5	50[g]	**VIIf**	48	–	–
5	THF–Et_2O[d]	40 20	1 18	65[g]	**VIIf**	17[h]	–	–
6	THF–Et_2O[d]	40 20	1 18	60[g]	**VIIf**	50	–	–
7	THF–Et_2O[d]	40 20	2 18	53[i]	**VIIf**	45	–	–
8	Et_2O	30	0.5	60[g]	–	–	**IV**	35
9	Et_2O–benzene[d]	20	18	60	–	–	**VIa**	37[b]
10	Et_2O	20	18	28	**VIII**	31[b]	–	–
11	THF–Et_2O[d]	40 20	1 18	88[g]	**VIII**	73	–	–

[a] Preparative yield calculated on reacted isothiocyanate
[b] Without catalyst.
[c] Instead of MeI was used BuI.
[d] In 1:1 ratio (by volume).
[e] In the presence of DMSO (content of water ~0.5%) and CuI.
[f] Traces of **IXa**.
[g] CuBr (2–4 wt%) was added into the reaction mixture in the stage of isothiocyanate addition.
[h] Catalyst was not removed before distillation .
[i] In LiBr presence.

2-buten-1-imine **IXa**. Imine **VII** was easily freed from impurities by distillation in a vacuum. However imine **IXa** we failed to isolate in a pure state due to its extremely low content in the reaction products

It should be noted that when copper(I) salts are used as catalyst they must be thoroughly removed after completion of reaction (for instance, by treating the reaction mixture with a saturated water solution of ammonium chloride in the presence of sodium or potassium cyanide). The distillation of reaction products containing the catalyst or its traces (at incomplete removal) results in decomposition and drastic decrease in the yield of the target product (to 17%) (Table 2, run no. *5*).

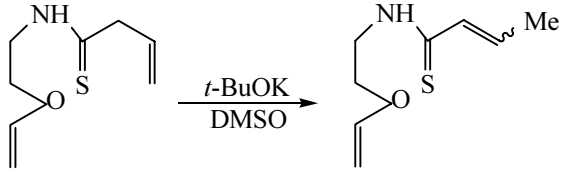
The optimum conditions we found for the synthesis of *N*-allyl-1-(methylmercapto)-3-buten-1-imine **VII** were reproduced in alkylation of the reaction product of allylmagnesium bromide and 2-(vinyloxy)ethyl isothiocya-nate. As seen from Table 2, in the reaction carried out in a solvents mixture (Et_2O–THF) in the presence of CuBr we succeeded in raising isothiocyanate **II** conversion to 88% and the yield of *N*-[2-(vinyloxy)ethyl]-1-(methyl-mercapto)-3-buten-1-imine **VIII** to 73% (Table 2, run no. *11*). *N*-[2-(vinyloxy)ethyl]-1-(methylmercapto)-2-buten-1-imine **IXb** was not identified among the reaction products.Yet the alkylation of adduct obtained from isothiocyanate **II** and ethylmagnesium bromide proceeded as efficiently in pure THF without catalyst (isothiocyanate **II** conversion 90%, imidothioate yield 70%) [11].

The results obtained here and before [11] strongly suggest that both stages of isothiocyanates reaction with the organomagnesium reagents (namely, adduct formation and its alkylation) unexpectedly proved to be exceptionally sensitive not only to the parameters of the process but also to the structure of both reagents. By and large the reaction of allyl and 2-(vinyloxy)ethyl isothiocyanates with allylmagnesium bromide proceeds less efficiently than with ethyl- and phenylmagnesium bromides [11] (both isothiocyanates conversion and yields of reaction products is considerably lower in the former case).

The prototropic rearrangements of unsaturated compounds are widely used in the organic synthesis, also in the synthesis of naturally occurring compounds. In this respect. thioamides **IV–VI** and imines **VII** and **VIII** are incomparable objects for the study of isomerization in-

volving double bond migration in nonequivalent allyl substituents of the type CH_2=$CHCH_2NHC$(=S), CH_2=$CHCH_2C$(=S)NH–, CH_2=$CHCH_2N$=C(SMe), and CH_2=$CHCH_2C$(SMe)=N–. We did not find any publications reporting on these isomerizations although the so-called «allyl» rearrangements, including prototropic processes, are relatively well studied [39]. They are especially frequent in the series of allyl sulfones, sulfoxides, and sulfides [39, 40]. However although they occur relatively easily, these processes still require a prolonged heating in the presence of a catalyst. For instance, allyl aryl sulfones are quantitatively converted into aryl 1-propenyl sulfones in alcoholic medium in the presence of catalytic amounts of Et_3N at 60–80°C in 6–10 h [40]. The reason for the prototropic rearrangement of allyl sulfones is the ease of proton abstraction from the methylene adjacent to the sulfonyl group.

By an example of reaction between allylmagnesium bromide and allyl isothiocyanate we demonstrated for the first time that during the process carried out in Et_2O (Table 1, runs nos. *6* and *7*) or in a mixed solvent Et_2O–benzene (Table 2, run no. *9*) the transformation of the C-allyl group (3-butenyl into 2-butenyl one in thioamide **IV** or, more probably, in intermediate **III**) occurred under unusually mild conditions (20°C, 1 h) and afforded exclusively 2-butenethioamide **VIa** as was already mentioned before. However it cannot be excluded that the allylmagnesium bromide may exist in an equilibrium with its isomer, 2-propenylmagnesium bromide. The latter can react with isothiocyanate giving intermediate **IIIb** and further thioamide **VIa**.



V **VIb**

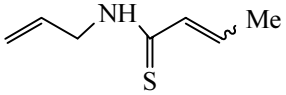
It is well known [41–43] that carbanions generated from unsaturated compounds as a rule exist in solution as an equilibrium mixture of isomeric anions whose reactions with electrophiles (including isothiocyanates [2]) strongly depend, among other things, on the electrophile character. For instance, a lithiated 2-butyne reacted with aliphatic isothiocyanates exclusively in allene form [CH_2=C=C(Me)Li] affording 2,3-dihydropyridines [12, 44] and with phenyl isothiocyanate under identical conditions it appeared on the contrary prevailingly in acetylene form (MeCa”CCH_2Li) giving a mixture of 4-ethyl- (80%) and 3,4-dimethyl- (20%) 2-(methylthio)quinolines [45].

We observed formation of 2-butenyl isomer **XI** (in a mixture with ~15% of 3-bytenylthioamide **X**) also in reaction of allylmagnesium bromidea with methyl isothiocyanate as mentioned above.

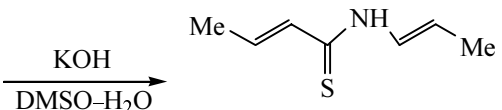
Unlike N-allyl- **IV** and N-methyl- **X** 3-butenethioamides, 3-butenethioamide **V** did not undergo prototropic rearrangement during the synthesis (as seen from the data of Table 1) and even treated by the system KOH–DMSO–H_2O (90°C, 4 h). We succeeded to carry out the quantitative conversion of 3-butenethioamide **V** into 2-butenethioamide **VIb** only using a superbasic system *t*-BuOK–DMSO (60°C, 3 h).

Yet the storage of thioamides **IV** and **V** for several months at 4–20°C without solvent resulted in their spontaneous partial or complete rearrangement into thioamides **VIa** and **VIb** respectively.

The rearrangement of the fragment CH_2=$CHCH_2NHC$(=S) (**C**) into CH_3–CH=CHNHC(=S) (**D**) occurred with more difficulty than transformation of structure **A** into **B**. This rearrangement we first accomplished by an example of N-allylbenzocarbothioamide [46]. The isomerization performed in the system KOH–DMSO–H_2O (90°C, 4 h) afforded *N*-(1-propenyl)benzocarbothioamide (yield 62%) as a mixture of *cis*-(*Z*)- and *trans*-(*E*)-isomers (due to *p*-diastereomerism) that were isolated as individual compounds in 19 and 57% yield respectively [46]. We found that thioamide **VIa** under the same conditions cleanly converted into *N*-(1-propenyl)-2-butenethioamide **XII** existing as two geometric isomers separated by column chromatography and present in different states of aggregation. The liquid stereoisomer **XIIa** was isolated in ~18% yield, the solid stereoisomer **XIIb** of mp 119–120°C in ~50% yield. A *trans,trans*-(*E*,*E*)-configuration (spatial orientation of substituents at the carbon-carbon double bonds) was established for both isomers with the use of ^{1}H NMR spectroscopy basing on the values of the vicinal coupling constants of vinyl protons in the 1-propenyl and 2-butenyl fragments of the molecules.



VIa



XIIa, b

The different state of aggregation of stereoisomers **XIIa** and **XIIb** originates apparently either from dissimi-

Table 3. Main frequencies in the IR spectra of thioamides and imines (cm^{-1})

Compd no.	ν(NH)	ν (C=C)	ν(C=N)	δ[C(S)NH]	ν(CN)	ν_{as}(COC)	ωCH_2=CH)	ω(CH=CH)	ν_s(COC), ω(CH_2=CHO)	ν(CS)
IV	3260 (3435, 3395)	1640, 1655	–	1515 (1500)	1238, 1220 sh	–	930, 995	–	–	–
V	3300 (3395)	1620, 1640, 1660 sh	–	1510 (1490)	1310 br	1190, 1170	920, 990	–	820, 970	–
VIa	3300 (3390, ~3400 sh)	1642, 1658 sh	–	1520 (1500)	1220, 1230 sh	–	920, 995	720, 980	–	–
VIb	3300 (3392)	1620, 1640, 1660 sh	–	1515 (1490)	1310 br	1190, 1170	920,995	720, 980	820, 970	–
XIIa, b	3200 (3370)	1650	–	1520 (1500)	1202	–	–	740, 960	–	–
VII	–	1630, 1650	1580	–	–	–	920, 995	–	–	690
VIII	–	1620, 1640, 1650 sh	1590	–	–	1180	910, 995	–	820, 960	690

Note: The values in parentheses were obtained at recording in $CHCl_3$ solution.

lar orientation of 1-propenyl and 2-butenyl substituents with respect to the thioamide fragment of the molecule or from existing *cis-trans*-isomerism in the thioamide fragment proper. However the answer to this question requires special more thorough investigation.

N-allyl-3-butenethioamide **IV** under similar conditions (KOH–DMSO–H_2O, 90°C, 4 h) cleanly undervent isomerization into *N*-allyl-2-butenethioamide **VIa.**

The attempts to perform a prototropic rearrangement of *N*-allyl- **VII** and *N*-[2-(vinyloxy)ethyl]- **VIII** 1-(methylmercapto)-3-buten-1-imines in similar conditions (DMSO–KOH–H_2O or DMSO–*t*-BuOK, 40–65°C, 2–3 h) were unsuccessful. In all cases only the decomposition of the initial compounds occurred with tarring.

The composition and structure of compounds synthesized are consistent with elemental analyses, IR (Table 3), ^{1}H and ^{13}C NMR spectra (EXPERIMENTAL). In order to prove the structure of thioamides **IV**, partially double character of the heteronuclear ^{1}H×^{13}C–HMBC experiment was carried out. Analysis of ^{1}H NMR spectra revealed that thioamides **IV–VI** exist as a mixture of two geometric isomers [*cis*-(*Z*)- and *trans*-(*E*)-] due to a hindered rotation around the bond N–C in thioamide fragment of **IV–VI** having a partially double bond character and /or around the C=C bond in the 2-butenyl fragment in **VI.**

Imines **VII** and **VIII** also are present in two isomeric states, most likely, *syn*-(*Z*)- and *anti*-(*E*)- (as a result of hindered rotation around the N=C bond). Thus in the ^{1}H NMR spectrum of compound **VII** appear two proton signals of different intensity from =CH– groups and also two signals of different intensity from the terminal =CH_2 group. Since the signals of protons from groups CH_2N, CH_2CS, and SMe also appear in a double set, obviously the compound **VII** exists as two isomers. The unequal intensity of the signals evidences the different amount of the isomers. At the same time the assignment of these split signals of the ^{1}H NMR spectrum to definite isomers meets with difficulties.

The assignment of absorption bands in the IR spectra (Table 3) was performed basing on the data of [11, 46] and publications cited therein. Inasmuch as in the solid and liquid state thioamides **IV–VI** and **XII** are strongly associated due to formation of intermolecular hydrogen bonds involving groups C=S...H–N [ν(N–H) at 3200–3300 cm^{-1}] to facilitate the identification of absorption bands in the IR spectra we recorded the spectra in diluted (5×10^{-2} mol l^{-1}) solutions in $CHCl_3$ where as a rule the hydrogen bonds are completely destroyed.

The compounds of amide and thioamide type are known to possess (*E*,*Z*)-isomerism with respect to the C–N bond [47], and the more stable is usually the (*Z*)-isomer. To this isomer corresponds the high-frequency component of the N–H bond vibrations [46]. As seen from the frequency values listed in Table 3 belonging to the main structural fragments of thioamides and supporting their structure, in diluted solutions of thioamides **IV** and **VIa** exists an equilibrium of isomers, since simultaneously absorption bands of both isomers

are registered with unlike intensity of the N–H group bands (corresponding to different occupancy of the isomeric forms): the band of (*Z*)-isomer is at 3435 cm^{-1}, that of (*E*)-isomer at 3395–3390 cm^{-1} [46].

At the same time in the IR spectra of thioamides **V** and **VIb** is observed a single band at 3395 and 3392 cm^{-1} respectively, apparently because of prevailing formation of (*E*)-isomer.

EXPERIMENTAL

IR spectra were recorded on a double-beam spectrophotometer Specord 75IR from thin films of liquid samples, from solid samples pelletized with KBr, and from solutions in $CHCl_3$ at concentration excuding self-association (5×10^{-2} mol l^{-1}). The resolution in the region 1700–1600 cm^{-1} was 1 cm^{-1}, in the region 3000–3400 cm^{-1} it was 2 cm^{-1}. ^1H and ^{13}C NMR spectra were registered on spectrometers Varian VXR-500 (operating frequency 500 MHz for ^1H) and Bruker DPX-400 (operating frequencies 400.13 MHz for ^1H and 100.69 MHz for ^{13}C) from ~5–30% solutions of samples in $CDCl_3$ at room temperature, internal reference HMDS.

THF was purified by stirring powdered KOH (~50 g l^{-1}) and by distillation from $LiAlH_4$ in the presence of benzophenone under argon atmosphere. Ethyl ether and DMSO were dried as described in [48] and were distilled before use. Allylmagnesium bromide was prepared from magnesium and allyl bromide in ethyl ether in the presence of $HgCl_2$ by a known procedure [36]. 2-(Vinyloxy)ethyl isothiocyanate **II** was prepared by the method [25]. Allyl isothiocyanate was a commercial product purified by distillation. All operations were carried out under nitrogen or argon atmosphere.

General procedure of thioamides (IV–VIa) synthesis. To a solution of 0.05 mol of allylmagnesium bromide in 50 ml of Et_2O at 5–7°C was added by small portions 50 ml of THF. The reaction mixture was cooled to –10°C, and 0.037 mol of isothiocyanate was added dropwise. Then the reaction was carried out in conditions indicated in Table 1. The reaction mixture was cooled to 20°C (if the process was performed at higher temperature) and poured into 400 ml of ice water acidified with 5 ml of hydrochloric acid. The organic layer was separated, the water layer was extracted with ethyl ether. The combined organic solutions were washed with water, dried with potassium carbonate, the solvent was removed on a rotary evaporator, and the residue was distilled in a vacuum. Yields of thioamide **IV–VIa** are listed in Table 1, IR spectra in Table 3.

***N*-Allyl-3-butenethioamide (IV).** Bp 96–100°C (1 mm Hg), n_D^{20} 1.5095. ^1H NMR spectrum, δ, ppm: 2.30 m, 2.38 m (2H, CH_2C=S), 4.00 d.t, 4.13 d.t, 4.24 d.t (2H, CH_2N), 5.09 m, 5.20 m (2H, CH_2=), 5.09 m, 5.20 m (2H, CH_2=), 5.65 q.t, 5.80 q.t (1H, CH=), 5.65 q.t, 5.80 q.t (1H, CH=), 6.30 s, 6.80 s (1H, NH). ^{13}C NMR spectrum, δ, ppm: 47.13, 48.44 ($\underline{C}H_2C$=S), 51.20 (CH_2N), 117.95, 118.52 (CH_2=), 120.41, 120.69 (CH_2=), 130.37, 131.80 (=$\underline{C}HCH_2N$), 132.80, 133.42 (=$\underline{C}HCH_2C$=S), 201.72 (C=S). Found, %: C 59.47; H 8.00; N 9.90; S 22.75. $C_7H_{11}NS$. Calculated, %: C 59.53; H 7.85; N 9.92; S 22.70.

***N*-[2-(Vinyloxy)ethyl]-3-butenethioamide (V).** Bp 140–147°C (2 mm Hg), n_D^{20} 1.5155. ^1H NMR spectrum, δ, ppm (*J*, Hz): 3.50 d (2H, CH_2C=S, ^3J 6.9), 3.9 t (2H, CH_2O), 3.97 q (2H, CH_2N), 4.06 d.d, 4.24 d.d (2H, CH_2=, J_{trans} 14.4, J_{cis} 6.8, ^2J 2.3), 5.24 d.d.t, 5.29 d.d.t (2H, CH_2=, J_{trans} 17.1, J_{cis} 6.9, $^2J = {}^4J$ 1.0), 5.94 q.t (1H, OCH=, J_{trans} 17.1, J_{cis} 6.9), 6.45 d.d (1H, CH=, J_{trans} 14.4, J_{cis} 6.8), 7.40 s, 7.70 s (1H, NH). ^{13}C NMR spectrum, δ, ppm: 37.23, 41.61 ($\underline{C}H_2C$=S), 43.98 (CH_2N), 65.13, 65.62 (CH_2O), 87.02, 87.12 (CH_2=), 117.63, 117.90 (CH_2=), 132.83, 133.00 (CH=), 150.79, 150.88 (OCH=), 189.86 (C=S). Found, %: C 56.30; H 7.51; N 8.22; S 18.77. $C_8H_{13}NOS$. Calculated, %: C 56.10; H 7.65; N 8.18; S 18.72.

***N*-Allyl-2-butenethioamide (VIa).** Bp 110–116°C (1 mm Hg), n_D^{20} 1.5850. ^1H NMR spectrum, δ, ppm (*J*, Hz): 1.86 d.d (3H, Me, ^3J 6.8, ^4J 1.5), 4.35 d (2H, CH_2N, ^3J 5.6), 5.19 d.d, 5.24 d.d (2H, CH_2=, J_{cis} 9.8, J_{trans} 17.3, ^2J 1.0), 5.89 q.t (1H, $CH_2C\underline{H}$=, J_{cis} 9.8, J_{trans} 17.3, ^3J 5.6), 6.32 d.q (1H, =CHC=S, J_{trans} 14.9, ^4J 1.5), 7.01 d.q (1H, $MeC\underline{H}$=, J_{trans} 14.9, ^3J 6.8), 7.80 br.s (1H, NH). ^{13}C NMR spectrum, δ, ppm: 15.35, 18.13 (Me), 48.15, 48.47 (NCH_2), 118.52, 118.47 (CH_2=), 120.14 (CH_2=$\underline{C}H$), 131.75, 131.79 ($Me\underline{C}H$=), 195.43, 201.86 (C=S). Found, %: C 59.66; H 7.93; N 9.92; S 22.87. $C_7H_{11}NS$. Calculated, %: C 59.53; H 7.85; N 9.92; S 22.70.

General procedure of imines (VII, VIII) synthesis. To a solution of 0.06 mol of intermediate **III** prepar-ed as described above was added at 20°C first 2–4 wt% of CuBr, then 0.08 mol of methyl iodide. The reaction was carried out under conditions described in Table 2. Compound **IXa** was identified in the reaction products in trace amounts and was not isolated in individual state.

Procedures of reaction mixture workup: (a) *Reaction without catalyst*. The reaction mixture was poured into water solution of ammonium chloride cooled to ~2–4°C. The organic layer was separated, the water layer

was extracted with ethyl ether. The combined organic solutions were washed with water, dried with potassium carbonate, the solvent was removed on a rotary evaporator, and the residue was distilled. .

(b) *Reaction with a catalyst*. To a reaction mixture cooled to 20°C was added at vigorous stirring first 0.5 g of sodium cyanide in 3 ml of water solution of NH_4Cl, then 200 ml of cold aqueous NH_4Cl. The organic layer was separated, the water layer was extracted with ethyl ether. The combined organic solutions were washed with water, dried with potassium carbonate, and passed through a small bed of neutral aluminum oxide. The solvent was distilled off, thioamide was separated from imine by vacuum distillation. Yields and IR spectra of imines **VII** and **VIII** are compiled in Tables 2 and 3.

***N*-Allyl-1-(methylmercapto)-3-buten-1-imine (VII).** Bp 130–137°C (1 mm Hg), n_D^{20} 1.5422. ^{1}H NMR spectrum, δ, ppm: 2.28 s, 2.31 s (3H, SMe), 2.36 d, 2.37 d (2H, CH_2CS), 3.79 d.t, 4.05 d.t (2H, CH_2N), 5.06 m (2H, CH_2=), 5.19 m (2H, CH_2=), 5.76 m (1H, CH=), 5.89 m (1H, CH=). ^{13}C NMR spectrum, δ, ppm: 12.95, 14.40 (SMe), 34.91, 37.12 ($\underline{C}H_2CS$), 51.10, 54.76 (CH_2N), 114.04, 117.23 (CH_2=), 133.96, 135.99 (CH=), 155.80 (C=N). Found, %: C 61.24; H 8.77; N 9.11; S 20.57. $C_8H_{13}NS$. Calculated, %: C 61.89; H 8.44; N 9.02; S 20.65.

***N*-[2-(Vinyloxy)ethyl]-1-(methylmercapto)-3-buten-1-imine (VIII).** Bp 92–98°C (1 mm Hg), n_D^{20} 1.5180. ^{1}H NMR spectrum, δ, ppm: 2.25 s, 2.46 s (3H, SMe), 3.53 t, 3.64 t (2H, CH_2CS), 3.75 t, 3.85 t (2H, CH_2O), 3.94 t, 3.96 t (2H, CH_2N), 4.20 d.d (2H, CH_2=), 4.22 d.d (2H, CH_2=), 5.14 d.d (2H, CH_2=), 5.15 d.d (2H, CH_2=), 5.80 m, 5.95 m (1H, OCH=), 6.44 q, 6.48 q (1H, CH=). ^{13}C NMR spectrum, δ, ppm: 12.00, 17.77 (SMe), 33.68 ($\underline{C}H_2CS$), 50.73, 51.52 (CH_2N), 65.45, 65.57 (CH_2O), 86.14, 86.22 (CH_2=), 114.46 (CH_2=), 140.27 (CH=), 151.39, 151.61 (CH=), 154.03, 163.63 (C=N). Found, %: C 58.14; H 7.99; N 7.31; S 17.51. $C_9H_{15}NOS$. Calculated, %: C 58.34; H 8.16; N 7.56; S 17.31.

Prototropic rearrangement of *N*-allyl-2-butenethioamide (VIa). A mixture of 1.5 g (0.01 mol) of thioamide **VIa**, 3.81 g (0.1 mol) of KOH, 3.8 ml of water, and 42 ml of DMSO was stirred for 4 h at 90°C. Then the reaction mixture was cooled to room temperature, poured with water, and extracted with ethyl ether. The organic solution was washed with water, dried with potassium carbonate, and the solvent was removed at a reduced pressure. We obtained 1.11 g (74%) of thioamide **XII**. The reaction product was subjected to chromatography on a column (2.1×23 cm) packed with silica gel (Silika gel 60, d 0.063–0.200 mm). Eluent chloroform. From the first fraction (TLC, Silufol, R_f 0.26, $CHCl_3$) on removing the solvent in a vacuum 0.27 g (18%) of *N*-[1-propenyl]-2-butenethioamide **XIIa** was obtained (yellow liquid). ^{1}H NMR spectrum, δ, ppm: 1.76 d.d (3H, $\underline{Me}$CH=CHN), 1.89 d.d (3H, $\underline{Me}$CH=CHS), 5.15 d.q (1H, MeC$\underline{H}$=CHN), 6.34 d.q [1H, =CHC(S), ^3J 15.8], 7.08 d.q [1H, MeC$\underline{H}$=CHC(S)], 7.35 d.d (1H, NCH=), 9.20 s (1H, NH). Found, %: C 59.64; H 7.37; N 10.05; S 22.25. $C_7H_{11}NS$. Calculated, %: C 59.53; H 7.85; N 9.92; S 22.70.

From the second fraction (TLC, Silufol, R_f 0.15, $CHCl_3$) on removing the solvent in a vacuum 0.75 g (50%) of *N*-[1-propenyl]-2-butenethioamide **XIIb** was obtained, yellow crystals, mp 119–120°C (benzene–hexane, 1:1). IR spectrum, KBr, cm^{-1}: 730, 960 (CH=CH), 1320 (CN), 1520 [C(S)NH], 1650 (C=C), 3200–3260 (NH). ^{1}H NMR spectrum, δ, ppm, (*J*, Hz): 1.76 d.d (3H, $\underline{Me}$CH=CHN, ^3J 6.9, ^4J 1.6), 1.87 d.d (3H, $\underline{Me}$CH=CHS, ^3J 6.9, ^4J 1.6), 5.54 d.q (1H, MeC$\underline{H}$=CHN, ^3J 14.0, ^3J 7.0), 6.23 d.q [1H, =CHC(S), ^3J 14.6, ^4J 1.6], 7.04 d.q [1H, MeC$\underline{H}$=CHC(S), ^3J 14.6, ^3J 6.9], 7.47 d.d.q [1H, NCH=, ^3J 14.0, ^3J(CHNH) 10.2, ^4J 1.6), 8.50 c (1H, NH). ^{13}C NMR spectrum, δ, ppm: 15.02 ($\underline{Me}$CH=CHN), 18.11 [$\underline{Me}$CH=CHC(S)], 114.52 (Me$\underline{C}$H=CHN), 127.29 (NCH=), 132.08 [=$\underline{C}$HC(S)], 141.60 [Me$\underline{C}$H=CHC(S)], 190.16 (C=S). Found, %: C 59.05; H 7.76; N 9.45; S 22.49. $C_7H_{11}NS$. Calculated, %: C 59.53; H 7.85; N 9.92; S 22.70.

Prototropic rearrangement of *N*-[2-(vinyloxy)-ethyl]-3-butenethioamide (V). A mixture of 1.22 g (0.01 mol) of thioamide **V**, 0.112 g (0.001 mol) of *t*-BuOK, and 2 ml of DMSO was stirred for 3 h at 60°C, cooled to room temperature, poured into 40 ml of water solution of NH_4Cl, and extracted with ethyl ether. The organic solution was washed with water, dried with K_2CO_3, and the solvent was removed. We obtained 1.0 g (82%) of *N*-[2-(vinyloxy)ethyl]-2-butenethioamide **VIb**, bp 150–153°C (1 mm Hg), n_D^{20} 1.5672. ^{1}H NMR spectrum, δ, ppm (*J*, Hz): 1.86 d.d (3H, $\underline{Me}$CH=, ^3J 7.0, ^4J 1.7), 3.91 t (2H, CH_2O, ^3J 4.9), 4.04 q [2H, NCH_2, ^3J(CH_2–CH_2) = ^3J(CH_2N) 4.9], 4.06 d.d [2H, CH_2=, *cis*, J_{cis} 6.9, ^2J 2.3], 4.23 d.d [2H, CH_2=, *trans*, J_{trans} 13.8, ^2J 2.3], 6.44 d.d (1H, OCH=, J_{cis} 6.9, J_{trans} 13.8), 6.28 d.q [1H, =CHC(S), J_{trans} 15.0, ^4J 1.7], 7.00 d.q (1H, MeC$\underline{H}$=, J_{trans} 15.0, ^3J 7.0). ^{13}C NMR spectrum, δ, ppm: 18.05 (Me), 44.73 (NCH_2), 65.37 (OCH_2), 87.81 (CH_2=), 132.36 [=$\underline{C}$HC(S)], 140.76 (=$\underline{C}$HMe), 151.18 (OCH=), 195.94 (C=S). Found, %: C 55.94; H 7.85; N 8.78; S 18.69. $C_8H_{13}NOS$. Calculated, %: C 56.10; H 7.65; N 8.18; S 18.72.

The study was carried out under financial support of the Russian Foundation for Basic Research (grant 01-03-32698a).

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