U.D.C. 547.385

Advances in the Chemistry of Ethynyl Ketones

R.L.Bol'shedvorskaya and L.I.Vereshchagin

The review deals with problems of the reactivity and the chemical properties of ethynyl ketones. The bibliography includes 201 references.

CONTENTS

I.	Introduction	225
II.	Reactivity of ethynyl ketones	225
III.	Hydrogenation	225
IV.	Addition of hydrogen halides	226
V.	Addition of halogens	227
VI.	Addition of amines	227
VII.	Addition of hydroxylamine, hydrazines, semicarbazides, and other nitrogen-containing compounds	229
VIII.	Addition of alcohols, phenols, thiols, and thiophenols	230
IX.	Addition of acids	231
X.	Hydration	232
XI.	Michael condensation and related reactions	232
XII.	Diels-Alder synthesis	234
XIII.	Addition of 1,3-dipolarophiles	235
XIV.	Ethynyl ketones in organomagnesium synthesis	235
XV.	Reactions of the ethynyl hydrogen atom	236
XVI.	Various reactions	237

I. INTRODUCTION

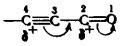
Ethynyl ketones have been attracting increasing interest not only in view of the wide variety of their chemical properties and synthetic possibilities but also owing to their biological activity, particularly their capacity to suppress the growth of various fungi. However, hitherto no reviews have been published on the chemistry of ethynyl ketones with the exception of one [1] on methods of synthesis of these substances. This review is a first attempt at a systematic discussion of the available literature data for the chemical properties of the ketones in which the carbonyl and ethynyl groups are conjugated.

The review covers the periodical literature up to February, 1971.

II. REACTIVITY OF ETHYNYL KETONES

The chemical behaviour of ethynyl ketones is in general determined by the presence in the molecule of three reaction centres—the carbonyl and ethynyl groups and the hydrogen atom involved in the triple bond. The triple bond is known to be less reactive than the double bond in electrophilic addition reactions (addition of halogens, ozone, and peracids [2]) and more reactive in relation to nucleophilic agents (alcohols, amines, thiols, etc.) [2-6].

The reactivity of the ethynyl group in ethynyl ketones is not due solely to the electrophilic properties of the triple bond alone but depends also on the electron-accepting carbonyl group conjugated with it:



As a result 1,2-, 3,4-, and 1,4-addition reactions are characteristic of compounds of this type. Whereas amines, alcohols, and malonic ester add in the 3,4-positions [8-10], hydrazines and semicarbazides (these are much stronger bases and nucleophilic agents than amines) add preferentially in the 1,2-positions. Hydroxylamine, which is a weaker nucleophilic agent than hydrazines and semicarbazides but stronger than amines, can react simultaneously with both electrophilic centres [11].

A wide variety of reactions makes it possible to employ ethynyl ketones as the starting materials for the synthesis of heterocyclic systems. One must note that a particular mode of reaction is determined not only by the basicity of the substance being added but also by the structure of the ethynyl ketone.

III. HYDROGENATION

Depending on the method of hydrogenation, the addition of hydrogen to ethynyl ketones can occur either stepwise with intermediate formation of vinyl ketones and subsequent more far reaching transformation or in a single stage with formation of a reaction product involving the carbonyl group alone. All the methods of hydrogenation of ethynyl ketones described in the literature can be combined in three groups.

1. Catalytic Hydrogenation

Selective hydrogenation of ethynyl ketones depends primarily on the nature of the catalyst. Thus the use of relatively inactive catalysts (colloidal palladium [12], palladium deposited on silica [13] or calcium carbonate [14-17], and Raney nickel [16-18]) makes it possible to stop the hydrogenation process at the stage involving the addition of one mole of hydrogen per mole of the substance hydrogenated. Further saturation with hydrogen leads to the hydrogenation of the double bond and other secondary reactions [19]. The order in which various groups in ethynyl vinyl ketones

of the type $R-CH=CH-CO-C\equiv C-R^1$ (I) are hydrogenated depends mainly on the nature of the substituents R and R^1. The unsubstituted ethynyl vinyl ketone (Ia) and also ethynyl methylvinyl ketone (Ib) are hydrogenated on the $Pd/CaCO_3$ catalyst initially at the triple bond with formation of the divinyl ketone (II) (yield 76%) [20-22]:

$$\underset{\text{(I)}}{R-CH=CH-CO-C\equiv C-R^1} + H_2 \rightarrow \underset{\text{(II)}}{RCH=CH-CO-CH=CHR^1}$$

(Ia, R=R'=H; Iб, R=CH_3, R'=H; Iв, R=H, R'=CH_3)

In the hydrogenation of the ketone (Ic), the first mole of hydrogen adds to approximately equal extents to both triple and double bonds; subsequently $CH_2=CH-CO-CH=CH-CH_3$ (20.6%) and $CH_2=CH-COC_3H_7$ (25.5%) are formed. Moreover, in the first stage, the CO group is also reduced with subsequent isomerisation of the secondary α-ethynylalcohol to the ketone (III):

$$CH_3-CH=CH-CO-C\equiv C-CH_3 \rightarrow \underset{\text{(III)}}{CH_3-CH=CH-CHOH-C\equiv C-CH_3} \rightarrow CH_2=CH-CH=CH-CO-CH_3$$

Isomerisation is observed also in the hydrogenation of disubstituted ethynyl vinyl ketones. Selective hydrogenation of unsubstituted ethynyl vinyl ketone can probably be accounted for by the favourable conditions for the adsorption of the ketone on the catalyst via its triple bond. In this case, steric hindrance results in the reduction of the CO group alone [21].

In the hydrogenation of oct-1-en-3-yn-5-one on $Pd/CaCO_3$, hydrogen adds in the first place to the vinyl group [16]. Unsaturated ketones obtained catalytically have preferentially the *cis*-configuration [16].

2. Chemical Reduction

Ethynyl ketones are readily reduced by nascent hydrogen (zinc + acetic acid) and also by lithium aluminium hydride. The first method is frequently used to reduce the triple bond to a double bond. The reaction takes place in an aqueous alcoholic solution after the addition of catalytic amounts of copper sulphate [23,24]:

$$CH_3-CO-C\equiv C-R \rightarrow \underset{\text{(IV)}}{CH_3-CO-CH=CH-R}$$

$$\rightarrow \underset{\text{(V)}}{R-C\equiv C-C(OH)(CH_3)-C(OH)(CH_3)-C\equiv C-R}$$

(R=CH_3, C_3H_7, C_4H_9)

Together with vinyl ketones (IV), small amounts of ditertiary diethynyl-α-glycols (V) are formed. Aryl-substituted ethynyl ketones are hydrogenated under these conditions to saturated ketones [24]; the vinyl ketones obtained by this method have preferentially the *trans*-configuration.

Lithium aluminium hydride [25] and complexes of the type $Li^+[(RO)_2AlH_2]$ [25,26] reduce ethynyl ketones smoothly to the corresponding ethynylalcohols.

Dibenzoylacetylene (VI) reacts with lithium aluminium hydride in ether or tetrahydrofuran (THF) in different ways at 0-25°C and at −80°C: [27]

$$C_6H_5CHC\equiv C-COC_6H_5 \xleftarrow{-80^\circ} C_6H_5COC\equiv CCOC_6H_5 \rightarrow$$

(VI)

$$C_6H_5-CHC\equiv C-CH-C_6H_5 + \text{(VII)}$$

$$\xrightarrow{0-25^\circ} C_6H_5CHCH=CH=CHC_6H_5 \quad \text{(VII)}$$

$$C_6H_5CHCH_2CH_2CHC_6H_5$$

3. Electrochemical Reduction

The reactivity of ethynyl ketones in electrochemical reduction is determined by the presence of the electron-accepting carbonyl group, which increases the capacity of the triple bond for reduction by an electronic mechanism [28]. Whereas an isolated triple bond combines at a mercury cathode with only one mole of hydrogen, the activated triple bond in diethynyl ketones combines with two moles to form the saturated ketone (VIII): [29,30]

$$(C_6H_5-C\equiv C)_2CO \xrightarrow[\text{Hg cathode}]{H_2} \underset{\text{(VIII)}}{(C_6H_5CH_2CH_2)_2CO}$$

The reduction of disubstituted ethynyl ketones is frequently accompanied by the dimerisation of the vinyl ketone (IX): [30]

$$C_6H_5-CO-C\equiv C-C_6H_5 \xrightarrow{H_2} \underset{\text{(IX)}}{C_6H_5COCH=CH-C_6H_5} \rightarrow C_6H_5COCH=C(C_6H_5)-C_6H_5$$

$$\rightarrow C_6H_5COCH_2-CH(C_6H_5)-C_6H_5$$

The photochemical reduction of 5,5-dimethylhex-3-yn-5-one (X) in isopropyl alcohol has also been described [31]:

$$CH_3-C(CH_3)_2-C\equiv C-CO-CH_3 \xrightarrow[h\nu]{(CH_3)_2CHOH} CH_3-C(OH)(CH_3)-C(OH)(CH_3)-CH_3 + (CH_3)_3C-C\equiv C-C(OH)(CH_3)-C(OH)(CH_3)-CH_3 +$$

(X)

$$+ (CH_3)_3C-C\equiv C-C(OH)(CH_3)-C(OH)(CH_3)-C\equiv C-C(CH_3)_3$$

IV. ADDITION OF HYDROGEN HALIDES

The activated triple bond in ethynyl ketones is capable of combining equally readily with both nucleophilic and electrophilic agents. Whereas the hydrogenation of ethynyl ketones proceeds via consecutive stages involving the addition of initially one and then another mole of hydrogen, the reaction with hydrogen halides terminates in the first stage. The halide ion adds to the β-carbon atom of the triple bond, in agreement with the generally accepted ideas concerning the electron shift in unsaturated ketone molecules [32]. The addition of hydrogen halides to ethynyl ketones usually takes place in chloroform or a mixture of acetic acid and chloroform [33-35]; in some cases, copper(I) chloride was added [33,36]. With strictly equivalent proportions of the starting materials at −40°C, the reaction takes place stereospecifically with formation of the pure *cis*-isomer [34,37,38]. A slight excess of the hydrogen halide or an increase of reaction temperature to 20°C results in the formation either of the sterically pure *trans*-isomer or a mixture of *cis*- and *trans*-isomers (depending on the hydrogen halide used) [34]:

$$p\text{-}R-C_6H_4-CO-C\equiv C-R + HX \xrightarrow{-40^\circ} p\text{-}R-C_6H_4CO-C(X)=C(H)-H$$

$$\xrightarrow{20^\circ} p\text{-}R-C_6H_4CO-C(H)=C(X)-H$$

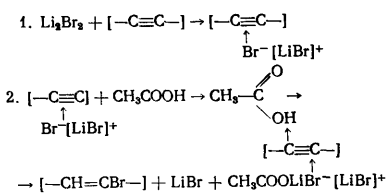
(R=H; OCH_3; Cl
X=Cl; Br, I)

Cis- and *trans*-aryl 2-chloro-1-deuteriovinyl ketones were synthesised under analogous conditions [34]:

$$ArCOC{\equiv}CH + DCl \rightarrow ArCOCD{=}CHCl$$

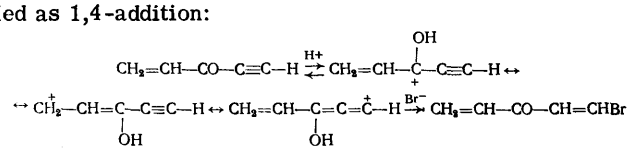
It is believed that the initial reaction stage is nucleophilic attack by the halide ion on the triple bond [34].

Ethynyl ketones are also capable of adding the elements of HBr from LiBr solution in acetic acid [38,39]:



It has been established that the rate of reaction is limited by that of the first stage and depends on the electron-donating properties of the substituents at the triple bond. As the electron-donating properties of the substituent become more pronounced, the reaction rate constant falls, in agreement with the reaction mechanism proposed [39].

In the hydrobromination of the symmetrical ethynyl vinyl ketone, HBr adds to the triple bond only [20,40]. It has been shown [40] that the reaction begins with the protonation of the oxygen atom in the carbonyl group and can be regarded as 1,4-addition:



The reaction takes place stereospecifically in a saturated aqueous solution in the cold with formation of the *cis*-isomer.

V. ADDITION OF HALOGENS

Halogens are added to ethynyl ketones either in ethereal solution [41,42] or in the absence of solvent on heating [37,43]. The reaction with chlorine takes place only when gaseous chlorine is passed through the fused ketone:

$$o\text{-}R{-}C_6H_4{-}C{\equiv}C{-}CO{-}C_6H_5 + X_2 \rightarrow o\text{-}R{-}C_6H_4{-}CX{=}CX{-}CO{-}C_6H_5$$
$$(R{=}H, Cl;\ X{=}Br, I, Cl)$$

The addition of a second halogen molecule was not observed under the above conditions.

The bromination of silylethynyl ketones in chloroform leads to a mixture of the *cis*- and *trans*-isomers of $\alpha\beta$-dibromovinyl ketones (XI) (yield 70–75%):

$$R_3SiC{\equiv}C{-}COCH_3 + Br_2 \rightarrow R_3SiCBr{=}CBrCO{-}CH_3$$
$$(XI)$$
$$(R{=}CH_3, C_2H_5)$$

When two moles of bromine are allowed to react with the ketone, a mixture of $\alpha\beta$-dibromovinyl ketones and the corresponding tetrabromoketones (yield 15–20%) is formed [44].

Symmetrical ethynyl vinyl ketones are brominated first at the double bond and then at the triple bond with formation of the tetrabromide (XII):

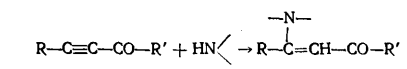
$$R{-}CH{=}CH{-}CO{-}C{\equiv}C{-}R + Br_2 \rightarrow RCHBrCHBrCOC{\equiv}C{-}R \xrightarrow{Br_2} RCHBr{-}CHBr{-}CO{-}CBr{=}CBr{-}R$$
$$(XII)$$
$$(R{=}H, CH_3)$$

This difference between the reactivities of bromine and HBr can be explained by the different site of electrophilic attack owing to the different nature of the attacking reactant. While the hydrobromination reaction is regarded as 1,4-addition with participation of the CO group, the bromination reaction is regarded as 3,4-addition and the authors believe it to be purely electrophilic [20,40].

Ketones of the type $RCOC{\equiv}CCH{=}CH_2$ are brominated non-selectively at the triple and double bonds simultaneously. The comparatively high rate of addition of bromine to the triple bond, which is usually relatively unreactive in relation to bromine, is striking. Evidently the presence of the carbonyl group increases the reactivity of the triple bond, but this influence is difficult to account for if one regards the addition of bromine as an electrophilic addition reaction. It is more likely that, as postulated by Chelpanova et al.[45], nucleophilic addition takes place in the bromination of ethynyl vinyl ketones.

VI. ADDITION OF AMINES

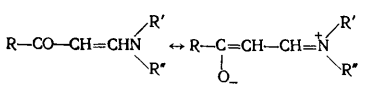
The reaction of amines with ethynyl ketones has been known for a long time. As early as 1904, Watson [46] established that amines add to ethynyl ketones as readily as to vinyl ketones. However, the exact structure of the products was not determined. Somewhat later Andre [47] and then Bowden and coworkers [37,48] and other investigators [49–58] demonstrated that the products of the addition of aliphatic and aromatic amines as well as ammonia to ethynyl ketones have the structure of $\alpha\beta$-unsaturated β-aminoketones (XIII):



(XIII)

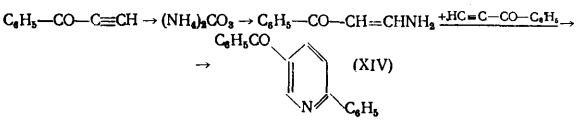
(R=H, Alk, Ar; R′=Alk, Ar)

The aminovinyl ketones formed are polarised to a very high degree. As a result of the increase of the negative charge on the oxygen atom and of the positive charge on the nitrogen atom, the dipole moments of the aminovinyl ketone increases sharply [59].



As a result, the reactivity of the double bond relative to nucleophilic agents decreases and a second mole of the amine is not added. Only in a single study by Hoffmann [60], who employed pyrazole and its derivatives as the nucleophilic reactant, diadducts were obtained together with monoadducts. However, the formation of diadducts was demonstrated spectroscopically without their isolation in a pure form.

Ethynyl phenyl ketones react with ammonium carbonate in aqueous alcohol to yield pyridine derivatives (XIV): [61,62]

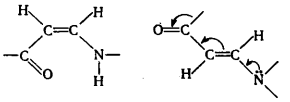


(XIV)

One should note that ethynyl ketones react with amines even at room temperature in the absence of any catalyst in both protic and aprotic solvents. The rate of reaction depends not only on the basicity of the amine [54,58] but also on the structure of the ethynyl ketone involved in the reaction.

The stereochemistry of the addition of amines to ethynyl ketones was studied in only one investigation [63], where it

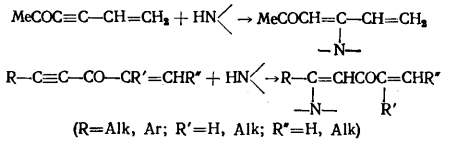
was shown, on the basis of the ^1H NMR data for the reaction mixture, that the reaction of *p*-tolylacetylene with α-phenylethylamine yields the *cis*- and *trans*-isomers of β-(1-phenylethylamino)vinyl-*p*-tolyl ketone [(XV) and (XVI)] with the *cis*-isomer (XV) predominating:



(XV) (XVI)

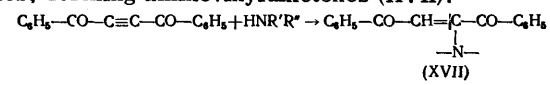
The stability of the *cis*-isomer can be explained by the formation of an intramolecular hydrogen bond [63].

Conjugated ethynyl vinyl ketones combine smoothly with amines at room temperature via the triple bond only [48,64,65]:



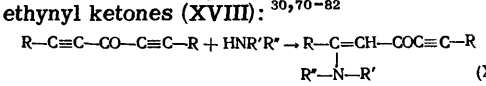
(R=Alk, Ar; R'=H, Alk; R"=H, Alk)

Diketones of the acetylene series readily react with amines, forming aminovinyldiketones (XVII): [66-69]



(XVII)

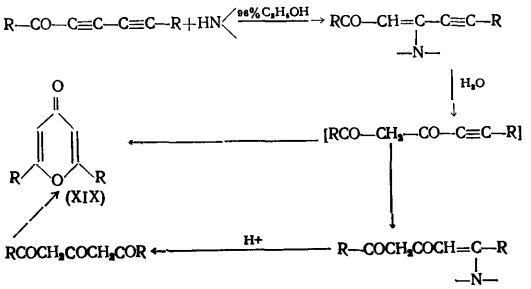
Aliphatic and aromatic amines add to symmetrical diethynyl ketones of the type R−C≡C−CO−C≡C−R' preferentially at one triple bond with formation of aminovinyl ethynyl ketones (XVIII): [30,70-82]



(R=H, Alk, Ar; R'=R"=H, Alk, Ar) (XVIII)

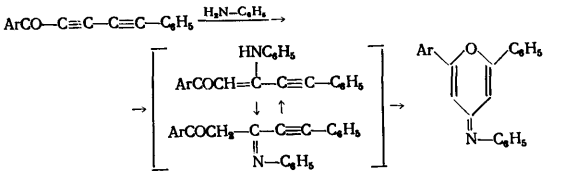
The deactivation of the second triple bond in relation to nucleophilic agents can be explained by the formation of a conjugated system analogous to that in compound (XVI), which evidently greatly weakens the conjugation of the carbonyl group with the second triple bond [80].

The reaction of diacetylenic ketones of the type R−COC≡C−C≡CR' with secondary aliphatic amines leads to the formation of 2,6-diaryl-4-pyrones (XIX), where R = R' = Ar: [83]



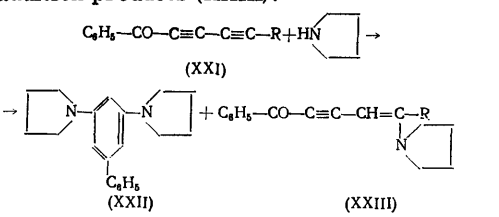
(R=C_6H_5)

When 1,5-diarylpenta-2,4-diyn-1-ones were allowed to react with aromatic amines, 2,6-diaryl-4-arylaminopyrans (XX) were obtained; it is believed that they are formed via a stage involving the nucleophilic addition of the aromatic amine to the triple bond nearest to the carbonyl group with subsequent cyclisation [83]:



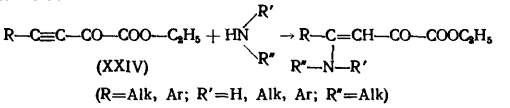
(XX)

On the other hand, treatment of 4-alkyl-1-benzoyldiacetylenes (XXI) with pyrrolidine leads to the formation of diamino-derivatives of biphenyl (XXII) together with the normal addition products (XXIII): [84]



(XXII) (XXIII)

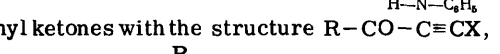
In α-ketoacid esters of the acetylene series (XXIV) containing in the molecule two adjacent electron-accepting molecules, the triple bond is even more reactive with respect to nucleophilic agents. Secondary aliphatic-aromatic amines, morpholine, piperidine [85], as well as primary aromatic amines [86] and aromatic amines containing other functional groups in the ring (aminophenols, aromatic aminoacids, anisidines, and others) [87] readily add to the triple bond of these compounds even at room temperature:

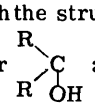


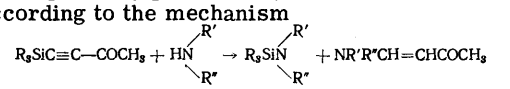
(XXIV)

(R=Alk, Ar; R'=H, Alk, Ar; R"=Alk)

Aniline adds to the triple bond of ketoacids of the type R−CO−C≡C−COO−CH_3 in the β-position relative to the keto-group [88]:

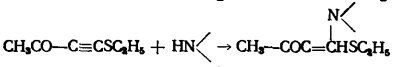


Ethynyl ketones with the structure R−CO−C≡CX, where X = SiR_3, SR, NR_2, or  are of special interest, since the presence of functional group can alter to some extent the mode of addition of nucleophilic agents to the triple bond. When trialkylsilylethynyl ketones react with methyl- and diethyl-amines, only products the formation of which is probably preceded by the cleavage of the Si−C bond according to the mechanism

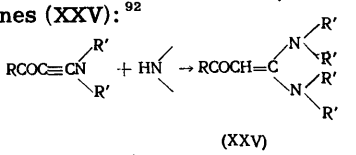


were isolated instead of the expected compounds. On the other hand, the interaction of the ketones investigated with aniline yields the expected anils $R_3SiC{\equiv}C-\underset{\underset{NC_6H_5}{\|}}{C}-CH_3$. [89]

The addition of amines to ethylthioethynyl ketones $R-CO-\overset{1}{C}\equiv\overset{2}{C}-\overset{3}{C}-SC_2H_5$ can take place in principle in the 2- and 3-positions. It was found that, as for ethylthiopropiolate esters [90], the addition of an amine to ethylthioethynyl ketones [91] in fact takes place in the 2-position:



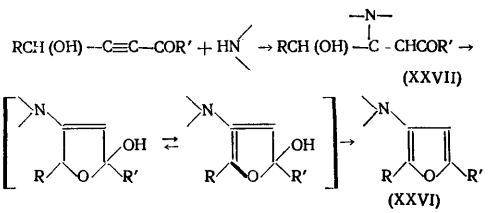
Ethynyl ketones of the type >N−C≡C−CO−R, where the electrophilic properties of the β-carbon atom are greatly enhanced, behave quite differently. The reaction of such ketones with amines at 20°C leads to αβ-unsaturated β-diaminoketones (XXV): [92]



(XXV)

(R=H, Alk; R'=Alk)

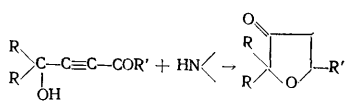
The interaction of secondary α-ethynyl-γ-ketols with primary and secondary amines leads to the formation of β-aminofurans (XXVI): [93]



(XXVII)

(XXVI)

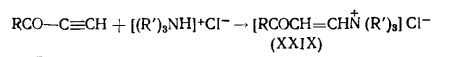
It is believed that initially nucleophilic addition of the amine to the triple bond takes place with subsequent cyclisation of the resulting aminovinylketol (XXVII) to the β-aminofuran (XXVI). When acted upon by secondary amines, tertiary γ-ketols are converted into β-furanones (XXVIII): [93]



(XXVIII)

(R=Alk, R'=Alk, Ar)

Monosubstituted ethynyl ketones react with inorganic salts of tertiary amines, forming quaternary ammonium salts (XXIX) in high yields (87–88%): [94,95]



(XXIX)

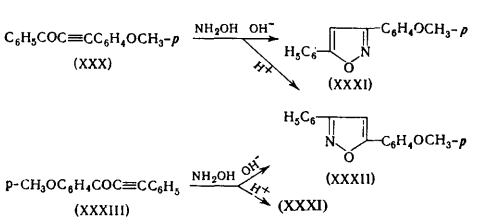
(R=Alk, Ar; R'=Alk)

According to spectroscopic data, the compounds (XXIX) have the *trans*-configuration [95].

VII. ADDITION OF HYDROXYLAMINE, HYDRAZINES, SEMICARBAZIDES, AND OTHER NITROGEN-CONTAINING COMPOUNDS

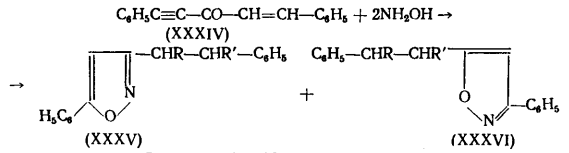
As already mentioned, hydrazines and semicarbazides are stronger bases and nucleophilic agents than amines and therefore they react with ethynyl ketones mainly via the carbonyl group. Hydroxylamine occupies an intermediate position and is therefore capable of attacking simultaneously both reaction centres [11].

Thus the reaction of *p*-anisylbenzoylacetylene (XXX) and other substituted benzoylacetylenes [46,62,96] in an alcoholic alkaline solution proceeds with formation of 3-(*p*-anisyl)-5-phenylisoxazole (XXXI). In an acid medium, the attack on the carbonyl group is facilitated and 5-(*p*-anisyl)-3-phenylisoxazole (XXXII) is formed [11,97]. Directly opposite results were obtained when the starting material was *p*-anisoylphenylacetylene (XXXII):



(XXX) (XXXI) (XXXII) (XXXIII) (XXXI)

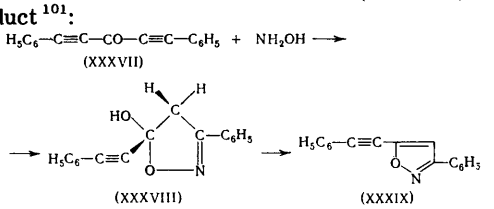
Ferrocenyl-substituted ethynyl ketones [98] and also esters of $\beta\gamma$-acetylenic α-keto-acids [99] and $\alpha\beta$-acetylenic γ-keto-acids [88] behave similarly in the reaction with hydroxylamine. In the reactions with symmetrical disubstituted ethynyl vinyl ketones (XXXIV), the formation of isoxazole derivatives is accompanied by the subsequent addition of a second hydroxylamine molecule to the double bond and, depending on the reaction conditions, the isomeric isoxazoles (XXXV) [100] and (XXXVI) [101] can be obtained:



(XXXIV) (XXXV) (XXXVI)

(a) R=NHOH, R'=H; (b) R=H, R'=NHOH)

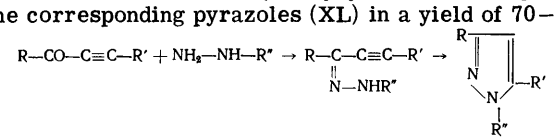
The reaction of 1,5-diphenylpenta-1,4-diyn-3-one (XXXVII) with hydroxylamine in an aqueous alcoholic solution involved the formation of Δ^2-isoxazoline (XXXVIII) as the only product [101]:



(XXXVII) (XXXVIII) (XXXIX)

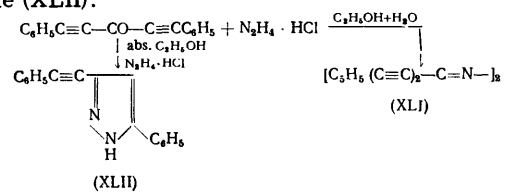
Prolonged heating of the isoxazoline (XXXVIII) in xylene or an aqueous alcoholic solution with distillation of water yields 3-phenyl-5-phenylethynylisoxazole (XXXIX).

In most cases the interaction of hydrazines with ethynyl ketones proceeds via the carbonyl group. Mono- [62,92,98] and di-substituted [62,96,98,101,102] ethynyl ketones and α-diketones [68,98] as well as γ-ethynyl-α-ketols [103] give rise to the corresponding pyrazoles (XL) in a yield of 70–80%:



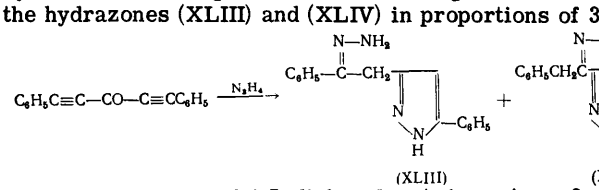
(R = H, Alk, Ar, —COOR; R'=H, Alk, Ar, —COC_6H_5, —C(OH)<, —N(R)$_2$)

Depending on the experimental conditions, the reaction of 1,5-diphenylpenta-1,4-diyn-3-one with hydrazine hydrochloride gives two different products. In aqueous ethanol solution, the azine (XLI) is formed, while in absolute ethanol the product is 3(5)-phenyl-5(3)-phenylethynylpyrazole (XLII): [101]



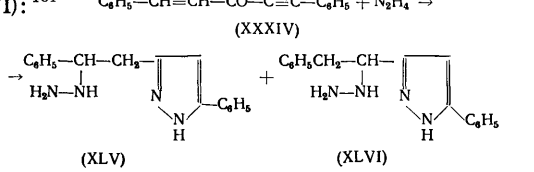
(XLI) (XLII)

1,5-Diphenylpenta-1,4-diyn-3-one reacts with an excess of hydrazine in boiling absolute alcohol to give a mixture of the hydrazones (XLIII) and (XLIV) in proportions of 3:2:



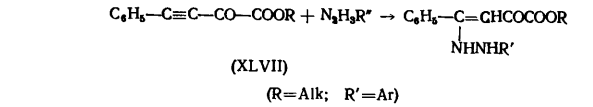
(XLIII) (XLIV)

The interaction of 1,5-diphenylpent-1-en-4-yn-3-one (XXXIV) with anhydrous hydrazine in absolute alcohol gives rise to a mixture of the pyrazoles (XLV) and (XLVI): [101]



(XXXIV) (XLV) (XLVI)

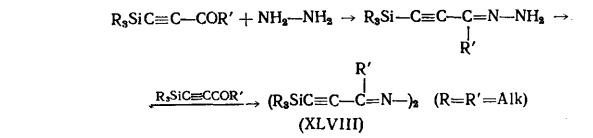
In contrast to the ethynyl ketones discussed above, esters of phenylethynylglyoxalic acids (XLVII) react with hydrazine derivatives and aromatic acid hydrazides according to the same mechanism [99] as with amines:



(XLVII)

(R=Alk; R'=Ar)

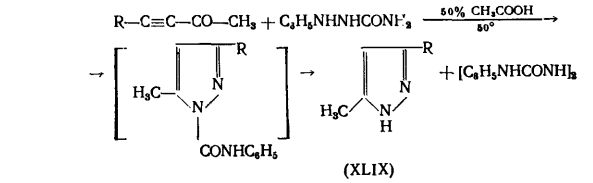
When trialkylsilylethynyl ketones react with hydrazine, the products are not pyrazoles but hydrazones, which are converted in the presence of an excess of the ketone into the azines (XLVIII): [44]



(XLVIII)

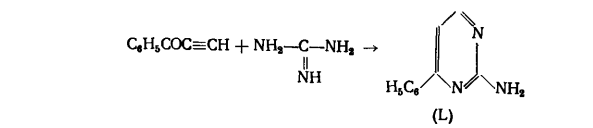
The reaction of silylethynyl ketones with 2,4-dinitrophenylhydrazine and 3,5-dinitrobenzoylhydrazine terminates in the hydrazone stage. The hydrazones obtained do not cyclise with the corresponding pyrazoles under the influence of acetic anhydride and acetic acid and char under these conditions [104]. Thus the trialkylsilyl group in the α-ethynylhydrazones is in fact an obstacle to their cyclisation.

In the reaction with ethynyl ketones, semicarbazides behave like hydrazines. Thus phenylsemicarbazide gives rise to pyrazoles (XLIX): [105]



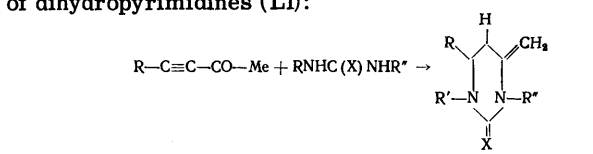
(XLIX)

The only product of the condensation of guanidine with ethynyl phenyl ketone is 2-amino-4-phenylpyrimidine (L): [62]



(L)

Urea and thiourea derivatives react with ethynyl ketones in ethereal solution in the presence of concentrated sulphuric acid to give the corresponding derivatives of dihydropyrimidines (LI): [106]



(LI)

(R=Alk; R'=Alk, Ar; R"=Alk; X=O, S)

VIII. ADDITION OF ALCOHOLS, PHENOLS, THIOLS, AND THIOPHENOLS

Whereas the addition of amines to the activated triple bond of ethynyl ketones takes place readily in the absence of catalysts even at room temperature, the addition of alcohols is possible only in the presence of a basic catalyst. The reaction with terminal ethynyl ketones does not stop at the stage involving the addition of one mole of the alcohol but continues until the formation of the acetal of the corresponding β-ketoaldehyde (LII) (yield 60–75%) [37,97]:

(LII)

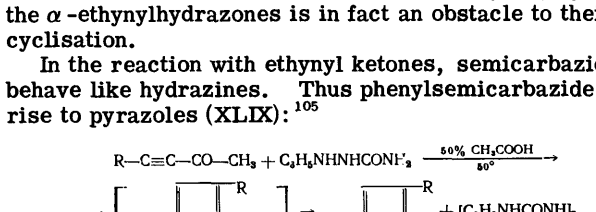
(R=Alk, Ar; R'=Alk)

The reaction was carried out in the presence of sodium alkoxide at 0–5°C. [107] The formation of alkoxyvinyl ketones was not observed under these conditions. Primary, and secondary alcohols add to disubstituted ethynyl ketones in the presence of both alkoxides [9,37,108–110] and tertiary amines [110] with the exclusive formation of the monoadducts (LIII):

(LIII)

(R=Alk, Ar; R'=Alk, Ar)

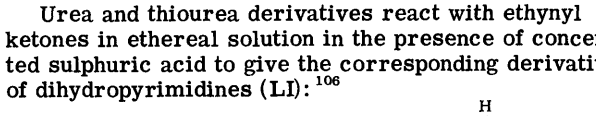
The addition of alcohols to phenylbenzoylacetylene in the presence of potassium hydroxide takes place with the cleavage of the initial ketone to acetophenone and potassium benzoate [110]. It is interesting that alcohols add in the presence of BF_3 as the catalyst. Thus dibenzoylacetylene reacts with alcohol in the presence of BF_3, yielding 3-alkoxy-2,5-diphenyldihydrofuranone (LIV) as the sole product [111]:



(LIV)

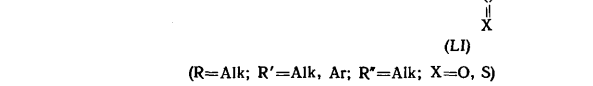
One should note that the addition of alcohols to ethynyl ketones is stereospecific like the addition of amines [33,112,114]. For example, the reaction of isopropyl methylethynyl ketone with methanol in aqueous potassium carbonate solution yielded a pure $\alpha\beta$-unsaturated *cis*-β-methoxyketone, which did not isomerise under the reaction conditions.

The reaction of cyclo-oct-2-ynone with deuteriated aqueous methanol in the presence of potassium carbonate gives 2-deuterio-3-methoxycyclo-oct-2-enone (LV) containing a small admixture (less than 10%) of the non-deuteriated product [113]. There is no doubt about the *cis*-configuration of compound (LV):



(LV)

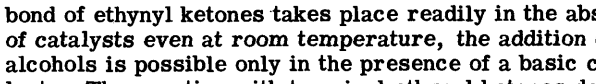
The addition of phenols to ethynyl ketones in the presence of sodium phenoxide [37] or pyridine [114] takes place sluggishly and always results in the formation of a monoadduct:



(R=H, Ar; R'=Ar)

In the reaction with alcohols and phenols under analogous conditions, silylethynyl ketones are cleaved at the Si–C bond [89].

Thiols and thiophenols add similarly to alcohols and phenols, and in both cases only the monoadducts were isolated [33,37,112,113]:



(R=H, Alk; R', R"=Alk, Ar)

The reaction takes place at room temperature in the presence of alkali metal alkoxides [37,112,113], alkali, and in a few cases also in the absence of the catalyst [65]. Thiols add to symmetrical ethynyl vinyl ketones at the triple bond in the first place and then at the double bond [65]:

$$R{-}CH{=}CH{-}CO{-}C{\equiv}CH + RSH \rightarrow RCH{=}CH{-}COCH{=}CHSR + RCH(SR)CH_2{-}CO{-}CH{=}CHSR$$

The study of the stereochemistry of the addition of thiols and thiophenols to ethynyl ketones showed that the reaction is rigorously stereospecific and takes place in accordance with the *trans*-addition rule, yielding the *cis*-adducts only [37,112,113].

IX. ADDITION OF ACIDS

As with amines, alcohols, and thiols, the addition of acids to ethynyl ketones is a nucleophilic process; the anionoid fragment of the acid is directed towards the β-carbon atom of the multiple bond. The addition of an arenesulphonic acid to the triple bond of ethynyl ketones was first described by Kohler and Barrett [115], who treated benzoylphenylacetylene with toluene-*p*-sulphonic acid and isolated two stereoisomeric sulphones (LVI). Somewhat later Bowden et al. [37] obtained similar results in the reaction of ethynyl phenyl ketone with the same sulphonic acid:

$$C_6H_5COC{\equiv}CR + p\text{-}CH_3C_6H_4SO_2H \rightarrow C_6H_5COCH{=}\overset{R}{\underset{|}{C}}{-}SO_2C_6H_4{-}CH_3\text{-}p$$

(R=H, C_6H_5) (LVI)

cis- and *trans*-

The addition of acetic and benzoic acids to ethynyl phenyl ketone in the presence of basic catalysts takes place fairly smoothly and yields the acetate (LVIIa) and the benzoate (LVIIb) respectively, which are mixtures of the *cis*- and *trans*-isomers [116]:

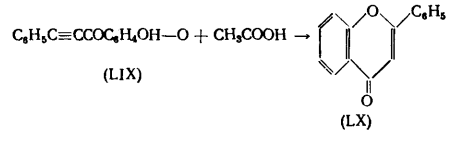
$$C_6H_5COC{\equiv}CH \xrightarrow[RCOOH]{RCOONa} C_6H_5COCH{=}CHOCOR \quad (LVII)$$

$$C_6H_5COC{\equiv}CH \xrightarrow[N(C_2H_5)_3]{CH_3COOH} C_6H_5COCH_2CH(OCOCH_3)_2 \quad (LVIII)$$

(a) R=CH_3; (b) R=C_6H_5)

Treatment of ethynyl phenyl ketone with an excess of acetic acid in the presence of triethylamine yields the diacetate (LVIII).

The addition of acetic acid to 3-(*o*-hydroxyphenyl)-1-phenylprop-1-yn-3-one (LIX) in the presence of polyphosphoric acid at 100°C leads to the flavone (LX): [117]



(LIX) (LX)

The reaction of hydrogen selenide and also of selenols with ethynyl phenyl ketone takes place successfully without a solvent and a catalyst and also in ether in the presence of catalytic amounts of pyridine. The yield of selenovinyl ketones (LXI) reaches 60–80%: [118]

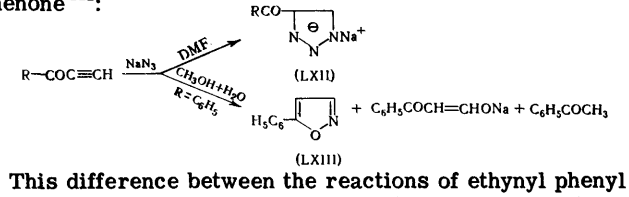
$$RCOC{\equiv}CH + RSeH \rightarrow RCOCH{=}CH{-}SeR \quad (LXI)$$

In contrast to the acids discussed above, the addition of diesters of phosphorous and phosphorothious acids to ethynyl ketones takes place only at the carbonyl group without involving the C≡C bond [119,120]:

$$R'COC{\equiv}CR'' + (RO)_2PH \xrightarrow{RONa} (RO)_2P(X){-}CR'(OH){-}C{\equiv}C{-}R''$$

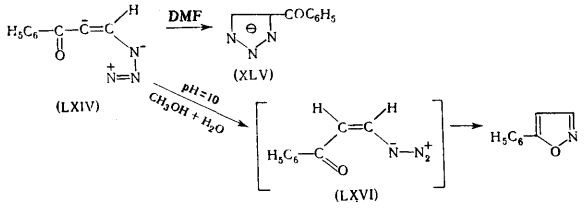
(X=O, S)

The reaction of ethynyl ketones with sodium azide, investigated by Nesmeyanov and Rybinskaya [121,122], which leads to the formation of either triazoles or isoxazoles depending on the reaction conditions, occupies a special place. Thus ethynyl propyl or ethynyl phenyl ketone reacts with sodium azide in dimethylformamide (DMF) to give the corresponding triazole (LXII). [121] On the other hand, the reaction of ethynyl phenyl ketone with NaN_3 in a proton-donating solvent proceeds with formation of 5-phenylisoxazole (LXIII) and a small admixture of the sodio-derivatives of benzoylacetaldehyde and acetophenone [122]:



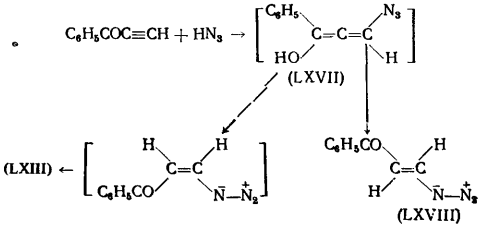
(LXII) (LXIII)

This difference between the reactions of ethynyl phenyl ketone with the azide ions in DMF and a protic solvent can be accounted for by a change in the conditions governing the stabilisation of the carbanion (LXIV) formed as a result of the nucleophilic attack by the azide ion on the triple bond. It is suggested that in aprotic solvents the lifetime of the carbanion (LXVII) is long enough for its cyclisation to the stable triazolyl anion system (LXV):



(LXIV) (XLV) (LXVI)

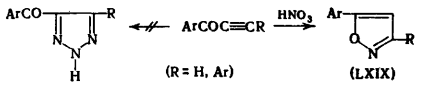
In proton-donating solvents, this carbanion can be protonated, which apparently results in the formation of an unstable intermediate—*cis*-β-azidovinyl phenyl ketone (LXVI), which, owing to the favourable disposition of the carbonyl and azide groups, is converted into the stable heterocyclic system of 5-phenylisoxazole with evolution of nitrogen. However, one cannot rule out the possibility that at low pH ethynyl phenyl ketone reacts with HN_3 to give a 1,4-addition product, from which a mixture of the *cis*- and *trans*-isomers [(LXVII) and (LXVIII) respectively] of azidovinyl phenyl ketone is formed as a result of a prototropic rearrangement:



(LXVII) (LXIII) (LXVIII)

trans-β-Azidovinyl phenyl ketone is quite stable under the usual conditions and can be isolated, while the *cis*-form is unstable and decomposes spontaneously with formation of 5-phenylisoxazole (LXIII).

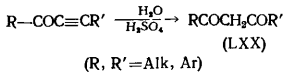
Ethynyl ketones react with NH_3 in chloroform to form isoxazoles (LXIX) and not triazoles [123]:



(R = H, Ar) (LXIX)

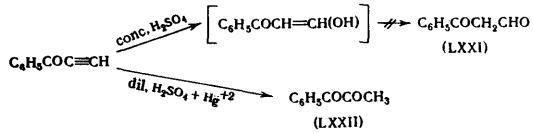
X. HYDRATION

The addition of water to disubstituted ethynyl ketones has been known for a long time. As early as 1899, Nef [41] obtained dibenzoylmethane by treating benzoylphenylacetylene with concentrated sulphuric acid. This method has been used in many other investigations [47,108,109,124-126] and regardless of the nature of the substituent led in all cases to β-diketones (LXX):



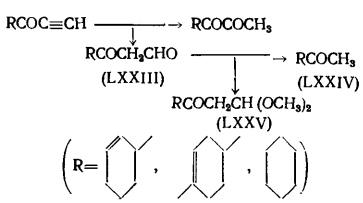
(R, R'=Alk, Ar)

Monosubstituted ethynyl ketones are not hydrated in concentrated sulphuric acid; in dilute sulphuric acid, the reaction proceeds only on heating in the presence of mercury salts with formation of α-diketones (LXXII) instead of the expected α-ketoaldehydes (LXXI): [37]

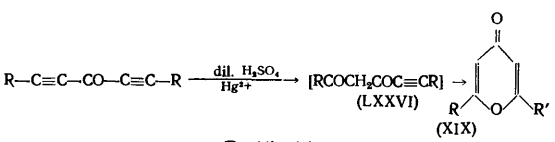


(LXXI) (LXXII)

However, the study of the reactivities of compounds of the Δ^3-cyclohexane series showed that, together with the main products, which are α-diketones, the isomeric β-ketoaldehydes (LXXIII) as well as their conversion products—the methyl ketones (LXXIV) and acetals (LXXV)—are nevertheless formed in comparatively small amounts [127]:

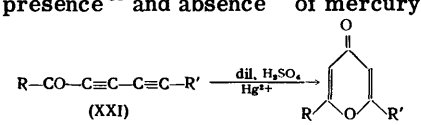


The products of the hydration of symmetrical ethynyl ketones in dilute sulphuric acid on heating in the presence of mercury salts are γ-pyrones (XIX): [70,75,128]



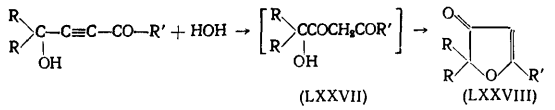
(R=Alk, Ar)

Probably water adds to one triple bond with formation of the intermediate ketone (LXXVI), which then cyclises to (XIX). Similar results were obtained in the hydration of asymmetric diacetylenic ketones (XXI) by dilute sulphuric acid in the presence [83] and absence [84] of mercury salts:



(XXI) (R=C_6H_5; R'=Alk, Ar)

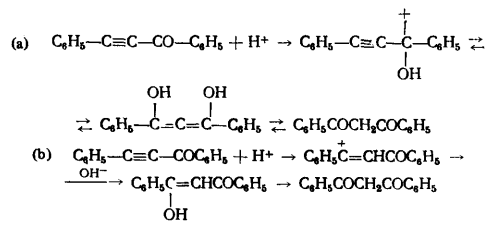
α-Ethynyl-γ-ketols are fairly readily hydrated in dilute sulphuric acid and in an alkaline alcoholic medium in the presence of mercury salts as well as in the presence of amines in protic solvents [93,103], being converted under these conditions into β-furanones (LXXVIII) in 80–90% yield via the β-diketol (LXXVII) stage. In aqueous dioxan, the yield of furanone is scarcely 50%:



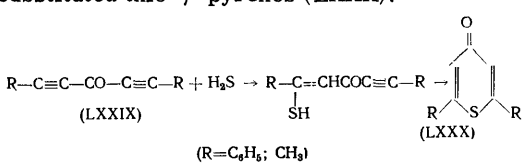
(LXXVII) (LXXVIII)

The addition of water to dibenzoylacetylene in the presence of mercury salts in an acid medium and in the presence of aliphatic amines in an aqueous alcoholic solution results in the formation of 1,4-diphenylbutane-1,2,4-trione [68].

By analogy with the available literature data for the mechanism of the hydration of unsaturated acids [129] and ketones [130-132], two possible mechanisms have been proposed [133] for the hydration of ethynyl ketones in an acid medium:



In the first case, the rate-limiting stage of the process is probably the transformation of the phenylbenzoylacetylene oxonium salt and in the second case a proton adds to phenylbenzoylacetylene. Having measured the rate constants for the hydration of ethynyl ketones of different basicities, Noyce and Debruin [133] showed that the hydration of phenylbenzoylacetylene proceeds via a stage involving proton transfer from the acid medium to the α-carbon atom of the triple bond [i.e. via mechanism (b)]. Probably the interaction of symmetrical diethynyl ketones (LXXIX) with hydrogen sulphide can be interpreted likewise. The reaction in absolute ethanol takes place with formation of 2,6-disubstituted thio-γ-pyrones (LXXX): [128,134]



(LXXIX) (LXXX)

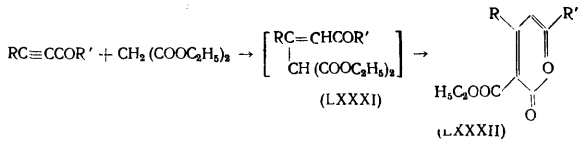
(R=C_6H_5; CH_3)

XI. MICHAEL CONDENSATION AND RELATED REACTIONS

The most typical property of ethynyl ketones is their capacity to undergo the Michael condensation with compounds containing active methylene groups. The nucleophilic agents can be not only carbonyl and carboxylated substances of the type $O{=}\overline{C}-CH_2-\underset{|}{C}{=}O$, but also the corresponding nitriles, nitro-compounds, and sulphones.

The interaction of ethynyl ketones with malonic ester has been investigated in greatest detail. By analogy with the reactions discussed above, it might have been expected that ethynyl ketones involved in the Michael condensation would form $\alpha\beta$-unsaturated ketones. However, in most

cases cyclisation products—derivatives of α-pyrones (LXXXII)—were isolated and not the open-chain compounds (LXXXI):[10,135-138]

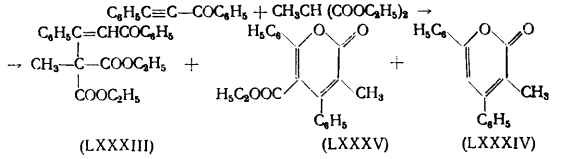


(LXXXI) (LXXXII)

The interaction of ethynyl ketones with malonic ester has been suggested[10] as a method for their identification. However, in studies on ethynyl furyl ketones, it was found that the reaction is not general[139].

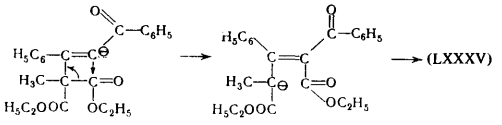
Michael condensation involving ethynyl ketones took place smoothly in an alcoholic medium in the presence of traces of the corresponding sodium alkoxides. When the reaction is carried out in the presence of an equimolar amount of sodium alkoxide or metallic sodium, its course changes. Thus the reaction of diethyl methylmalonate with phenylbenzoylacetylene yields under these conditions the "normal" adduct—4,4-diethoxycarbonyl-1,3-diphenyl-pent-2-en-1-one (LXXXIII) together with 3-methyl-4,6-diphenyl-2-pyrone (LXXXIV) and ethyl 3-methyl-4,6-diphenyl-2-pyrone-5-carboxylate (LXXXV).[140]

Compound (LXXXIV) is a product of the decarboxylation of the ester (LXXXIII) or (LXXXV):

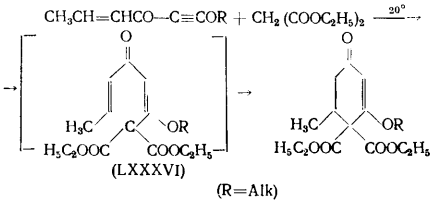


(LXXXIII) (LXXXV) (LXXXIV)

It is suggested that the pyrone (LXXXV)—the "anomalous" reaction product—is formed from the "normal" adduct (LXXXIII) according to the following mechanism:



The interaction of malonic ester with the ethynyl vinyl ketone $CH_3CH{=}CHCOC{\equiv}COR$ in absolute t-butyl alcohol in the presence of catalytic amounts of potassium t-butoxide involves the formation of the intermediate open-chain product (LXXXVI) which subsequently cyclises as follows:

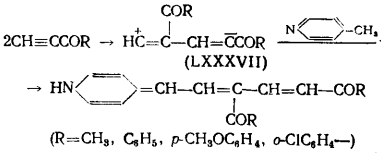


(LXXXVI)

(R=Alk)

The antibiotic griseofulvin was obtained from ethynyl vinyl ketones and coumaranone via this reaction[124].

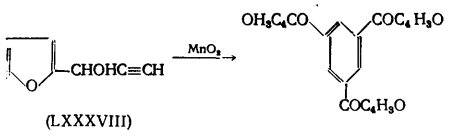
The intermediate formation of the zwitter-ion (LXXXVII) in reactions of ethynyl ketones with γ-picoline and related compounds has been postulated[141]:



(LXXXVII)

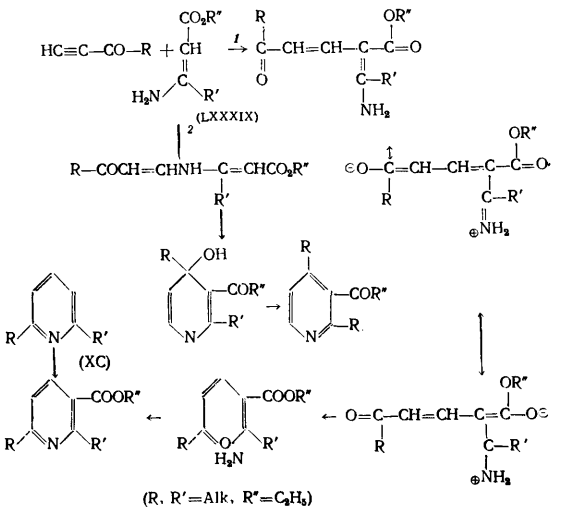
(R=CH_3, C_6H_5, p-$CH_3OC_6H_4$, o-ClC_6H_4—)

Probably ethynylfurylmethanol (LXXXVIII) reacts similarly under the influence of activated manganese dioxide[142]:



(LXXXVIII)

An interesting reaction of ethynyl ketones with esters of α-aminovinylcarboxylic acids (LXXXIX) has been described[61]:



(LXXXIX)

(XC)

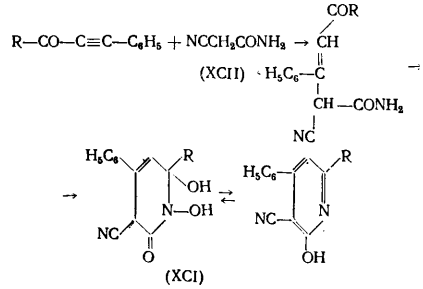
(R, R'=Alk, R"=C_6H_5)

In principle, this reaction can proceed via a mechanism of the type of Michael condensation (*1*) and via a pathway (*2*), where the amino-group adds to the activated C≡C bond. The study of the physical and chemical properties of the final reaction products [pyridine derivatives (XC)] demonstrated unambiguously that the reaction has mechanism (*1*).

The low probability of the addition of the amino-group of aminovinyl ketones to the triple bond of ethynyl ketones can be accounted for by the reduced basicity of the amino-group owing to the conjugation of the lone electron pair of the nitrogen atom with the carbonyl group[143].

Pyrroles and indoles, which have similar structures, react with ethynyl ketones via the hydrogen atom in the α- or β-position in the ring[141].

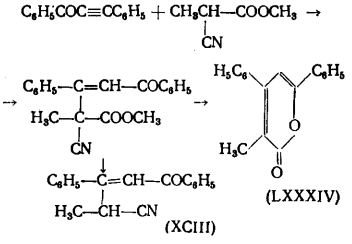
Another characteristic instance of this type of condensation is the formation of pyridones (XCI) by the reaction of ethynyl ketones with cyanacetamide (XCII):[137,144]



(XCII) (XCI)

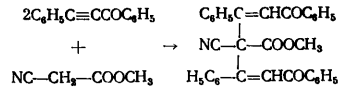
The reaction of phenylbenzoylacetylene with ethyl phenylacetate yielded 3,4,6-triphenyl-2-pyrone[145], while the reaction with methyl α-cyanopropionate in the presence

of an excess of sodium alkoxide gave the α-pyrone (LXXXIV) and a small amount of the unsaturated nitrile (XCIII):[115]



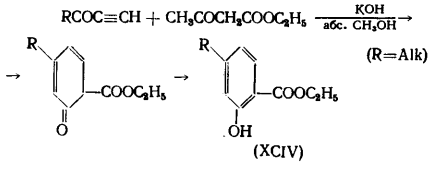
(XCIII) (LXXXIV)

Methyl α-cyanoacetate reacts with phenyl benzoylacetylene via the mechanism



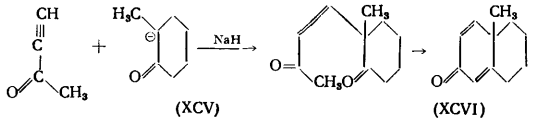
A change in the ratio of the initial reactants does not affect the course of the reaction[115].

The condensation of unsubstituted ethynyl ketones with acetoacetic ester takes place quite differently. The final product of this reaction is a derivative of ethyl salicylate (XCIV):[146]



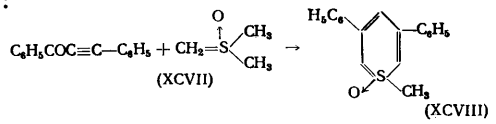
(XCIV)

The addition of methylcyclohexanone (XCV) to ethynyl methyl ketone in the presence of sodium hydride proceeds via a stage of internal aldol condensation with subsequent dehydration and formation of 10-methyl-2-oxo-Δ 1,9;3,4-hexahydronaphthalene (XCVI):[147]



(XCV) (XCVI)

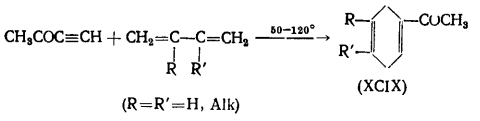
An example of the condensation of ethynyl ketones with compounds containing an active methylene group is provided also by the reaction of phenylbenzoyl acetylene with dimethyloxosulphonium methylide (XCVII), which takes place in dimethyl sulphoxide solution at 20°C with formation of 1-methyl-3,5-diphenylthiabenzene-1-oxide (XCVIII):[148]



(XCVII) (XCVIII)

XII. DIELS-ALDER SYNTHESIS

Ethynyl ketones are extremely active dienophiles in Diels-Alder synthesis. Thus butynone, the simplest ethynyl ketone, reacts readily at 50–120°C with butadiene and many of its homologues (isoprene, piperylene, dipropenylene, and di-isopropenylene), yielding dihydrobenzophenones (XCIX):

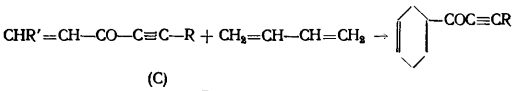


(R=R'=H, Alk) (XCIX)

Ethynyl propyl ketone and ethynyl phenyl ketone enter into a Diels-Alder reaction with butadiene under similar conditions[149,150]. The reactivity of disubstituted ethynyl ketones in this process is somewhat lower[22,100,151].

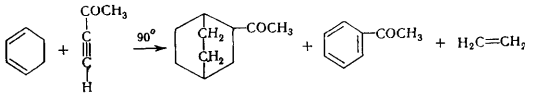
The condensation of ethynyl methyl ketone with chloroprene, bromoprene, and 1-chlorobutadiene at 80–125°C in benzene solution gave high yields of the corresponding halogenodihydrobenzophenones[152,153].

Petrov and coworkers[20,154], showed that in the reactions between butadiene and isomeric hex-2-en-5-yn-4-one and hex-1-en-4-yn-3-one (C, b) the process involves the unsubstituted multiple bond, preferentially in the first case and exclusively in the second, regardless of its nature. The addition of butadiene to pent-1-en-4-yn-3-one (C, a) and hept-2-en-5-yn-4-one takes place exclusively at the double bond:

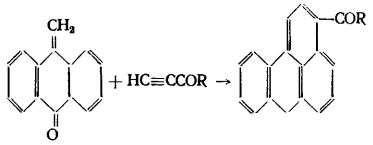


(C)
(a) R=H; (b) R=CH$_3$

Ethynyl ketones react fairly readily with cyclopentadiene[150,155,156]. The condensation with cyclohexa-1,3-diene takes place with greater difficulty and is accompanied by the splitting off of the endoethylene bridge with formation of acetophenone and ethylene[155]:



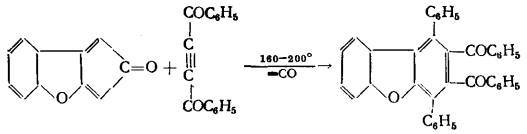
On heating in acetic acid solution, ethynyl ketones condense with methyleneanthrone (CI), the final product being 3-substituted mesobenzanthrones (CII):[157]



(CI) (CII)

Dibenzoylacetylene, which readily condenses with dienes in ether or dioxan, is used as a dienophile similarly to ethynyl monoketones[18,158].

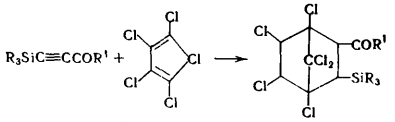
"Indanocyclone" (CIII) reacts with dibenzoylacetylene in ethyl acetate at 160–200°C to form 1,4-diphenyl-2,3-dibenzoylfluorenone (CIV):[159]



(CIII) (CIV)

The condensation of diacetylacetylene with butadiene could not be achieved, since the initial diacetylacetylene decomposed under the reaction conditions[160].

Silylethynyl ketones do not react with cyclopentadiene [161], probably owing to the deactivation of the critical bond under the influence of a_π-p_π-conjugation with the silicon atom. However, these studies show at the same time that silylethynyl ketones condense with hexachlorocyclopentadienone at 150–180°C with formation of hexachlorosilylbicycloheptadienyl ketones (CV) in a yield of 15–30%: [161]

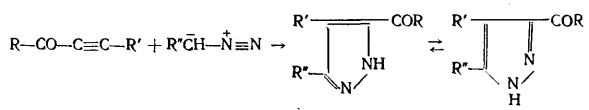


(R = CH_3, C_2H_5; R' = CH_3) (CV)

XIII. ADDITION OF 1,3-DIPOLAROPHILES

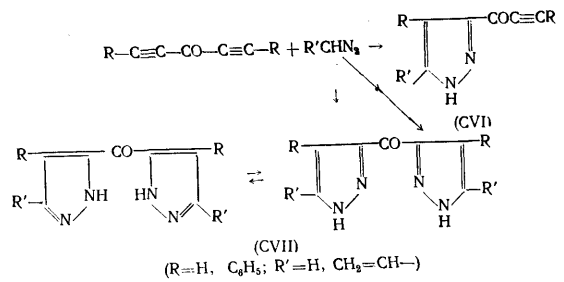
1. Addition of Diazoalkanes

Ethynyl ketones react fairly readily with diazoalkanes, which are powerful nucleophilic agents. The reaction is general for ethynyl ketones and is regarded as dipolar 1,3-addition to the triple bond [62,162–167]:



(R = Alk, Ar; R' = H, Alk, $-COOCH_3$; R'' = H, CH_2=CH–, CH_3)

Ketones of the type RC≡CCOC≡CR react with diazoalkanes to form 1 : 1 and 1 : 2 adducts [(CVI) and (CVII) respectively] [163,168]:

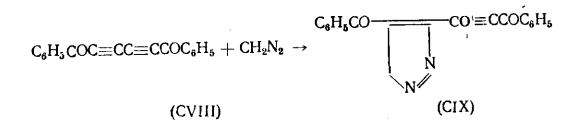


(CVI)

(CVII)

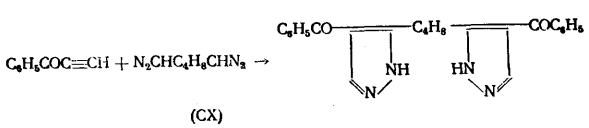
(R = H, C_6H_5; R' = H, CH_2=CH–)

Diazomethane adds to 1,6-diphenylhexa-2,4-diyne-1,6-dione (CVIII) at only one C≡C bond with formation of 4-benzoyl-3(5)-benzoylethynylpyrazole (CIX): [168]



(CVIII) (CIX)

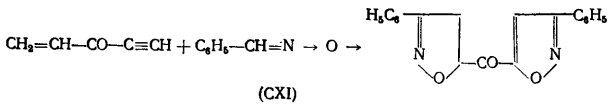
Bisdiazohexane (CX) reacts with benzoylacetylene as follows [169]:



(CX)

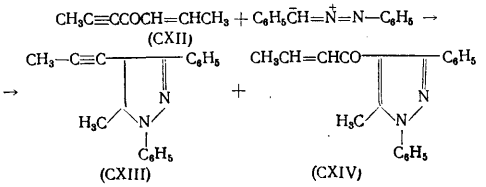
2. Addition of Nitrile *N*-Oxides

Like diazoalkanes, nitrile *N*-oxides and nitronic esters react with ethynyl ketones according to the dipolar 1,3-addition mechanisms. Benzonitrile *N*-oxide (CXI) add to unsubstituted ethynyl vinyl ketones at both multiple bonds [170]:



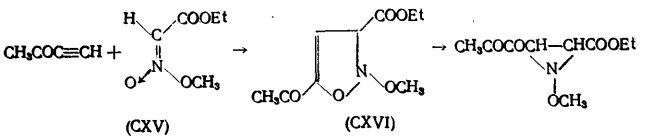
(CXI)

In the interaction of monosubstituted ethynyl vinyl ketones with benzonitrile *N*-oxide, 3-nitrobenzonitrile *N*-oxide, and diphenylnitrylimine, the less substituted multiple bond is the more reactive [170]. Hept-2-en-5-yn-4-one (CXII) reacts with diphenylnitrylimine both via the double bond and the triple bond, forming a pyrazoline (CXIII) and a pyrazole (CXIV): [171]



(CXIII) (CXIV)

The reaction of butynone with the methyl nitrolic ester of ethyl nitroacetate (CXV) yielded 82% of the corresponding aziridine derivative. Its formation is probably associated with a rearrangement of the substituted 4-isoxazoline (CXVI) obtained in the first stage of the reaction via the general dipolar 1,3-cycloaddition mechanism [172]:

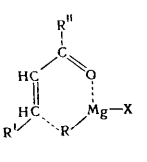


(CXV) (CXVI)

XIV. ETHYNYL KETONES IN ORGANOMAGNESIUM SYNTHESIS

The interaction of vinyl ketones with organomagnesium compounds has been investigated by many Soviet and foreign workers. In particular, special studies have been made on the effect of polar and steric factors on the ratio of the 1,2- and 1,4-addition products [172–174].

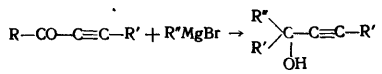
The literature data for the involvement of ethynyl ketones in organomagnesium synthesis are not quite so systematic. It has been suggested [175] that the 1,4-addition of organomagnesium reagents to vinyl ketones proceeds via an intermediate stage involving an unstable chelate complex (CXVII). In ethynyl ketones, this type of steric distribution of reacting molecules is difficult owing to the linear configuration of the –C≡C group and therefore the main reaction pathway should be 1,2-addition to the carbonyl group:



(CXVII)

Indeed, as early as 1907 Kohler [176], showed that phenyl magnesium bromide enters into the 1,2-addition reaction

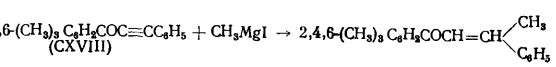
with benzoylphenylacetylene and into the 1,4-addition reaction with its vinyl analogue. Subsequently, studies of the interaction of ethynyl ketones with aromatic [177,178], aliphatic [178,179], and acetylenic [178,180,181] organomagnesium compounds and also of silylethynyl ketones with Iotsich reagents [182] showed that in most cases the main reaction products are tertiary α-ethynyl alcohols (or diethynyl alcohols):



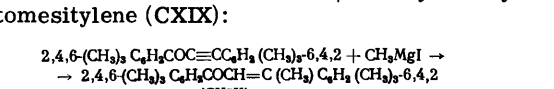
(R=R'=Alk, Ar; R"=Alk, Ar, HC≡C—)

Traces of unsaturated ketones (1,4-addition products) were detected chromatographically in some cases [178].

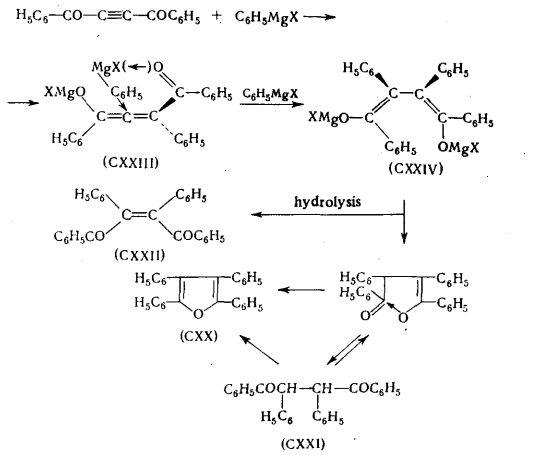
As a result of the presence of bulky substituents at the carbonyl group, the main reaction pathway becomes 1,4-addition. Thus mesitoylphenylacetylene (CXVIII), in which approach to the carbon atom of the carbonyl group is hindered, readily condenses with methylmagnesium iodide and with phenyl- and mesitylmagnesium bromides via the mechanism [183]:



The condensation of mesitoylmesitylacetylene with methylmagnesium iodide yields two isomeric products, namely the *cis*- and *trans*-isomers of β-methylmesitylideneacetomesitylene (CXIX):



Another instance of 1,4-addition occurs in reactions of dibenzoylacetylene [184] which can react, in principle, with Grignard agents via the following pathways: (1) two consecutive 1,2-additions; (2) two consecutive 1,4-additions; (3) a combination of consecutive 1,2- and 1,4-additions. In fact, the reaction with C_6H_5MgX takes place via mechanism (2), since hydrolysis of the reaction mixture yielded tetraphenylfuran (CXX), *meso*-dibenzoyldiphenylethane (CXXI), the thermodynamically unstable *cis*-dibenzoylstilbene (CXXII), and a small amount of *trans*-dibenzoylstilbene [184]. This is probably due to the high reactivity of the allenolate (CXXIII), which is an $\alpha\beta$-unsaturated ketone with a sterically accessible β-carbon atom:

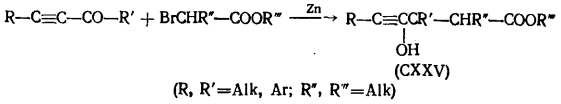


A further 1,4-addition to the allenolate (CXXIII) leads to the saturated diketodienolate (CXXIV), the subsequent hydrolysis of which yields the unsaturated diketone (CXXII), the saturated diketone (CXXI), and tetraphenylfuran (CXX). It is interesting that the main reaction product is *cis*-dibenzoylstilbene (CXXII) when hydrolysis is carried out in effective contact with air. The formation of *cis*-dibenzoylstilbene is minimal if the reaction is performed in an atmosphere of nitrogen.

The differences in the modes of addition of the Grignard reagent to dibenzoylacetylene and phenylbenzoylacetylene cannot be accounted for solely by steric factors. Indeed the electrophilic properties of the triple bond in dibenzoylacetylene are greatly enhanced under the influence of the strong inductive $-I$ effect of the two benzoyl groups. Phenylbenzoylacetylene has only one acetylenic carbon atom in the β-position relative to the carbonyl group, the electrophilic properties of which are somewhat weakened, in relation to dibenzoylacetylene, by the electron-donating influence of the phenyl group [184]:



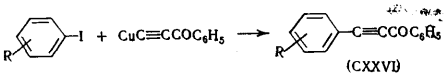
Mono- and di-substituted ethynyl ketones readily enter into the Reformatskii reaction with α-bromoacetic esters in the presence of metallic zinc, forming β-hydroxyacid esters (CXXV) in a yield of 45–62%: [185,186]



(R, R'=Alk, Ar; R", R"'=Alk)

XV. REACTIONS OF THE ETHYNYL HYDROGEN ATOM

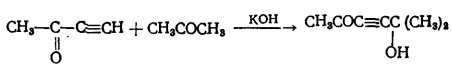
The mobility of the hydrogen atom in monosubstituted ethynyl ketones is due not only to the nature of the triple bond itself but also to the presence of the electron-accepting carbonyl group [187]. Treatment of ethynyl ketones with ammoniacal solutions of silver(I) and copper(I) salts by the usual method yielded the corresponding silver and copper acetylides, which can be used as starting materials for the synthesis of various disubstituted ethynyl ketones (CXXVI) and monosubstituted arylacetylenes [188]:



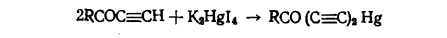
1,4-Dibenzoylbutadiyne (CVIII) has been synthesised by oxidative dihydrocondensation from benzoylacetylene [168]:



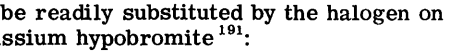
The capacity of ethynyl ketones to give rise to acetylides on treatment with powdered potassium hydroxide permits their employment for the synthesis of the simplest homologues of aliphatic α-ethynylketoalcohols (CXXVII) under the conditions of the Favorskii reaction [189]:



Mercury derivatives of ethynyl ketones can be obtained with the aid of K_2HgI_4 in alcoholic alkali [190]:



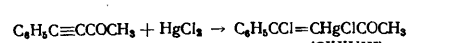
The ethynyl hydrogen atom in the ethynyl ketone molecule can be readily substituted by the halogen on interaction with potassium hypobromite [191]:



XVI. VARIOUS REACTIONS

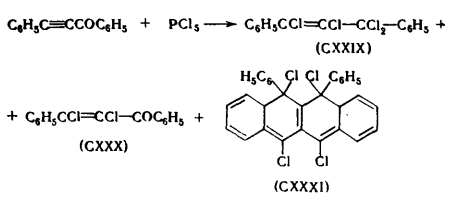
Apart from the reactions already discussed, a number of interactions of a non-general type have been described for ethynyl ketones.

Acetylphenylacetylene readily combines with mercury(II) chloride in saturated aqueous sodium chloride solution to form a crystalline substance (CXXVIII) which is fairly stable in an acid medium but decomposes readily on heating to the initial compounds [192]:



(CXXVIII)

When phosphorus pentachloride is allowed to react with ethynyl ketones, there is both addition of chlorine to the multiple bond and substitution of the carbonyl oxygen by chlorine. The mode of reaction depends on the reactant ratio and on the structure of the ethynyl ketone. Thus the reaction of PCl_5 with benzoylphenylacetylene yields a mixture of products consisting of 1,2,3,3-tetrachloro-1,3-diphenylpropene (CXXIX), 2,3-dichloro-1,3-diphenylprop-1-en-3-one (CXXX), and compound (CXXXI):



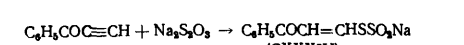
(CXXIX) (CXXX) (CXXXI)

With acetylphenylacetylene, two products are formed—3-chloro-1-phenylbut-3-en-1-yne (CXXXII) and 3,3-dichloro-1-phenylbut-1-yne (CXXXIII) in proportions of 3 : 1: [193]



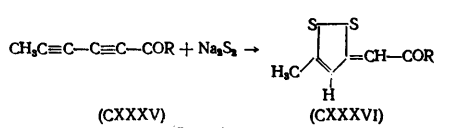
(CXXXII) (CXXXIII)

When ethynyl phenyl ketone reacts with sodium thiosulphate in a polar solvent in the presence of acid, the thiosulphate residue adds to the triple bond [194]. The reaction takes place on heating with a 69% yield of the vinyl ketone (CXXXIV):



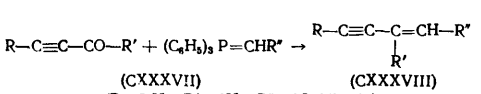
(CXXXIV)

Diacetylenic ketones (CXXXV) react with sodium disulphide in methanol to form cyclic acetonylidenedithiols (CXXXVI) in quantitative yields [195]:



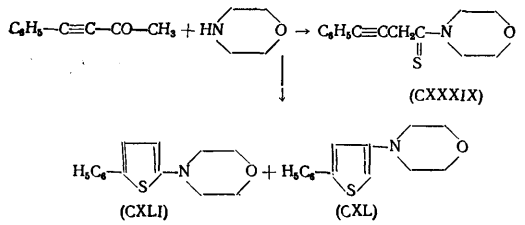
(CXXXV) (CXXXVI)
(R=Alk, Ar)

The interaction of ethynyl ketones with phosphorane (CXXXVII) and its derivatives leads to the corresponding ethynyl vinyl compounds (CXXXVIII): [196]



(CXXXVII) (CXXXVIII)
(R=C_6H_5; R′=CH_3; R″=CO_2Alk, Ar)

Nightingale and Carpenter [197] carried out the Willgerodt reaction with acetylphenylacetylene using morpholine and sulphur and obtained a 51% yield of a compound to which they attributed the structure of γ-phenylethynylthioacetomorpholide (CXXXIX):

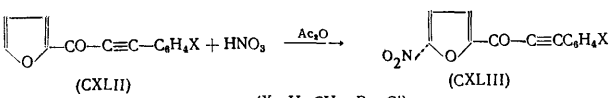


(CXXXIX)

(CXLI) (CXL)

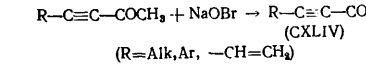
Ozonolysis of the morpholide (CXXXIX) resulted in the cleavage of the molecule to benzoic acid, but the attempt at hydrolysis to phenylacetic was unsuccessful. Later Bacchetti et al. [198] demonstrated by infrared and NMR spectroscopy that the main product of this reaction is 4-(*N*-morpholonyl)-2-phenylthiophen (CXL) with a small admixture of the isomer (CXLI). [198]

Apart from the reactions involving the multiple bond and the carbonyl group, ethynyl ketones can also enter into reactions involving substituents. For example, when furyl phenylethynyl ketones (CXLII) were nitrated in acetic anhydride, 5-nitrofuryl phenylethynyl ketones (CSLIII) were obtained. It was noted that the rate of nitration depends to a considerable degree on the benzene ring substituent conjugated with the furan ring [199]:



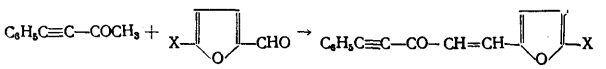
(CXLII) (CXLIII)
(X=H, CH_3, Br, Cl)

The haloform cleavage of ethynyl ethyl ketones takes place fairly smoothly with formation of substituted propiolic acids (CXLIV). [200] The reaction can be used as a method for the synthesis of α-ethynylcarboxylic acids:



(CXLIV)
(R=Alk,Ar, $-CH=CH_2$)

The crotonic condensation of ethynyl methyl ketones with aldehydes in an alkaline medium has been used to synthesise symmetrical ethynyl vinyl ketones (CXLV): [201]



(CXLV)
(X=Br, I NO_2)

REFERENCES

1. R. I. Katkevich and L. I. Vereshchagin, Uspekhi Khim., 38, 1965 (1969) [Russ. Chem. Rev., No. 11 (1969)].
2. F. Bohlmann, H. Sinn, and E. Inhoffen, Chem. Ber., 89, 1281 (1956).
3. F. Bohlmann, Angew. Chem., 69 (1957).
4. M. I. Batuev, Izv. Akad. Nauk SSSR, Otd. Khim. Nauk, 558 (1960).
5. A. A. Petrov and B. S. Kupin, Zhur. Obshch. Khim., 28, 1999 (1958).
6. A. M. Sladkov and Yu. P. Kudryavtsev, Uspekhi Khim. 32, 510 (1963) [Russ. Chem. Rev., No. 5 (1963)].
7. N. H. Cromwell, Chem. Rev., 38, 83 (1946).
8. I. A. Chekulaeva and L. V. Kondrat'eva, Uspekhi Khim., 34, 1583 (1965) [Russ. Chem. Rev., No. 9 (1965)].

9. C. L. Bickel, J. Amer. Chem. Soc., 71, 336 (1949).
10. C. L. Bickel, J. Amer. Chem. Soc., 72, 1022 (1950).
11. M. I. Rybinskaya, A. N. Nesmeyanov, and N. K. Kochetkov, Uspekhi Khim., 38, 980 (1969) [Russ. Chem. Rev., No. 6 (1969)].
12. Kh. V. Bal'yan, Zhur. Obshch. Khim., 31, 28 (1961).
13. F. Beck and L. Schuster, Belg. P. 647 708 (1964); Chem. Abs., 63, 9806e (1965).
14. G. P. Kugatova-Shemyakina and V. Vidugiriene, Zhur. Obshch. Khim., 34, 1729 (1964).
15. W. Surber, V. Thens, L. Colombi, and U. H. Schiz, Helv. Chim. Acta, 39, 1299 (1956).
16. N. V. Sushkova, R. I. Katkevich, and I. I. Kabaeva, Izd. Vys. Ucheb. Zaved., Khim. i Khim. Tekhnol., 13, 1312 (1970).
17. J. G. Dinwiddie, H. M. White, and W. J. Day, J. Org. Chem., 27, 327 (1962).
18. C. Dupont and J. Germain, Compt. rend., 223, 743 (1946).
19. A. I. Nogaideli, "Sbornik Statei Obshchei Khimii" (Collected Papers on General Chemistry), Izd. Akad. Nauk SSSR, Moscow–Leningrad, 1953, Vol. 3, p. 1642.
20. G. N. Bondarev, V. A. Ryzhov, L. F. Chelpanova, and A. A. Petrov, Zhur. Org. Khim., 3, 816 (1967).
21. G. N. Bondarev and A. A. Petrov, Zhur. Org. Khim., 2, 782 (1966).
22. K. B. Bowden, I. Heilbron, E. R. H. Jones, and B. C. L. Weedon, J. Chem. Soc., 39 (1946).
23. M. H. Durand and L. Piaux, Compt. rend., 250, 3029 (1960).
24. M. H. Durand, Bull. Soc. chim. France, 2393 (1961).
25. S. R. Landor, B. Miller, and A. Tatchell, J. Chem. Soc. (C), 1822 (1966).
26. S. R. Landor, B. Miller, and A. Tatchell, Proc. Chem. Soc., 227 (1964).
27. L. I. Vereshchagin, E. I. Titova, N. V. Sushkova, and L. D. Gavrilov, Zhur. Org. Khim., 7, 912 (1971).
28. A. P. Tomilov, S. G. Mairanovskii, M. Ya. Fioshin, and V. A. Smirnov, "Elektrokhimiya Organicheskikh Soedinenii" (Electrochemistry of Organic Compounds), Izd. Khimiya, Moscow, 1968, p. 160.
29. L. Horner and H. Roder, Annalen, 723, 11 (1969).
30. C. Prevost, P. Souchay, and J. Chauvelier, Bull. Soc. chim. France, 714 (1951).
31. J. Wilson and V. S. Stubblefield, J. Amer. Chem. Soc., 90, 3423 (1968).
32. V. D. Nemirovskii, L. F. Chelpanova, and A. A. Petrov, Zhur. Obshch. Khim., 31, 2552 (1961).
33. D. Landini and F. Montanari, Chem. Comm., 180 (1967).
34. B. L. Cavalchi, D. Landini, and F. Montanari, J. Chem. Soc., 1204 (1969).
35. E. Augeletty and F. Montanari, Bull. Sci. Fac. chim., Ing. Bologna, 16, 140 (1958).
36. A. N. Nesmeyanov, M. I. Rybinskaya, and T. G. Kelekhsaeva, Zhur. Org. Khim., 4, 921 (1968).
37. K. B. Bowden, E. A. Braude, and E. R. H. Jones, J. Chem. Soc., 945 (1946).
38. L. F. Chelpanova and L. N. Mashlyakovskii, Zhur. Org. Khim., 2, 602 (1966).
39. G. F. Dvorko and E. A. Shilov, Dopov. Akad. Nauk Ukrain. RSR, 636 (1959).
40. G. N. Bondarev and A. A. Petrov, Zhur. Org. Khim., 4, 32 (1968).
41. J. V. Nef, Annalen, 308, 277 (1899).
42. C. Dufraisse, Ann. Chim., [9], 17, 133 (1922).
43. C. L. Bickel, J. Amer. Chem. Soc., 70, 763 (1948).
44. V. B. Pukhnarevich, N. V. Komarov, and O. G. Yarosh, "Khimiya Atsetilena" (The Chemistry of Acetylene) (Edited by M. F. Shestakovskii), Izd. Nauka, Moscow, 1968, p. 148.
45. L. F. Chelpanova, V. D. Nemirovskii, A. A. Petrov, and T. V. Yakovleva, Zhur. Obshch. Khim., 30, 1445 (1960).
46. E. R. Watson, J. Chem. Soc., 1319 (1904).
47. M. E. Andre, Ann. Chim., [8], 29, 569 (1913).
48. K. B. Bowden, E. A. Braude, E. R. H. Jones, and B. C. L. Weedon, J. Chem. Soc., 45 (1946).
49. I. Hirao, J. Chem. Soc., Japan, Ind. Chem. Sect., 57, 62 (1954).
50. A. N. Grinev and V. I. Shvedov, Zhur. Obshch. Khim., 32, 2614 (1962).
51. R. Fusco, G. Bianchetti, D. Pocar, and R. Ugo, Gazzetta, 92, 1040 (1962).
52. V. Vesa and G. K. Kupetis, Trudy Akad. Nauk Lit. SSR, B, 1, 89 (1967).
53. V. Vidugiriene, Trudy Akad. Nauk. Lit. SSR, B, 2, 55 (1968).
54. Z. B. Alaune, Z. Talaikyte, and G. Dienys, Trudy Akad. Nauk Lit. SSR, B, 2, 65 (1968).
55. T. Cuvigny and H. Normant, Compt. rend., 247, 1744 (1958).
56. J. Reisch, Arch. Pharm., 297, 59 (1965).
57. C. Lutz, Chem. Ber., 91, 1867 (1958).
58. R. L. Bol'shedvorskaya, S. P. Korshunov, S. I. Demina, and L. I. Vereshchagin, Zhur. Org. Khim., 4, 1541 (1968).
59. A. N. Shidlovskaya, Ya. K. Syrkin, and N. K. Kochetkov, Izv. Akad. Nauk SSSR, 254 (1956).
60. S. Hoffmann and E. Muhle, Z. chem., 419 (1968).
61. F. Bohlmann and D. Rahtz, Chem. Ber., 90, 2265 (1957).
62. K. B. Bowden and E. R. H. Jones, J. Chem. Soc., 953 (1946).
63. C. H. Mullen and C. J. M. Stirling, J. Chem. Soc. (C), 1221 (1966).
64. W. Parker and R. Raphael, J. Chem. Soc., 3871 (1958).
65. G. N. Bondarev and A. A. Petrov, Zhur. Org. Khim., 4, 27 (1968).
66. G. Dupont, Bull. Soc. chim. France, 41, 1167 (1927).
67. J. Ballet, Bull. Soc. chim. France, 41, 1170 (1927).
68. E. I. Titova, L. D. Gavrilov, R. L. Bol'shedvorskaya, and L. I. Vereshchagin, Zhur. Org. Khim., 5, 2113 (1969).
69. R. E. Lutz, T. Amacker, and S. M. King, J. Org. Chem., 15, 181 (1950).
70. J. Chauvelier, Ann. Chim., [12], 3, 393 (1948).
71. P. F. Gaudemar-Bardone, Ann. Chim., [13], 3, 52 (1958).
72. J. Chauvelier, Bull. Soc. chim. France, 734 (1954).
73. J. Chauvelier, Compt. rend., 224, 476 (1947).
74. J. Chauvelier, Compt. rend., 226, 677 (1948).
75. J. Chauvelier, Compt. rend., 226, 927 (1948).
76. Ch. Prevost and J. Chauvelier, Compt. rend., 224, 1232 (1947).
77. J. Chauvelier and F. Bardone, Bull. Soc. chim. France, 386 (1952).
78. J. Chauvelier, Bull. Soc. chim. France, 1721 (1966).
79. J. Chauvelier, Compt. rend., 212, 793 (1941); Chem. Abs., 37, 2376 (1943).
80. T. Metler, A. Uchida, and S. I. Miller, Tetrahedron, 24, 4285 (1968).
81. J. Chauvelier and P. Lacombe, Compt. rend., 230, 2210 (1950).

82. J. Chauvelier and M. Eugene, Bull. Soc. chim. France, 272 (1950).
83. L. I. Vereshchagin, R. L. Bol'shedvorskaya, and L. L. Okhapkina, Zhur. Org. Khim., 6, 32 (1970).
84. I. Kichida, T. Hiraoka, and M. Yoshimoto, Chem. Pharm. Bull. (Tokyo), 17 (10), 2126 (1969).
85. I. I. Lapkin and Yu. S. Andreichikov, Izv. Vys. Ucheb. Zaved., Khim. i Khim. Tekhnol., 9 (1), 157 (1966).
86. I. I. Lapkin and Yu. S. Andreichikov, Zhur. Org. Khim., 1, 1212 (1965).
87. I. I. Lapkin and Yu. S. Andreichikov, Zhur. Org. Khim., 2, 388 (1966).
88. E. R. H. Jones, T. Y. Shen, and M. C. Whiting, J. Chem. Soc., 236 (1950).
89. M. F. Shostakovskii, N. V. Komarov, and V. B. Pukhnarevich, Zhur. Obshch. Khim., 38, 1172 (1968).
90. J. Bonnema, H. J. Alkema, and J. F. Arens, Rec. Trav. chim., 79, 937 (1960).
91. J. Bonnema and J. F. Arens, Rec. Trav. chim., 79, 1137 (1960).
92. H. J. Gais, K. Hafner, and M. Neuenschwander, Helv. chim. Acta, 52, 2641 (1969).
93. L. I. Vereshchagin, S. R. Gainulina, L. P. Kirillova, and T. V. Lipovich, Zhur. Org. Khim., 5, 1557 (1969).
94. C. J. Cavallito, J. Amer. Chem. Soc., 77, 4159 (1955).
95. G. Ficher, Z. Chem., 269 (1968).
96. L. I. Vereshchagin, S. P. Korshunov, V. I. Skoblikova, and T. V. Lipovich, Zhur. Org. Khim., 1, 1089 (1965).
97. K. M. Johnston and R. G. Shotter, J. Chem. Soc., 1774 (1968).
98. K. Schlöegl and A. Mohar, Monatsh., 93, 861 (1962).
99. I. I. Lapkin and B. S. Andreichikov, Zhur. Org. Khim., 2, 2075 (1966).
100. D. Nightingale and F. Wadsworth, J. Amer. Chem. Soc., 67, 416 (1945).
101. H. Reimlinger and J. M. Vandewalle, Annalen, 720, 117 (1969).
102. G. Coispeau and J. Elguero, Bull. Soc. chim. France, 2717 (1970).
103. L. I. Vereshchagin, S. R. Gainulina, R. L. Bol'shedvorskaya, and L. P. Kirillova, Izd. Vys. Ucheb. Zaved, Khim. i Khim. Tekhnol., 12, 1527 (1969).
104. M. F. Shostakovskii, N. V. Komarov, V. B. Pukhnarevich, and O. G. Yarosh, Zhur. Obshch. Khim., 38, 2303 (1968).
105. R. E. Rosenkranz, K. Allner, and R. Good, Helv. Chim. Acta, 46, 1259 (1963).
106. French P. 1 522 696 (1968); Chem. Abs., 71, 81 405b (1969).
107. G. P. Kugatova-Shemyakina and V. Vidugiriene, Zhur. Org. Khim., 2, 682 (1966).
108. C. L. Bickel, J. Amer. Chem. Soc., 69, 73 (1947).
109. C. Mour·u and M. Brachin, Bull. Soc. chim. France, 33, 131 (1905).
110. C. Moureu and R. Delange, Compt. rend., 130, 1259 (1900).
111. E. I. Titova, L. D. Gavrilov, T. V. Lipovich, and L. I. Vereshchagin, Zhur. Org. Khim., 7, 903 (1971).
112. W. E. Truce and R. F. Heine, J. Amer. Chem. Soc., 79, 5311 (1957).
113. P. E. Eaton and C. E. Stubbs, J. Amer. Chem. Soc., 89, 5722 (1967).
114. R. Celin and D. Makula, Bull. Soc. chim. France, 2347 (1966).
115. E. P. Kohler and I. P. Barrett, J. Amer. Chem. Soc., 46, 748 (1924).
116. G. D. Appleyard and C. J. M. Stirling, J. Chem. Soc. (C), 2686 (1967).
117. Okajima Yakutaro, J. Pharm. Soc. Japan, 80, 318 (1960).
118. J. Gosselck and E. Wolters, Naturforsch., 17b, 131 (1962); Chem. Abs., 57, 4582e (1962).
119. A. N. Pudovik and O. S. Durova, Zhur. Obshch. Khim., 36, 1460 (1966).
120. A. N. Pudovik and O. S. Shulyndina, Zhur. Obshch. Khim., 38, 2074 (1968).
121. A. N. Nesmeyanova and M. I. Rybinskaya, Dokl. Akad. Nauk SSSR, 158, 408 (1964).
122. A. N. Nesmeyanova and M. I. Rybinskaya, Zhur. Org. Khim., 2, 2081 (1966).
123. U. Turck and H. Behringer, Chem. Ber., 98, 3020 (1965).
124. G. Stork and M. Tomasz, J. Amer. Chem. Soc., 86, 471 (1964).
125. C. Moureu and R. Delange, Bull. Soc. chim. France, [3], 25, 303 (1901).
126. C. L. Bickel and A. J. Fabens, J. Amer. Chem. Soc., 71, 1450 (1949).
127. G. P. Kugatova-Shemyakina and V. I. Vidugiriene, Zhur. Org. Khim., 2, 851 (1966).
128. P. F. Gaudemar-Bardone, Ann. chim., [13], 3, 52 (1958).
129. D. S. Noyce, M. A. Matesich, and P. E. Peterson, J. Amer. Chem. Soc., 89, 6225 (1967).
130. D. S. Noyce and M. J. Jorgenson, J. Amer. Chem. Soc., 83, 2525 (1961).
131. D. S. Noyce and W. L. Reed, J. Amer. Chem. Soc., 80, 5539 (1958).
132. R. P. Bell, J. Preston, and R. B. Whitney, J. Chem. Soc., 1166 (1962).
133. D. S. Noyce and K. E. Debruin, J. Amer. Chem. Soc., 90, 372 (1968).
134. F. Bardone, Compt. rend., 238, 1716 (1954).
135. E. P. Kohler, J. Amer. Chem. Soc., 44, 379 (1922).
136. R. M. Anker and A. H. Cook, J. Amer. Chem. Soc., 311 (1945).
137. J. C. Bardhan, J. Amer. Chem. Soc., 2223 (1929).
138. L. I. Smith and R. E. Kelly, J. Amer. Chem. Soc., 74, 3305 (1952).
139. S. P. Korshunov, L. I. Vereshchagin, G. N. Bugrova, and L. L. Okhipkina, Zhur. Org. Khim., 1, 2212 (1965).
140. K. Buggle, G. P. Hughes, and E. M. Philbin, Chem. a. Ind., 77 (1969).
141. A. W. Johnson, J. Chem. Soc., 1626 (1947).
142. Taddashi Sasaki and Yasushi Suzuki, Tetrahedron Letters, 3137 (1967).
143. N. K. Kochetkov, Tetrahedron Letters, Akad. Nauk SSSR, Otd. Khim. Nauk, 991 (1953).
144. C. Barat, J. Indian. Chem. Soc., 7, 321 (1930).
145. T. Eicher and A. Hansen, Tetrahedron Letters, 1169 (1967).
146. G. P. Kugatova-Shemyakina and V. I. Vidugiriene, Zhur. Org. Khim., 2, 685 (1966).
147. R. B. Woodward and T. Singh, J. Amer. Chem. Soc., 72, 494 (1950).
148. A. G. Hortmann, J. Amer. Chem. Soc., 87, 4972 (1965).
149. A. A. Petrov, Zhur. Obshch. Khim., 17, 497 (1947).
150. K. B. Bowden and E. R. H. Jones, J. Chem. Soc., 52 (1946).
151. E. A. Braude, E. R. H. Jones, F. Sondheimer, and J. B. Toogood, J. Chem. Soc., 607 (1949).

152. A. A. Petrov and N. P. Sopov, Zhur. Obshch. Khim., 17, 1295 (1947).
153. R. N. Engibaryan and V. O. Babayan, Zhur. Org. Khim., 5, 1548 (1969).
154. G. N. Bondarev and A. A. Petrov, Zhur. Org. Khim., 2, 1005 (1966).
155. A. A. Petrov and N. P. Sopov, Zhur. Obshch. Khim., 23, 1034 (1953).
156. J. G. Dinwiddie and S. P. Manus, J. Org. Chem., 28, 2416 (1963).
157. F. Irving and A. W. Johnson, J Chem. Soc., 2037 (1948).
158. J. Sauer, H. Wiest, and A. Mielert, Chem. Ber., 97, 3183 (1964).
159. W. Ried and D. Freitag, Chem. Ber., 99, 2675 (1966).
160. S. Goldschmidt and A. Zoebelein, Chem. Ber., 94, 169 (1961).
161. V. B. Pukhnarevich, L. N. Maksyuta, N. V. Komarov, and G. R. Lapgvagen, Zhur. Obshch. Khim., 39, 823 (1969).
162. G. Manecke and H. U. Schenck, Tetrahedron Letters, 2061 (1968).
163. G. Manecke and H. U. Schenck, Tetrahedron Letters, 617 (1969).
164. K. Auwers and O. Ungemach, Ber., 66B, 1198 (1933).
165. C. Dumont, J. Naire, and M. Vidal, Compt. rend., C268, 348 (1969).
166. J. Bastide and J. Lematre, Compt. rend., C268, 532 (1969).
167. J. Bastide, J. Lematre, and J. Soulier, Compt. rend., C266, 1393 (1968).
168. H. Reimlinger, J. M. Vandewalle, and A. Overstaeten, Annalen, 720, 124 (1969).
169. H. Reimlinger, Chem. Ber., 93, 1857 (1960).
170. G. N. Bondarev, V. A. Ryzhov, V. N. Chistokletov, and A. A. Petrov, Zhur. Org. Khim., 3, 821 (1967).
171. V. A. Tartakovskii, O. A. Lik'yanov, and S. S. Novikov, Dokl. Akad. Nauk SSSR, 178, 123 (1968).
172. E. P. Kohler, J. Amer. Chem. Soc., 31, 642 (1904).
173. P. G. Stewens, J. Amer. Chem. Soc., 57, 1112 (1935).
174. H. O. House and H. W. Thompson, J. Org. Chem., 28, 360 (1963).
175. L. D. Bergel'son, Symposium, "Reaktsii i Metody Issledovaniya Organicheskikh Soedinenii" (Reactions and Methods of Investigation of Organic Compounds), Goskhimizdat, 1956, Vol. 4, p. 41.
176. E. P. Kohler, J. Amer. Chem. Soc., 38, 511 (1907).
177. R. C. Fuson, G. U. Ullyot, and J. L. Huckson, J. Amer. Chem. Soc., 61, 410 (1939).
178. I. A. Favorskaya, A. A. Nikitina, and E. G. Rumyantseva, Zhur. Org. Khim., 3, 1402 (1967).
179. J. Gore and M. Roumestant, Tetrahedron Letters, 1303 (1970).
180. M. Batkibekova, N. V. Zotchik, and I. A. Rubtsov, Symposium, "Biorogicheskie Aktivnye Soedineniya (Zhur. Obshch. Khim.)" [Biologically Active Compounds (General and General Chemistry)], Izd. Nauka, Leningrad, 1968.
181. D. Plouin, S. Jacquet, and R. Glenat, Compt. rend., C268, 190 (1969).
182. M. S. Shostakotskii, N. V. Komarov, V. B. Pukhnarevich, and O. G. Yarosh, Zhur. Obshch. Khim., 38, 2303 (1968).
183. R. C. Fuson and J. Meek, J. Org. Chem., 10, 551 (1945).
184. R. E. Lutz, J. Org. Chem., 28, 711 (1963).
185. K. E. Schulte, J. Reisch, and O. Heine, Arch. Pharm., 294, 234 (1961).
186. R. H. Wiley and C. E. Staples, J. Org. Chem., 28, 3408 (1963).
187. T. F. Rutledge, "Acetylenic Compounds", Reinhold Book Corporation, New York–Amsterdam–London, 1968, Vol. I, p. 5.
188. M. S. Shvartsberg, A. N. Kozhevkina, and I. L. Kotnyrevskii, Izv. Akad. Nauk SSSR, Ser. Khim., 466 (1967).
189. D. I. Mikhailovskii, V. N. Rozhkova, and T. A. Favorskaya, Zhur. Org. Khim., 6, 397 (1970).
190. Kazunari Iwai and Haruo Yura, Japanese P. 11 511 (1960); Chem. Abs., 55, 457 (1961).
191. J. Reisch and H. Walker, Arch. Pharm., 297, 628 (1964).
192. A. N. Nesmeyanov and N. K. Kochetkov, Izv. Akad. Nauk SSSR, 3, 305 (1949).
193. M. S. Newman, J. Org. Chem., 31, 3861 (1966).
194. BRD P. 1 249 854 (1967); Chem. Abs., 68, 68716X (1968).
195. F. Bohlmann and E. Bresinsky, Chem. Ber., 100, 107 (1967).
196. I. Castells, R. Roser, and J. Soler, Am. Quim., 65, 673 (1969).
197. D. Nightingale and R. A. Carpenter, J. Amer. Chem. Soc., 71, 3560 (1949).
198. T. Bacchetti, A. Alemagna, and B. Danieli, Tetrahedron Letters, 2001 (1965).
199. S. A. Giller, L. I. Vereshchagin, K. K. Venter, S. P. Korshunov, V. V. Tsirule, and D. O. Lolya, Dokl. Akad. Nauk SSSR, 164, 99 (1965).
200. L. I. Vereshchagin, R. L. Bol'shedvorskaya, E. N. Sokolovskaya, and L. D. Gavrilov, Izd. Vys. Ucheb. Zaved., Khim. i Khim. Tekhnol., 13, 214 (1970).
201. L. I. Vereshchagin, S. P. Korshunov, R. I. Katkevich, and O. G. Yashina, Khim. Geterosikl. Soed., 177 (1968).

Institute of Petrochemical
and Cold-chemical Synthesis,
Zhdanov State University,
Angarsk