ORGANOLITHIUM, ORGANOSODIUM, AND ORGANOMAGNESIUM COMPOUNDS OF AZOLES (REVIEW)

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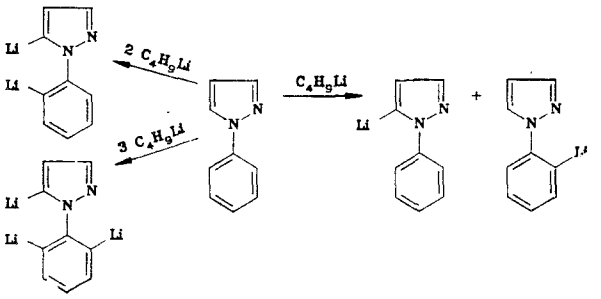
The results of research on the synthesis and transformations of metallated azoles that contain the metal (lithium, sodium, magnesium) in the heterorings and in the C- and N-substitutents are systematized and correlated. The factors that affect the metallation of azoles and data that pertain to the mechanism of these reactions are discussed.

The chemistry of active organometallic compounds of azoles came into existence in the nineteen fifties and sixties and began to undergo intensive development only in the last 10-15 years. In this review we examine the synthesis of organolithium, organosodium, and organomagnesium compounds of azoles (pyrazole, indazole, imidazole, benzimidazole, thiazole, benzothiazole, isothiazole, oxazole, isoxazole, triazoles, thiadiazoles, oxadiazoles, tetrazole) by means of metallation, the factors that affect the reactions used to form them (CH acidity, aromatic stabilization of heterocycles, coordination, solvation), data related to the mechanism of metallation, and the transformations of C-metalloazoles.

METALLATION OF AZOLES

Pyrazole and Indazole

Unsubstituted pyrazole undergoes N,C-dilithiation under the influence of butyl- or phenyllithium; however, the yield of the reaction product – 1,3(5)-dilithiopyrazole – is low [1]. The metallation of 1-alkyl- and 1-aralkylpyrazoles gives considerably better results; the corresponding 5-lithiopyrazoles are formed [1-3]. 1-Lithiomethyl- and 1-(α-lithiobenzyl)pyrazole are the result of the kinetically controlled lithiation of 1-methyl- and 1-benzylpyrazole at −78°C [4]. These compounds undergo spontaneous isomerization at 0-20°C to the thermodynamically more stable 1-methyl- and 1-benzyl-5-lithiopyrazole. 1,5-Dimethyl-, 1,3,5-trimethyl-, 1-methyl-3-phenyl-5-methoxy-, 1-ethyl-3,5-dimethyl-, and 1-benzyl-3,5-dimethylpyrazole are lithiated exclusively at the N-substituent [3-6]. The resulting compounds do not undergo isomerization. This is explained by the fact that the free 3 and 4 (or only 4) positions that remain in the heterorings are inactive in lithiation reactions.



3,5-Dimethyl- and 3-methyl-5-methoxy-1-phenylpyrazole are metallated by butyllithium in the ortho position of the phenyl group [5]. 1-Phenylpyrazole may undergo mono-, di-, and trilithiation upon reaction with the same reagent in ether at 20-25°C [2].

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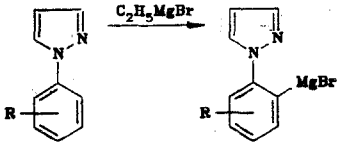
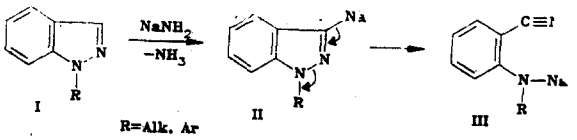
The ratio of the products of monolithiation of 1-phenylpyrazole with respect to the heteroring and the phenyl group is ~4:1. Because of the ambiguity of the results, the possibilities of the use of this reaction in organic synthesis are limited. Recently, however, Micetich and co-workers [7] were able to realize the selective metallation of 1-phenylpyrazole with butyllithium in THF at −70°C in the 5 position [7]. Under the influence of ethylmagnesium bromide 1-phenylpyrazole is converted primarily to 1-(o-bromomagnesiophenyl)pyrazole. Other 1-arylpyrazoles with a free 5 position form 1-(o-bromomagnesioaryl)pyrazoles in low yields [8]. 5-Bromomagnesio-1-arylpyrazoles are also formed in small amounts.



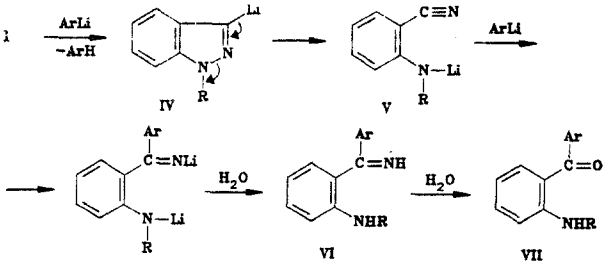
R=H, 2-CH_3, 4-CH_3, 4-OCH_3, 3-Cl, 4-Cl

Prior coordination of the metallating reagent at the $N_{(2)}$ atoms of the substrate molecules has a substantial effect on the direction of reactions involving the formation of organolithium and organomagnesium compounds of 1-arylpyrazoles (see below).

Under the influence of sodium amide in refluxing xylene 1-alkyl-, 1-aralkyl-, and 1-arylindazoles I give nitriles of the corresponding N-substituted anthranilic acids III, which may undergo subsequent transformations [9-11]. The authors assume that labile organosodium compounds II are formed in the first step of the reaction [11].



It is noteworthy that butyllithium and dibutylmagnesium, respectively, at −20°C and +25°C metallate indazoles I (R = CH_3, $C_6H_5CH_2$) at the methyl group and the methylene link of the benzyl group rather than in the 3 position [12, 13].* These reactions evidently proceed under kinetic-control conditions, as in the metallation of 1-methyl- and 1-benzylpyrazole [4]. However, if the lithiation of 1-alkylindazoles I is carried out at the boiling point of the reaction mixture (with diethyl ether as the solvent), the products are 3-lithioindazoles IV, which are ultimately converted to VII [14].



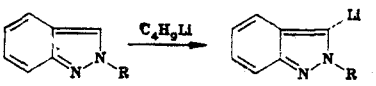
R=CH_3, $CH(CH_3)_2$; Ar=C_6H_5, $CH_3C_6H_4$

The formation of nitriles V from IV was confirmed by special experiments. Ketimine VI was isolated and identified.

3-Lithio-2-alkylindazoles, which were obtained in good yields by metallation of 2-alkylindazoles with butyllithium, should be classified as active organometallic compounds of indazole that may be of interest for the synthesis of various derivatives of this heterocycle [15].

2-Aralkylindazoles are metallated by organolithium and organomagnesium compounds only at the CH_2 group of the N-substituent [15].

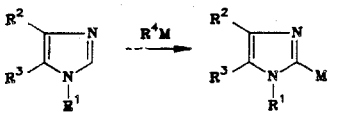
*The research in [12] was published simultaneously with the research in [5] on the metallation of 1,3,5-trimethylpyrazole at the N-substituent.



R=Alk

Imidazole and Benzimidazole

In contrast to pyrazole, imidazole does not undergo C-metallation; however, N-substituted imidazoles are converted to organolithium, organosodium, and organomagnesium compounds VIII readily and in good yields [16-20].

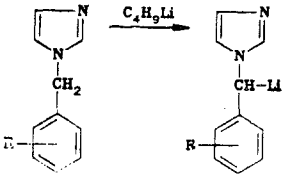


VIII a-g

VIII a-h, k, l, o-q $R^1 = CH_3$, i, m, $R^1 = C_6H_5CH_2$, j, n $R^1 = C_6H_5$; a, c, f, i-p, R^2 = H, b, d, $R^2 = CH_3$, e $R^2 = C_6H_5$, g, q R^2 = Cl, h R^2 = Br; a, b, e, g-k, m-o, q, R^3 = H, c, d $R^3 = CH_3$, f, l, p, R^3 = Cl; a-j, M = Li; k-n M = Na; o-q M = MgBr; $R^4M = C_4H_9Li$, C_6H_5Na, C_2H_5MgBr

Let us note that the formation of 2-sodio-1-methyl-5-chloroimidazole (VIIIl) is not complicated by the Wittig reaction.

The CH_2 group of the N-substituent in N-arylmethylimidazoles undergoes metallation with butyllithium in dimethoxyethane at −60°C [21].



R=H, 4-CH_3, 4-C_6H_5, 4-Cl, 2,4-Cl_2

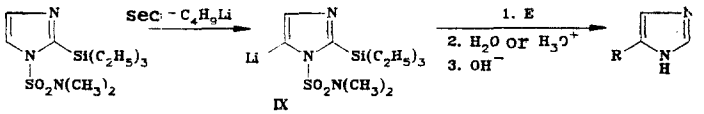
2-Lithioimidazoles containing, at the nitrogen atom, $SO_2C_6H_5$, CH_2OCH_3, $CH_2OC_6H_5$, $C(C_6H_5)_3$, $CH(OCH_3)_2$, and $CH(OC_2H_5)_2$ protective groups, which can be removed after replacement of the metal by any grouping, have been synthesized [22-24].

The metallation of 1,2-disubstituted imidazoles has been examined in detail. The metallation of 1,2-dimethylimidazole in the 5 position with butyllithium has been reported [25]. However, a detailed study of the products of this reaction showed that a mixture of 1,2-dimethyl-5-lithio- and 1-methyl-2-lithiomethylimidazole is actually formed. The ratio of the reaction products depends on the temperature, the solvent, and the nature of the metallation reagent [26-28]. Iddon and Lim [28] were able to obtain 1,2-dimethyl-5-lithioimidazole without admixed isomer by an exchange reaction of 1,2-dimethyl-5-trimethylstannylimidazole with butyllithium at −100°C.

The metallation of 1,2-dimethylimidazole with phenylsodium in toluene [9] and diethyl ether [28] has been described. In the latter case the reaction is evidently complicated by cleavage of the solvent by the metallating reagent.

If the 2 position in N-substituted imidazoles is occupied by groups that do not react with metallating reagents, only the 5 position is deprotonated [23, 29, 30].

The synthesis of 5-lithioimidazole with two protective groups (IX) was recently described. Compound IX was converted to various 5-substituted imidazoles [31].

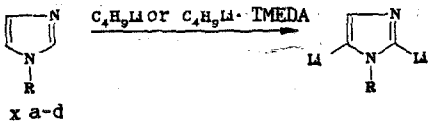


IX

E = $(CH_3)_2S_2$, CH_3I, $CH_2{=}CHCH_2I$, $(CH_3)_3SiCl$, $C_6H_5CH_2Br$, $(C_6H_5)_2CO$, CO_2, $(CH_3)_2NSO_2Cl$; R = CH_3S, CH_3, $CH_2{=}CHCH_2$, $(CH_3)_3Si$, $C_6H_5CH_2$, $(C_6H_5)_2COH$, COOH, Cl

The metallation of 1-substituted imidazoles with 2 or more moles of butyllithium made it possible to realize the 2,5-dilithiation of the imidazole ring [32-34]. The dimetallation

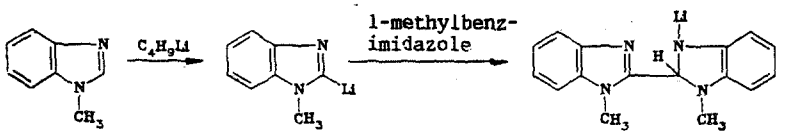
of imidazoles Xa, c gives good results only when a complex of butyllithium with tetramethylethylenediamine (TMEDA) is used [33, 34].



X a-d

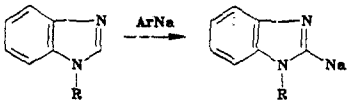
X a R=CH3, b R=C(C6H5)3, c R=CH2OCH3, d R=SO2N(CH3)2

The first active organometallic compound of benzimidazole – 2-lithio-1-methylbenzimidazole – was obtained by the action of butyllithium on 1-methylbenzimidazole at –60°C [35]. At 20°C the reaction between 1-methylbenzimidazole and butyllithium leads to 3'-lithio-1,1'-dimethyl-2',3'-dihydro-2,2'-dibenzimidazolyl. It is assumed [35] that the initial product is 2-lithio-1-methylbenzimidazole, which adds to unchanged 1-methylbenzimidazole at the azomethine bond.



Upon reaction with butyllithium at –60°C 1-phenylbenzimidazole only adds it to the C=N bond. Phenyllithium adds to 1-phenylbenzimidazole at a lower rate than butyllithium; however, the yield of 2-lithio-1-phenylbenzimidazole is very low [36]. The lithiation of 1-phenylbenzimidazole in the 2 position is accompanied not only by the addition of phenyllithium to the C=N bond of the heteroring but also by the formation of 3'-lithio-1,1'-diphenyl-2',3'-dihydro-2,2'-dibenzimidazolyl [37].

Phenylsodium metallates N-substituted benzimidazoles more smoothly than organolithium compounds. Thus benzimidazoles XIa-f are primarily converted to 2-sodio-1-alkyl(benzyl)-benzimidazole XIIa-f. The yields of 2-sodio-1-arylbenzimidazoles XIIg-j are 30-50%. The yields of XIIg-j increase appreciably when o-anisylsodium is used as the metallating agent [38].

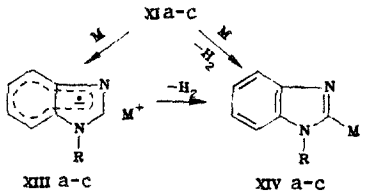


XI a-j XII a-j

XI, XII a R=CH3, b R=C2H5, c R=*n*-C3H7, d R=*iso*-C3H7, e R=*n*-C4H9, f R=CH2C6H5, g R=C6H5, h R=2-CH3C6H4, i R=4-CH3C6H4, j R=2,4,6-(CH3)3C6H2; Ar=C6H5, *o*-CH3OC6H4

In all likelihood, the increase in the yields of XIIg-j when phenylsodium is replaced by the less nucleophilic o-anisylsodium is associated with the fact that as the nucleophilicity of the reagent decreases, the rate of its addition to the C=N bond of the benzimidazole ring decreases faster than the rate of metallation.

It was found that 1-alkylbenzimidazoles XIa-c are capable of being metallated by alkali metals. The reaction is accompanied by the liberation of hydrogen and is sensitive to the inductive effect of the N-substituent. The following pathways for the formation of organosodium and organopotassium compounds XIV from benzimidazoles XI are most likely [39].

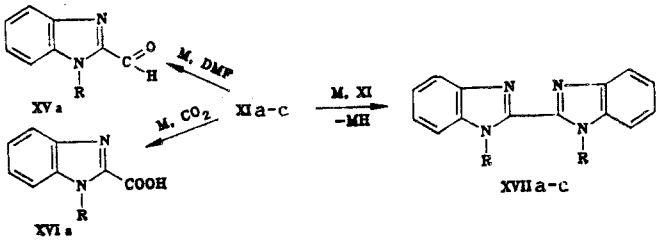


XIII a-c XIV a-c

XI, XIII, XIV a R=CH3, b R=C2H5, c R=*n*-C3H7; M=Na, K, K—Na (4:1)

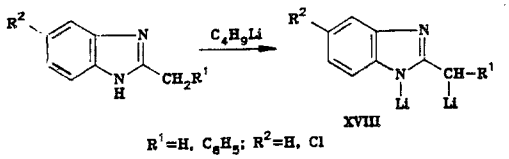
The absence of a signal in the EPR spectrum of the reaction mixture does not, of course, provide a basis for excluding the possibility of realization of the transition XI → XIII → XIV.

If the reaction is carried out in the presence of dimethylformamide and carbon dioxide, the heterocyclic ring of benzimidazole undergoes, respectively, formylation and carboxylation [40]. 1,1'-Dialkyl-2,2'-dibenzimidazolyls XVII are formed in the absence of the indicated reagents [39].



XV, XVI a $R=CH_3$; XVIIa: $R=CH_3$, b $R=C_2H_5$, c $R=n\text{-}C_3H_7$; M=Na, K

The relative case of the N,C-dilithiation of 2-methyl-, 2-methyl-5-chloro- and 2-benzylbenzimidazole was unexpected. Organolithium XVIII are formed as a result of the reaction [41].

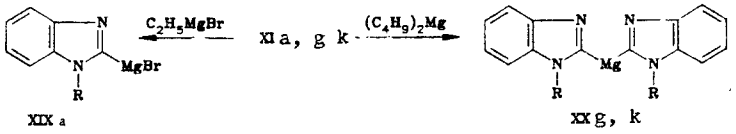


$R^1=H, C_6H_5$; $R^2=H, Cl$

2-Propylbenzimidazole does not undergo C-lithiation even in the presence of tetramethylethylenediamine and hexamethylphosphoric triamide — complexing additives that increase the protophilicity of the metallating reagents. A report of the metallation of benzimidazole with butyllithium to give 1,2-dilithiobenzimidazole [32] was published simultaneously with the research in [41].

Organolithium and organosodium compounds of 1,2-dimethyl-, 1-methyl-2-ethyl-, 1-methyl-2-propyl-, and 1-phenylbenzimidazole containing the metal in the alkyl group in the $C_{(2)}$ position were synthesized by the metallation reaction. Butyl- and phenyllithium and lithio- and sodionaphthalene were used as the metallating reagents [42].

The metallation of N-substituted benzimidazoles XI with ethylmagnesium bromide and dibutylmagnesium leads to the formation of XIX and XX, respectively [18, 20].

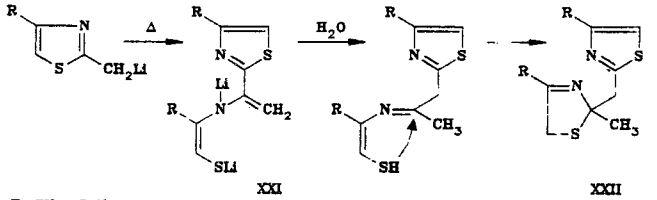


XI, XIX a $R=CH_3$; XI, XX g $R=C_6H_5$, k $R=CH_2OCH_3$

Thiazole, Benzothiazole, Isothiazole, Oxazole, and Isoxazole

The possibility of the lithiation of the thiazole ring was revealed for the first time in the case of the metallation of 4,5-dimethylthiazole with phenyllithium in the 2 position [43]. This reaction was then carried out with thiazole. Phenyl- [44] and butyllithium [45] were used as the metallating reagents.

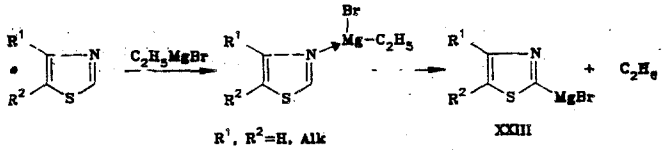
2-Methyl-, 2-methoxy-, and 2-methylmercapto-, and 2-chlorothiazole are lithiated in the 5 position on reaction with butyllithium [46, 47]. 2,4-Dimethyl-, 2-methyl-4-phenyl-, 2-



$R=CH_3$, C_6H_5, $p\text{-}CH_3OC_6H_4$

methyl-4-(p-methoxyphenyl)-, and 2-methyl-4-(p-chlorophenyl)thiazole give mixtures of products of metallation in the 5 position and at the methyl group in the 2 position [48]. 2-Lithio- and 2-lithiomethylthiazoles are stable only at low temperatures. For example, 4-substituted 2-lithiomethylthiazoles are converted at 25°C to XXI, the hydrolysis of which gives XXII [49, 50].

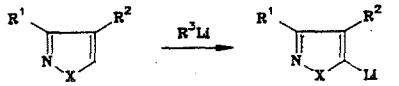
The metallation of thiazole and 4-methyl-, 5-methyl-, 4-ethyl-, 4,5-dimethyl, and 4,5-diethylthiazole with ethylmagnesium bromide is known [51]. The following scheme for the formation of organomagnesium compounds XXIII was proposed:



R^1, R^2=H, Alk

XXIII

Benzothiazole is metallated by butyllithium, phenylsodium, and ethylmagnesium bromide to give 2-lithio-, 2-sodio-, and 2-bromomagnesiobenzothiazole [20, 52, 53]. In the presence of TMEDA 2-methylbenzothiazole is metallated by butyl- or phenyllithium at the methyl group [54].

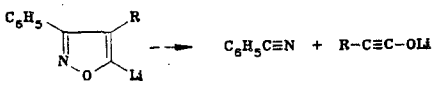


XXIVa-j, XXV a-c XXVIg-j, XXVII a-c

XXIV, XXVI X=S; a-e R^1=H, f-j R^1=CH_3; a-j R^2=H, b R^2=CH_3, c,g R^2=Cl, d,h R^2=Br, and R^2=I, e,j R^2=COOH; R^3=C_4H_9, C_6H_5; XXV, XXVII X=O; a R^1=H, b,c R^1=C_6H_5; a,b R^2=H, c R^2=C_6H_5; R^3=C_4H_9, (*iso*-C_3H_7)$_2$N, tetramethylpiperidyl

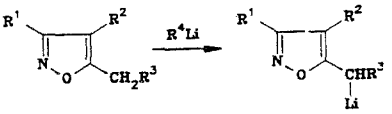
If the heteroring contains, in addition to nitrogen atoms, sulfur or oxygen atoms, metallation proceeds in the α-position with respect to the latter. Isothiazoles XXIVa-e and isoxazole XXVa are metallated precisely in this way. Other isothiazoles XXIV and isoxazoles XXV with a free 5 position are also converted to organometallic compounds XXVI and XXVII [55-61].

In the process of formation 5-lithio-3-phenyl- (XXVIIb) and 5-lithio-3,4-diphenylisoxazole (XXVIIc) undergo cleavage to benzonitrile and a lithium derivative of ketene (XXVIII) [59, 60].



XXVII b,c R=H, C_6H_5 XXVIII

Isoxazoles that contain CH_3, CH_3OCH_2, CH_3SCH_2, and $C_6H_5OCH_2$ groups in the 5 position form completely stable organolithium compounds XXIX [5, 62-68].



XXIXa-o

XXIXa, g – j R^1=CH_3, b, k R^1=OCH_3, c R^1=C_6H_5, d R^1=CH_2OCH_3, e R^1=$CH_2N(CH_3)_2$, f R^1=CH_2OH, l–n R^1=2,6-$Cl_2C_6H_3$, o R^1=$CH_2SO_2CH_3$; a–h, l–o R^2=H, k R^2=CH_3, i R^2=$CH_2N(CH_3)_2$, j R^2=CH_2OH; a–f, i–k, o R^3=H, g, l R^3=OCH_3, h, m R^3=SCH_3, n R^3=OC_6H_5; R^4Li=C_4H_9Li, (*i*-C_3H_7)$_2$NLi

In addition to organometallic compounds XXIXb, d, e, products of metallation of the isoxazole ring in the 4 position are formed by the action of butyllithium on 3-methoxymethyl-5-methyl-, 3-dimethylaminomethyl-5-methyl-, and 3-methoxy-5-methylisoxazole [5, 62, 64, 69].

If the 5 position of a 3-substituted isoxazole is occupied by a grouping that does not react with the metallating agent, metallation takes place in the 4 position. Thus 3-methoxy-5-arylisoxazoles are converted to 4-lithio-3-methoxy-5-arylisoxazoles (Ar = C_6H_5, o-ClC_6H_4, 2,6-$Cl_2C_6H_3$) by the action of butyllithium [70]. 3-(2,6-Dichlorophenyl)-5-dimethylaminomethylisoxazole is metallated exclusively in the 4 position [64].

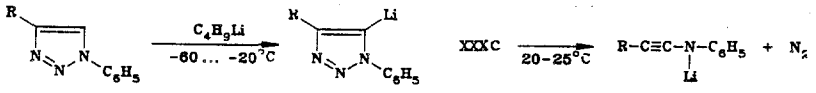
The metallation of 5-phenyl- and 4,5-diphenylisoxazole with butyllithium proceeds in the 2 position of the oxazole ring [71-73], whereas 2,4-diphenyloxazole is metallated in the 5 position [60]. 2-Methyl derivatives of oxazole that contain alkyl or aryl substitutents in the 4 and 5 positions undergo metallation by butyllithium and lithium diisopropylamide at the $C_{(2)}$-methyl group [74, 75].

It might be assumed that the lithiation of the above-mentioned alkyl derivatives of oxazole at the $C_{(2)}$-methyl group is a consequence of the fact that this group is in the ring position that is most active in metallation reactions in the unsubstituted heterocycle (the CH group in the 2 position of oxazole, which is located between two heteroatoms, will evidently have the maximum acidity). It was established that alkyl substituents of precisely this type are readily metallated in azoles [5, 50, 65-67].

An attempt to obtain 2-lithiobenzoxazole by lithiation of benzoxazole with butyllithium was unsuccessful [35]; however, 2-ethyl- and 2-benzylbenzoxazole are deprotonated by lithium amide in liquid ammonia, and 2-(α-lithioethyl)- and 2-(α-lithiobenzyl)benzoxazole are formed as a result [76].

Triazoles, Oxadiazoles, Thiadiazoles, and Tetrazole

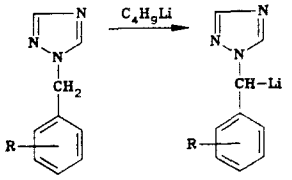
Organolithium compounds XXX are formed by the action of butyllithium at −60°C to −20°C on substituted 1,2,3-triazoles [77]. Opening of the heterocyclic ring of lithiotriazole XXXc occurs at higher temperatures [78].



XXXa R=H, b R=CH_3, c R=C_6H_5 XXX a-c

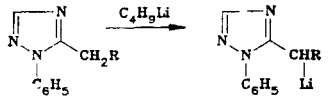
Other XXX compunds will also evidently behave like lithiotriazole XXXc. 1-Phenyl-5-methyl-1,2,3-triazole is lithiated by butyllithium at the methyl group [77, 79].

5-Lithio-1-phenyl-1,2,4-triazole is formed in the reaction of 1-phenyl-1,2,4-triazole with butyllithium [79]. 1-Benzyl-3-phenyl-1,2,4-triazole is similarly lithiated [80]. However, 1-arylmethyl-1,2,4-triazoles that are not substituted in the heterocyclic ring are metallated in dimethoxyethane at the CH_2 group of the N-substituent [21].



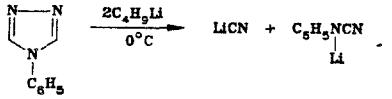
R=H, 4-CH_3, 4-Cl

5-Substituted 1-phenyl-1,2,4-triazoles are converted to organolithium compounds XXXI on metallation with butyllithium [79].



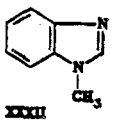
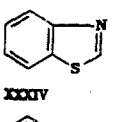
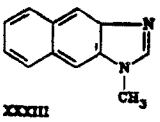
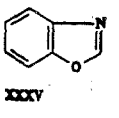
R=CH_3, OCH_3, COOH XXXI

Opening of the triazole ring occurs in the action of butyllithium on 1-phenyl-1,3,4-triazole at 0°C [81]. Ring cleavage is evidently preceded by metallation in the 2 or 2 and 5 positions.



3,4-Dimethyl-1,2,5-oxadiazole is metallated by butyllithium at one of the methyl groups, while 3-phenyl-5-methyl-1,2,4-oxadiazole and 2,5-dimethyl-1,3,4- and 3,5-dimethyl-1,2,4-thiadiazole are metallated at the methyl group in the 5 position [5]. In the case of 3-methyl-

TABLE 1. Isotope Exchange of the μ-H Atoms in Azoles in a 0.57 N Solution of C_2H_5OK in C_2H_5OD and the Results of the Action of Butyllithium on Azoles*

Azole	$-\lg k_{50\,°C}$	Literature	Azole	$-\lg k_{50\,°C}$	Literature
 XXXII	4,2	[35, 88]	 XXXIV	2,1	[52, 88]
 XXXIII	3,9	[89]	 XXXV	1,3	[35, 88]

*Compounds XXXII and XXXIV are metallated by C_4H_9Li, while XXXIII and XXXV are not metallated.

5-phenyl-1,2,4-oxadiazole butyllithium adds to the ring $C=N_{(4)}$ bond. The oxadiazole and thiadiazole rings are opened by the action of butyllithium on 2,5-dimethyl-1,3,4-oxadiazole and 3,4-dimethyl-1,2,5- and 4-methyl-5-phenyl-1,2,3-thiadiazole [5]. Benzo-2,1,3-thiadiazole behaves similarly on reaction with phenyllithium [82].

5-Phenyl-1,2,3-thiadiazole is converted to the 4-lithio derivative on reaction with methyllithium, while 4-phenyl-1,2,3-thiadiazole is metallated by lithium diisopropylamide in the 5 position [83].

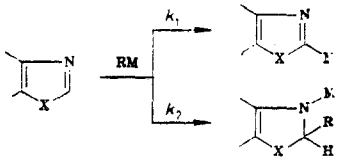
The synthesis of 5-lithio-1-methyl-, 5-lithio-1-phenyl- and 5-lithio-1-cyclohexyltetrazole by lithiation of the corresponding tetrazoles with butyllithium has been described [84, 85]. 1,5-Dialkyl-, 1-methyl-5-benzyl-, and 1-phenyl-5-methyltetrazole are lithiated by butyllithium in the side chain [86, 87].

Factors that Affect the Formation of Organometallic Compounds of Azoles

The CH acidity, aromatic stabilization of the heterocyclic system, coordination, solvation, and other factors affect the formation of organometallic compounds of azoles.

At first glance, there is no dependence between the kinetic CH acidity of a number of azoles and their ability to exchange a hydrogen atom for a metal atom. As an example, let us cite the H–D exchange constants in some azoles and the results of the action of butyllithium on the latter (Table 1).

The results presented in Table 1 are explained primarily by the fact that the indicated azoles can both be metallated and can add the metallating reagent to the C=N bond [35, 42, 52, 89].

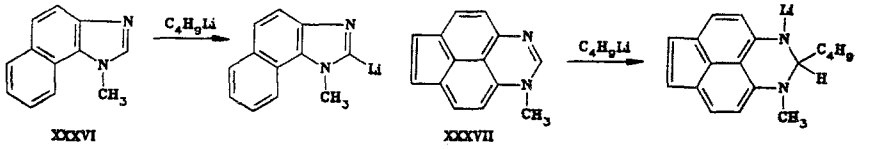


X=N, S, O; RM — metallating reagent

The final result depends on the ratio of the rate constants of the reactions k_1/k_2. Only the addition of butyllithium to the C=N bond actually occurs in the case of XXXIII and XXXV. Compounds XXXII and XXXIV undergo metallation to a significant extent. Thus, it must be assumed that, of a number of metallated azoles with k_2 values that differ slightly, the azole with the greatest CH acidity will give the highest yield of the C-metallo derivative.

The degree of resonance stabilization of the heterocycle may affect the k_1/k_2 ratio. Thus, for example, the corresponding products of metallation and addition of the metallating reagent to the C=N bond are formed almost quantitatively in the reaction with butyllithium of azole XXXVI [$-\log k_{50}°C$ = 4.7 (H–D exchange), REPE = 0.05β] and heterocycle XXXVII [$-\log k_{50}°C$ = 5.2 (H–D exchange), REPE = 0.04β], which can be regarded as an unusual azole [89].

The metallation of 1-arylbenzimidazoles with phenylsodium is another example. 1-Arylbenzimidazoles are noncoplanar as a consequence of overlapping of the effective radii of action of the hydrogen atoms in the 7 position and the atoms of hydrogen or the substituents in the ortho position of the N-aryl groups. With an increase in the angle between the plane of benzimidazole and the plane of the N-substituent the aromatic character of the heterocyclic ring will increase as a consequence of a decrease in the degree of conjugation of the indicated fragments; this should increase the k_1/k_2 ratio. In fact the yields of metallation products increase appreciably in the series 1-(p-tolyl)-, 1-(o-tolyl)-, 1-mesitylbenzimidazole [38].

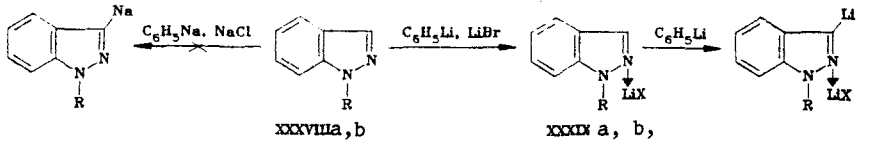


XXXVI XXXVII

The metallation of azoles may be complicated not only by the addition of the metallating reagent to the ring C=N bond but also by other side processes: reaction of the resulting organometallic compounds with unchanged azole and with one another and their partial decomposition (see above for these reactions).

The effect of coordination on metallation is illustrated by the following data.

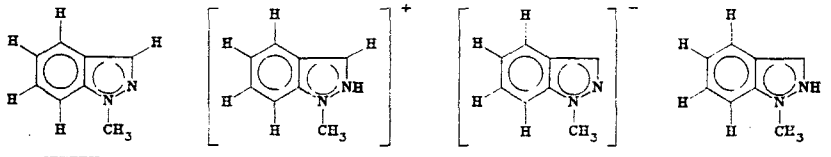
1. 1-Substituted indazoles XXXVIII are lithiated by phenyllithium, whereas they are not metallated by phenylsodium [14]. Lithium bromide is present in the reaction mixture in the first case, whereas sodium chloride is present in the second case. In the metallation of 1-substituted indazoles XXXVIII with phenyllithium containing lithium bromide the initial products are complexes XXXIX, which should have greater CH acidity than starting XXXVIII. Since the ability to undergo coordination is more weakly expressed for sodium compounds than for lithium compounds, the formation of complexes of the XXXIX type is hindered when phenylsodium is used as the metallating reagent.



XXXVIIIa,b XXXIX a, b,

XXXVIII, XXXIX a R=CH_3, б R=$CH(CH_3)_2$; X=Br, C_6H_5

The conclusion regarding the effect of coordination on the metallation of indazoles XXXVIII was confirmed by quantum-chemical calculation by the CNDO/2 method of the total charges on the hydrogen atoms of 1-methylindazole (XXXVIIIa) and the 1-methylindazolium ion (XL), as well as the total energies of these compounds and the corresponding conjugate bases XLI and XLII.



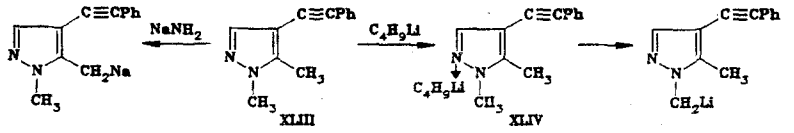
XXXVIII a XL XLI XLII

The charge on the $H_{(3)}$ atom in XXXVIIIa was +0.0288, as compared with +0.1006 in cation XL. The calculated $-[E_n(XXXVIIIa) - E_n(XLI)]$ and $-[E_n(XL) - E_n(XLII)]$ differences are 24.99 and 17.38 eV, respectively [14].

2. N-Substituted benzimidazoles are metallated by both organolithium and organosodium compounds [$-\log k_{50}°C \approx 4$ (H–D exchange) for N-substituted benzimidazoles [89]]. However, N → LiX coordination (X = halogen, Alk, Ar) increases the rate of addition of the metallating

reagent to the ring C=N bond. The metallation of 1-alkyl- and 1-arylbenzimidazoles with phenylsodium therefore gives better results than when butyl- and phenyllithium are used as the metallating reagent [35, 37, 38]. N-substituted imidazoles differ little from N-substituted benzimidazoles with respect to CH acidity [$-\log k_{50\,°C} \approx 4.7$ (H–D exchange) for N-alkylimidazoles [88]] and have a rather strong (with respect to metallating reagents) heterocyclic ring. N-Substituted 2-lithio- and 2-sodioimidazoles are therefore formed in virtually identical yields [16, 19].

Coordination may change not only the rate of metallation but also the site of incorporation of the metal atom into the azole. It was pointed out above that while 1-phenylpyrazole is lithiated by butyllithium in the 5 position of the heterocyclic ring and in the ortho position of the N-substituent, ethylmagnesium bromide metallates this compound primarily in the ortho position of the phenyl group. This result is explained by the fact that ethylmagnesium bromide gives a more stable complex of the XLIV type than butyllithium. Sodium amide metallates pyrazole XLIII at the $C_{(5)}$–CH_3 group, while butyllithium metallates it at the N-substituent [90]. In the latter case the formation of complex XLIV probably precedes metallation.



Coordination also affects the properties of organometallic compounds of azoles. It was found, for example, that organosodium compounds of benzothiazole and N-alkylbenzimidazoles are more stable than the corresponding lithio derivatives [35, 38, 52, 53]. This is explained by the fact that lithioazoles exist in the form of XLV complexes. The reactivity of the ring C=N bond in the XLV complexes with respect to carbanions is increased; this leads to different transformations of these compounds.

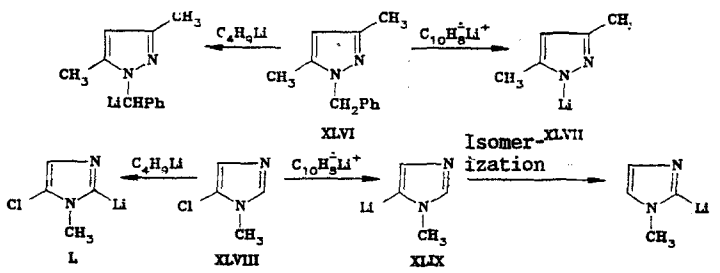
Unstable above −30 °C Stable at −15°C

X – halogen, Alk, Ar; Z = S, N—Alk

The rate of metallation usually increases with an increase in the solvating capacity of the solvent. This is associated with the fact that the solvent, by coordinating with the metallating reagent, increases its protophilicity. Solvents that contain 1,2-dimethoxyethane, tetramethylethylenediamine, hexamethylphosphoric triamide, and other complexing additives are particularly effective. For example, Chadwick and co-workers were able to accomplish the 2,5-dilithiation of N-substituted imidazoles with butyllithium in hexane or in ether in the presence of tetramethylethylenediamine [33, 34], and organomagnesium compounds of 1-aralkylindazoles were obtained in a mixture of ether with toluene containing 1,2-dimethoxyethane. In the latter reaction phenylmagnesium bromide and dibutylmagnesium were used as the metallating reagents [15].

MECHANISM OF THE METALLATION OF AZOLES

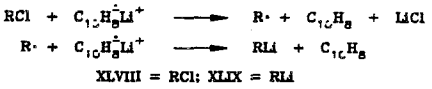
According to the most widely accepted point of view, metallation is an acid-base process, whereas according to another point of view, it is a redox process.



In a comparative study of the reaction of 1-benzyl-3,5-dimethylpyrazole (XLVI) and 1-methyl-5-chloroimidazole (XLVIII) with butyllithium and naphthyllithium – an effective electron donor – it was established that these metallating reagents react differently with the indicated heterocycles [6, 18].

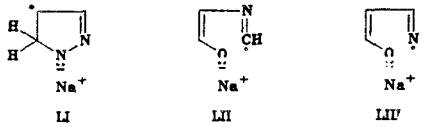
It is apparent that the formation of XLVII from pyrazole XLVI by the action of naphthyllithium is a redox reaction. Butyllithium does not react with 1-benzyl-3,5-dimethylpyrazole via this pathway, for otherwise debenzylation would occur.

If the redox mechanism presented below is assumed for the transformation XLVIII → XLIX, the mechanism should be an acid-base process in the case of the reaction XLVIII → L.



XLVIII = RCl; XLIX = RLi

The adducts of pyrazole, oxazole, and isoxazole with sodium obtained by the action of sodium metal on these azoles at ~4°K with the simultaneous irradiation with light with a wavelength of 550 nm have structures LI, LII, and LIII [91, 92].



LI LII LIII

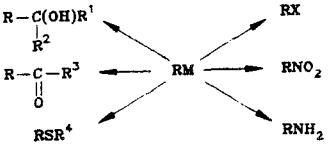
It is unlikely that adducts LI, LII, and LIII can be converted to 1,3(5)-disodiopyrazole, 2-sodiooxazole, and 5-sodioisoxazole, i.e., to products of metallation of the indicated azoles by organosodium compounds.

Thus the data presented above do not confirm the concept that the metallation of azoles by RM (R = Alk, Ar; M = Li, Na, MgX) proceeds via a redox mechanism that includes a step involving electron transfer from the reagent to the substrate but do constitute evidence in favor of an acid-base mechanism.

REACTIONS OF ORGANOMETALLIC COMPOUNDS OF AZOLES

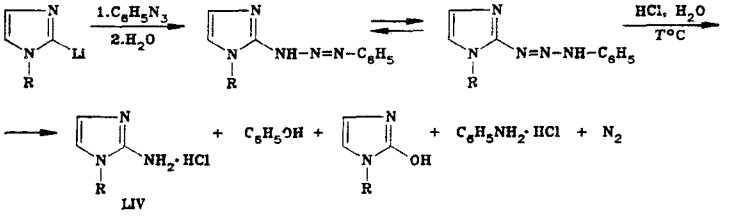
Synthesis of Derivatives of Azoles

Organolithium, organosodium, and organomagnesium compounds RM have been successfully used for the synthesis of many derivatives of azoles:



RM = C-metalloazole; R^1, R^2, R^3, R^4 = H, Alk, Ar; X = Br, I; M = Li, Na, MgX

Hydroxy, oxo, halo, nitro, and mercapto derivatives of azoles have been synthesized by the reactions of RM with compounds that contain a carbonyl group [1, 3-5, 15-24, 43, 45-48, 51, 52, 54, 56, 60, 61, 66, 71, 72, 74, 76, 80, 83, 84, 87, 93-104], epoxy compounds [45, 99], orthoformic ester [103], halogens [18, 22, 56, 70, 84, 102, 105-107], β-indophenylacetylene [38], N-bromodiethylamine [25], nitrogen tetroxide [108], nitric acid esters [42, 109], sulfur [84], and disubstituted disulfides [23, 33, 64, 65, 97, 99]. Since in the case of 2-lithioimidazoles the reactions described in the literature for the formation of primary amines from aromatic organolithium and organomagnesium compounds and chloramine and O-methyl- and O-benzylhydroxylamine did not give positive results, phenyl azide was used as the reagent [102, 110].

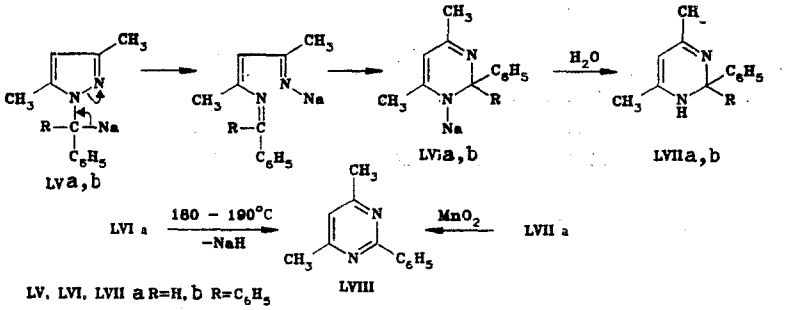


LIV

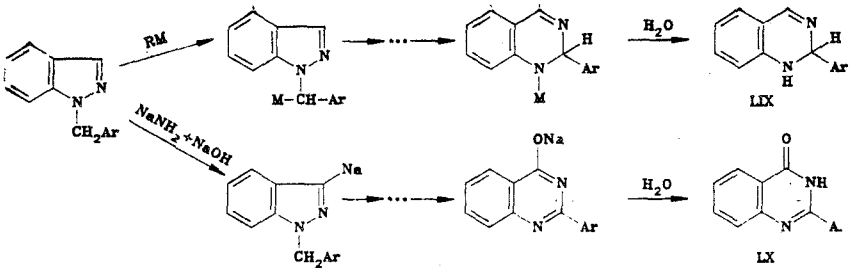
Compounds LIV and phenol are the principal reaction products. This method for the synthesis of 2-aminoimidazoles is currently considered to be one of the best [111].

Transformations to Other Heterocyclic Systems

In a study of the metallation of N-substituted pyrazoles it was observed that organosodium compounds of N-benyl- and N-benzylhydrylpyrazoles (LV) at 150-155°C undergo a rearrangement that proceeds with expansion of the pyrazole ring to a dihydropyrimidine ring. Dihydropyrimidines LVII are formed as a result of this reaction. If the process is carried out at higher temperatures, organosodium compound LVa is converted to pyrimidine LVIII [112].

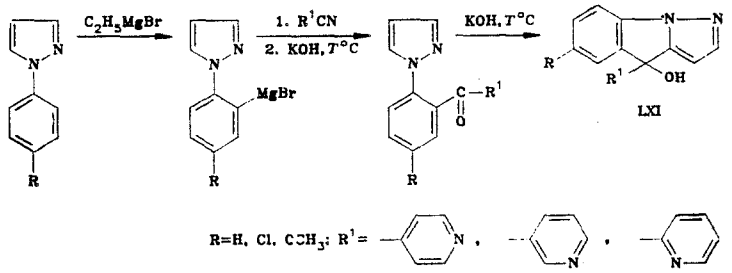


Expansion of the pyrazole ring to dihydropyrimidine and pyrimidine rings was also observed in the action of 1-arylmethylindazoles, with a free 3 position, of active organometallic compounds [13] and a mixture of sodium amide with sodium hydroxide [9]. The products of these reactions are, respectively, 2-aryl-1,2-dihydroquinazolines LIX and 2-aryl-4-quinazolones LX. In the first case organometallic compounds of 1-arylmethylindazoles containing the metal in the methylene group of the N-substituent are formed intermediately [13], whereas 3-sodio-1-arylmethylindazoles are formed in the second case [9, 11].

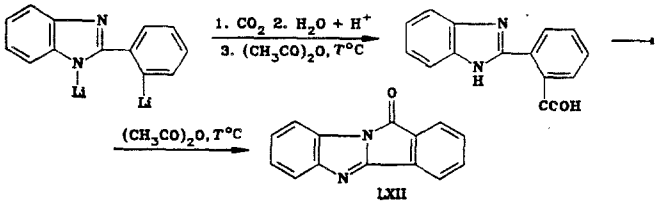


RM=C_4H_9Li, C_6H_5MgBr, $(C_4H_9)_2Mg$; Ar=C_6H_5, p-ClC_6H_4

Substituted pyrazolo[1,5-a]indoles LXI were synthesized from organomagnesium compounds of 1-arylpyrazoles [113].



The product of lithiation of 2-phenylbenzimidazole — 1-lithio-2-(o-lithiophenyl)benzimidazole — was converted to isoindolo[2,1-a]benzimidazol-11-one (LXII) by carbonization with subsequent treatment of the resulting compound with acetic anhydride [114].



It should be noted that synthesis based on organolithium, organosodium, and organomagnesium compounds of azoles are generally carried out under mild conditions and are distinguished in many cases by high yields of the desired compounds. There is no doubt that they substantially expand the possibilities of the synthetic chemistry of heterocycles.

LITERATURE CITED

1. R. Hüttel and M. E. Schön, Annalen, 625, 55 (1959).
2. P. W. Alley and D. A. Shirley, J. Am. Chem. Soc., 80, 6271 (1958).
3. D. E. Butler and S. M. Alexander, J. Org. Chem., 37, 215 (1972).
4. A. R. Katritzky, C. Jayram, and S. N. Vassilatos, Tetrahedron, 39, 2023 (1983).
5. R. G. Micetich, Can. J. Chem., 48, 2006 (1970).
6. B. A. Tertov and A. S. Morkovnik, Khim. Geterotsikl. Soedin., No. 3, 392 (1975).
7. R. G. Micetich, V. Baker, P. Spevak, T. W. Hall, and B. K. Bains, Heterocycles, 23, 943 (1985).
8. A. Marxer and M. Siegrist, Helv. Chim. Acta, 57, 1988 (1974).
9. A. M. Simonov, B. K. Martsokha, and F. T. Pozharskii, Zh. Obshch. Khim., 33, 1001 (1963).
10. A. M. Simonov and B. K. Martsokha, Khim. Geterotsikl. Soedin., No. 5, 774 (1965).
11. B. K. Martsokha and A. M. Simonov, Khim. Geterotsikl. Soedin., No. 5, 779 (1965).
12. B. A. Tertov and P. P. Onishchenko, Khim. Geterotsikl. Soedin., No. 10, 1435 (1970).
13. B. A. Tertov, P. P. Onishcheko, and V. V. Bessonov, Khim. Geterotsikl. Soedin., No. 10, 1410 (1974).
14. B. A. Tertov, P. P. Onishchenko, Yu. V. Koshchienko, G. M. Suvorova, and E. N. Malysheva, Khim. Geterotsikl. Soedin., No. 8, 1078 (1982).
15. B. A. Tertov and P. P. Onishchenko, Zh. Obshch. Khim., 41, 1594 (1971).
16. D. A. Shirley and P. W. Alley, J. Am. Chem. Soc., 79, 4922 (1957).
17. D. S. Noyce and G. T. Stowe, J. Org. Chem., 38, 3762 (1973).
18. B. A. Tertov, V. V. Burykin, P. P. Onischenko, A. S. Morkovnik, and V. V. Bessonov, Khim. Geterotsikl. Soedin., No. 8, 1109 (1973).
19. B. A. Tertov and V. V. Burykin, Khim. Geterotsikl. Soedin., No. 11, 1554 (1970).
20. I. N. Somin, Zh. Obshch. Khim., 39, 1854 (1969).
21. M. R. Cuberes, M. Moreno-Mañas, and A. Trins, Synthesis, No. 3, 302 (1985).
22. R. J. Sundberg, J. Heterocycl. Chem., 14, 517 (1977).
23. C. C. Tang, D. Davalian, P. Huang, and R. Breslow, J. Am. Chem. Soc., 100, 3918 (1978).
24. N. J. Curtis and R. S. Brown, J. Org. Chem., 45, 4038 (1980).
25. B. A. Tertov, V. V. Burykin, and I. D. Sadekov, Khim. Geterotsikl. Soedin., No. 3, 560 (1969).
26. D. S. Noyce, G. T. Srowe, and W. Wong, J. Org. Chem., 39, 2301 (1974).
27. E. F. Godefroi, J. J. H. Geenen, B. van Klingeren, and L. J. van Wijngaarden, J. Med. Chem., 18, 530 (1975).
28. B. Iddon and B. L. Lim, J. Chem. Soc., Perkin 1, No. 2, 271 (1983).
29. R. Breslow, J. T. Hunt, R. Smiley, and T. Tarnowski, J. Am. Chem. Soc., 105, 5337 (1983).
30. M. J. Kukla and J. M. Fortunato, J. Org. Chem., 49, 5003 (1984).
31. A. J. Carpenter and D. J. Chadwick, Tetrahedron, 42, 2351 (1986).
32. P. Jutzi and W. Sakriss, Chem. Ber., 106, 2815 (1973).
33. A. J. Carpenter, D. J. Chadwick, and R. J. Ngochindo, J. Chem. Res. (S), No. 8, 196 (1983).
34. D. J. Chadwick and R. I. Ngochindo, J. Chem. Soc., Perkin 1, No. 3, 481 (1984).
35. P. W. Alley and D. A. Shirley, J. Org. Chem., 23, 1791 (1958).
36. B. A. Tertov, N. A. Ivankova, and A. M. Simonov, Zh. Obshch. Khim., 32, 2989 (1962).
37. C. R. Ganellin, H. F. Ridley, and R. G. W. Spickett, J. Heterocycl. Chem., 3, 278 (1966).
38. B. A. Tertov, A. V. Koblik, and N. I. Avdyunina, Khim. Geterotsikl. Soedin., No. 9, 1238 (1971).
39. B. A. Tertov, A. V. Koblik, and Y. V. Kolodyazhnyi (Kolodyazhny), Tetrahedron Lett., No. 12, 4445 (1968).
40. B. A. Tertov and A. V. Koblik, Khim. Geterotsikl. Soedin., No. 6, 1123 (1967).
41. J. V. Hay, D. E. Portlock, and J. F. Wolfe, J. Org. Chem., 38, 4379 (1973).
42. B. A. Tertov, Yu. G. Bogachev, Yu. V. Koshchienko, G. M. Suvorova, E. B. Tsupak, N. K. Chub, and S. F. Breus, Khim. Geterotsikl. Soedin., No. 8, 1073 (1986).

43. M. Erne and H. Erlenmeyer, Helv. Chim. Acta, 31, 652 (1948).
44. J. Metzger and B. Koether, Bull. Soc. Chim. France, Nos. 7-8, 708 (1953).
45. J. Beraund and J. Metzger, Bull. Soc. Chim. France, Nos. 11-12, 2072 (1962).
46. D. S. Noyce and S. A. Fike, J. Org. Chem., 38, 3316 (1973).
47. D. S. Noyce and S. A. Fike, J. Org. Chem., 38, 3318 (1973).
48. G. Knaus and A. I. Meyers, J. Org. Chem., 39, 1192 (1974).
49. A. I. Meyers and G. N. Knaus, J. Am. Chem. Soc., 95, 3408 (1973).
50. G. Knaus and A. I. Meyers, J. Org. Chem., 39, 1189 (1974).
51. J. Metzger and B. Koether, Bull. Soc. Chim. France, Nos. 7-8, 702 (1953).
52. H. Gilman and J. A. Beel, J. Am. Chem. Soc., 71, 2328 (1949).
53. B. A. Tertov and S. E. Panchenko, Zh. Obshch. Khim., 33, 3671 (1963).
54. M. V. Costa and P. Lochon, J. Organomet. Chem., 293, 265 (1985).
55. M. Robba and R. C. Moreau, Ann. Pharm. France, 22, 201 (1964).
56. M. P. L. Caton, D. H. Jones, R. Slack, and K. R. H. Wooldridge, J. Chem. Soc., No. 1, 446 (1964).
57. W. Slack and H. R. Wooldridge, Swiss Patent No. 430719; Ref. Zh. Khim., 20N221P (1968).
58. D. E. Horning and I. M. Muckowski, Can. J. Chem., 52, 2950 (1974).
59. U. Schöllkopf and I. Hoppe, Angew. Chem., Int. Ed. Engl., 14, 765 (1975).
60. I. Hoppe and U. Schöllkopf, Annalen, 2, 219 (1979).
61. K. S. Hirsch, C. D. Jones, H. M. Taylor, and M. A. Winter, US Patent No. 4560695; Ref. Zh. Khim., 23081P (1986).
62. J. Gainer, G. A. Howarth, W. Hoyle, S. M. Roberts, and H. Suschitzky, J. Chem. Soc., Perkin 1, No. 9, 994 (1976).
63. C. Kashima and Y. Tsuda, Bull. Chem. Soc. Jpn., 46, 3533 (1973).
64. R. G. Micetich, C. C. Shaw, T. W. Mall, P. Spevak, and B. K. Bains, Heterocycles, 23, 585 (1985).
65. R. G. Micetich, C. C. Shaw, B. W. Hall, P. Spevak, R. A. Fortier, P. Molfert, B. C. Foster, and B. K. Bains, Heterocycles, 23, 571 (1985).
66. D. J. Brunelle, Tetrahedron Lett., 22, 2699 (1981).
67. G. D. Diana, M. A. McKinlay, C. J. Brisson, E. S. Zalay, J. V. Miralles, and U. J. Salvador, J. Med. Chem., 28, 748 (1985).
68. M. Yokovama, K. Tsuji, and M. Kushida, J. Chem. Soc., Perkin 1, No. 1, 67 (1986).
69. K. Bowden, G. Crank, and W. J. Ross, J. Chem. Soc., C, No. 2, 172 (1968).
70. R. G. Micetich and C. G. Chin, Can. J. Chem., 48, 1371 (1970).
71. D. Hoppe, Angew Chem. Int. Ed. Engl., 13, 789 (1974).
72. R. Schroeder, U. Schöllkopf, E. Blume, and I. Hoppe, Annalen, No. 3, 533 (1975).
73. L. N. Pridgen and S. C. Shilcrat, Synthesis, No. 12, 1048 (1984).
74. B. H. Lipshutz and R. W. Hungate, J. Org. Chem., 46, 1410 (1981).
75. T. Susaki, M. Ohno, and E. Ito, J. Chem. Soc., Perkin 1, No. 12, 3027 (1983).
76. V. Dryanska and Kh. Ivanov, Godishnik Sof. Univ., 1970-1971, 65, 261 (1973); Ref. Zh. Khim., 11Zh375 (1974).
77. R. Raap, Can. J. Chem., 49, 1792 (1971).
78. U. Schöllkopf and I. Hoppe, Annalen, No. 10, 1655 (1974).
79. R. G. Micetich, P. Spevak, T. W. Hall, and B. K. Bains, Heterocycles, 23, 1645 (1985).
80. H. Behringer and R. Ramert, Annalen, Nos. 7-8, 1264 (1975).
81. R. A. Olofson and J. P. Pepe, Tetrahedron Lett., No. 34, 3129 (1979).
82. E. S. Lane and C. Williams, British Patent No. 781790; Ref. Zh. Khim., 58027P (1959).
83. E. W. Thomas and D. C. Zimmermann, Synthesis, No. 10, 945 (1985).
84. R. Raap, Can. J. Chem., 49, 2139 (1971).
85. L. L. Garber and C. H. Brubaker, J. Am. Chem. Soc., 88, 4266 (1966).
86. C. R. Jacobson and E. D. Amstutz, J. Org. Chem., 18, 1183 (1953).
87. A. D'Adamo and R. A. La Forge, J. Org. Chem., 21, 340 (1956).
88. N. N. Zatsepina and I. F. Tupitsyn, Khim. Geterotsikl. Soedin., No. 12, 1587 (1974).
89. A. I. Belyashova, N. N. Zatsepina, E. N. Malysheva, A. F. Pozharskii, L. P. Smirnova, and I. F. Tupitsyn, Khim. Geterotsikl. Soedin., No. 11, 1544 (1977).
90. A. N. Sinyakov and M. S. Shvartsberg, Izv. Akad. Nauk SSSR, Ser. Khim., No. 5, 1126 (1979).
91. P. H. Kasai and D. J. McLeod, J. Am. Chem. Soc., 95, 27 (1973).
92. P. H. Kasai and D. J. McLeod, J. Am. Chem. Soc., 95, 4801 (1973).
93. H. C. Ooi and H. Suschitzky, J. Chem. Soc., Perkin 1, No. 12, 2871 (1982).
94. A. G. Milaev, V. B. Panov, B. A. Tertov, Yu. V. Koshchienko, O. Yu. Okhlobystin, Zh. Obshch. Khim., 50, 473 (1980).

95. B. A. Tertov, N. F. Vanieva, A. V. Koblik, and P. P. Onishchenko, Khim.-farm. Zh., 7, 27 (1973).
96. B. A. Tertov, G. V. Kovalev, Yu. K. Fomin, Yu. V. Koshchienko, and V. V. Burykin, Khim.-farm. Zh., 10, 34 (1976).
97. B. Iddon and B. L. Lim, J. Chem. Soc., Perkin 1, No. 2, 279 (1983).
98. R. S. Brown and J. Huguet, Can. J. Chem., 58, 889 (1980).
99. H. Chikashita and K. Itoh, Heterocycles, 23, 295 (1985).
100. A. M. Roe, J. Chem. Soc., No. 4, 2195 (1963).
101. P. E. Iversen and H. Lung, Acta Chem. Scand., 20, 2649 (1966).
102. K. L. Kirk, J. Org. Chem., 43, 4381 (1978).
103. M. El Borai, A. H. Moustafa, M. Anwar, and A. G. Ghattas, Croat. Chem. Acta, 54, 211 (1981).
104. S. Ohta, S. Hayakawa, H. Moriwaki, S. Tsuboi, and M. Okamoto, Heterocycles, 23, 1759 (1985).
105. M. El Borai, A. H. Moustafa, M. Anwar, and F. I. Abdel Hay, Pol. J. Chem., 55, 1659 (1981).
106. M. S. Shvartsberg, L. N. Bizhan, E. E. Zaev, and I. L. Kotlyarevskii, Izv. Akad. Nauk SSSR, Ser. Khim., No. 2, 472 (1972).
107. M. S. Shvartsberg, L. N. Bizhan, and I. L. Kotlyarevskii, Izv. Akad. Nauk SSSR, Ser. Khim., No. 7, 1534 (1971).
108. B. A. Tertov, V. V. Burykin, and A. S. Morkovnik, USSR Inventor's Certificate No. 437763; Byull. Izobret., No. 28, 53 (1974).
109. D. P. Davis, K. L. Kirk, and L. A. Cohen, J. Heterocycl. Chem., 19, 253 (1982).
110. B. A. Tertov, V. V. Burykin, and A. V. Koblik, Khim. Geterotsikl. Soedin., No. 11, 1552 (1972).
111. B. Iddon, Heterocycles, 23, 417 (1985).
112. B. A. Tertov and Yu. G. Bogachev, Khim. Geterotsikl. Soedin., No. 1, 119 (1981).
113. A. Marxer and M. Siegrist, Helv. Chim. Acta, 62, 1753 (1979).
114. A. C. Ranade and J. Gopal, Chem. Ind., No. 15, 582 (1978).