265. E. Booth, V.C.E. Burnop, and W.E. Jones, J. Chem. Soc., 666 (1944).
266. D. Goldschmith and M. Tishler, J. Amer. Chem. Soc., 68, 144 (1946).
267. A. Emr, Chem. Listy, 42, 6 (1948).
268. G. Barger and T.E. Weichselbaum, Biochem. J., 25, 997 (1931).
269. H. Plieninger, Ber., 83, 265 (1950).
270. H.R. Snyder, J.H. Andreen, G.W. Cannon, and C.F. Peters, J. Amer. Chem. Soc., 64, 2082 (1942).
271. H.R. Snyder and G.W. Cannon, J. Amer. Chem. Soc., 66, 511 (1944).
272. E.M. Hill and W. Robson, Biochem. J., 30, 248 (1936).
273. J.E. Livak, E.C. Briton, J.C. van der Weele, and M.F. Murray, J. Amer. Chem. Soc., 67, 2218 (1945).
274. H.E. Baumgarten, J.E. Dirks, J.M. Petersen, and R.L. Ley, J. Org. Chem., 31, 3708 (1966).
275. USSR P. 181556; Izobret., Prom. Obraztsy Tovar. Znaki, No. 9, 166 (1966).
276. H. Kawashima, T. Takami, and I. Iamada, Nippon Kagaku Zasshi, 86, 1190 (1965).
277. USSR P. 186496; Izobret., Prom. Obraztsy Tovar. Znaki. No. 19, 36 (1966).
278. French P. 1406157 (1965); Chem. Abs., 63, 18259 (1965).

Institute of Organic-Inorganic
("Organoelemental") Compounds, USSR
Academy of Sciences, Moscow

U.D.C. 546.263

CARBON SUBOXIDE IN ORGANIC SYNTHESIS

L.B. Dashkevich and V.G. Beilin

CONTENTS

I. Introduction 391
II. The structure and physicochemical properties of carbon suboxide 391
III. Methods of preparation 392
IV. Chemical properties of carbon suboxide 393

I. INTRODUCTION

Carbon suboxide C_3O_2 (dioxoallene, dioxopropadiene), discovered by Diels in 1906, is a very unusual compound with four cumulative double bonds. The first investigations of Diels and coworkers [1] showed that it should be regarded as an internal dianhydride of malonic acid. Like methylene, carbon suboxide should be included, in principle, among the few "key compounds", and the study of its chemical properties will undoubtedly lead to the discovery of new and specific methods of organic synthesis.

Although carbon suboxide was actually discovered before keten, it has been much less investigated. Nevertheless malonic addition reactions occupy a fairly important position in practical organic chemistry. The malonyl radical is known to be incorporated in many biologically active compounds: barbiturates, pyrazolidinediones, substituted esters and amides of malonic acid, etc.

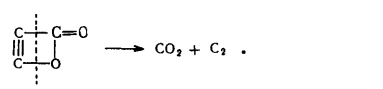
Nowadays, in the practical application of malonic addition reactions malonic acid, diethyl malonate, and malonyl dichloride are used. Compared with these compounds, carbon suboxide has a number of advantages, which consist in high yields of the desired products, their relative purity, and in the specificity of the reactions which take place only when carbon suboxide is used.

There exists no general review of the literature in which the reactivity of carbon suboxide with respect to various classes of chemical compounds is considered systematically. Grauer's review [2] published in 1960 covers the literature up to 1956 only and is far from complete. Of the earlier work, one may mention the paper of Vol'kenshtein [3], who more than thirty years ago drew attention to the promising possible applications of carbon suboxide. Recently carbon suboxide has been increasingly attracting the attention of investigators both in the Soviet Union and abroad.

The aim of the present article is to describe the present state of the chemistry of carbon suboxide, a knowledge of which may prove of interest to chemists working in the field of organic synthesis.

II. THE STRUCTURE AND PHYSICOCHEMICAL PROPERTIES OF CARBON SUBOXIDE

Until comparatively recently the structure of the C_3O_2 molecule remained controversial, which was to a large extent due to the difficulty of obtaining sufficiently pure carbon suboxide. Diels proposed the linear structure of 1,3-dioxopropadiene for carbon suboxide [1]. Most of the investigators working with carbon suboxide support this view, mainly on the basis of the methods of preparation of carbon suboxide — from malonic acid and its derivatives. Hypotheses have also been put forward that carbon suboxide can exist as the lactone of β-hydroxypropiolic acid [4]. Attempts were made to confirm this structure by the value of the dipole moment allegedly found for carbon suboxide [5], and also by its thermal decomposition to C_2 and CO_2: [6]



These views are in conflict with the molar refraction and molar dispersion of carbon suboxide [7,8].

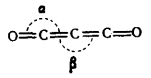
Numerous electron diffraction [9-12] and spectroscopic studies in the last decades established that carbon suboxide has an acyclic structure [13]. Infrared and Raman spectra [13-22] and also its ultraviolet spectra [23] have been investigated. The interatomic distances and the valence angles in the suboxide molecules were calculated from these data:

C=C	C=O
1.28±0.15Å	1.16±0.015Å

Thus the C=C bond in carbon suboxide is shorter than in alkenes (1.34 Å) and in keten (1.32 Å). [24] The length of the C=O bond is close to the interatomic distance in the carbonyl group of keten (1.17 Å) and in chloro- and fluoro-carbonyl compounds (1.18 and 1.17 Å), [25,26] but differs significantly from the length in aliphatic ketones (1.22–1.24 Å). [26]

Vol'kenshtein [27], who explained this shortening of the interatomic distance by the pronounced displacement of the electron cloud towards the oxygen atoms, suggested that the C_3O_2 molecule be represented thus: O=C=C=C=O.

While the interatomic distance data can be regarded as adequately reliable, the problem of the steric disposition of the atoms in carbon suboxide remained controversial until very recently. The following values have been calculated for the valence angles:



180±10°	180±10°	[11]
180°	158°	[14]
180°	180°	[15]

Data suggesting the presence of a dipole moment in carbon suboxide [5] and also calculations of the force constants of the molecule [28,29] suggested a zigzag structure (symmetry group C_{2h}). However, the study of the infrared spectra of carbon suboxide in various states of aggregation [18] and also the study of their fine structure [18,20,22] indicate a linear structure for the C_3O_2 molecule (point symmetry group $D_{\infty h}$). Earlier data [5], indicating a dipole moment of 0.7 D in carbon suboxide, were probably obtained in consequence of the presence of an admixture of keten [12,30].

Some of the physicochemical characteristics of carbon suboxide are as follows. At the normal temperature carbon suboxide is a gas with a sharp specific smell.

B.p. + 6.8°C (Refs. 31,32); m.p. −107°C (Ref. 33)
−108°C (Ref. 34)
−111.3°C (Ref. 35)
−112.5°C (Ref. 36)
Vapour pressure at 0° 567–568 mmHg (Ref. 31)

$n_D^0 = 1.45538$ (Ref. 7).

There are no reliable data in the literature on the heat of formation of carbon suboxide. The following values may be quoted

$\Delta H_f(C_3O_2)$ = 47.7 kcal mole^{-1} (Ref. 37)
55.0 kcal mole^{-1} (Refs. 38,39)
18.0 kcal mole^{-1} (Ref. 4)
8 ± 5 kcal mole^{-1} (Ref. 40)
Dissociation energy D_0 = 635.234 kcal mole^{-1} (Ref. 40)
Molar heat of combustion of C_3O_2 = 234.6 kcal mole^{-1} (Ref. 37), 300 kcal mole^{-1} (Ref. 6).

Tables of the thermodynamic functions of carbon suboxide at temperatures up to 2000°K [22] and 6000°K [40] have been set up.

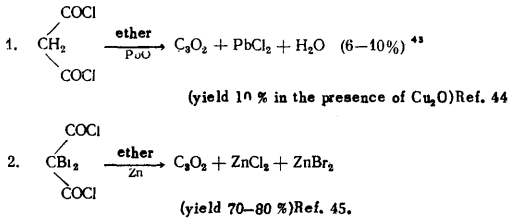
Carbon suboxide is soluble in the majority of organic solvents. Ethyl ether, tetrahydrofuran, and dioxan are especially often used in practice. It is a very toxic compound. Even at low concentrations it acts as a powerful lachrymator and at high concentrations causes asphyxiation. It has been established that carbon suboxide is a powerful blood poison (its effect on haemoglobin is analogous to that of carbon monoxide). The maximum permissible concentration of carbon suboxide in a dry atmosphere is 0.2–0.4%. [41]

III. METHODS OF PREPARATION

A fairly large number of reactions are known in which the formation of carbon suboxides is observed. However, only some of them are of practical importance. All the known methods can be arbitrarily divided into two groups. (a) preparations based on malonic acid and its derivatives (the structure of the carbon skeleton is retained in the process); (b) pyrolysis of β-dicarbonyl compounds which involves degradation of the carbon skeleton.

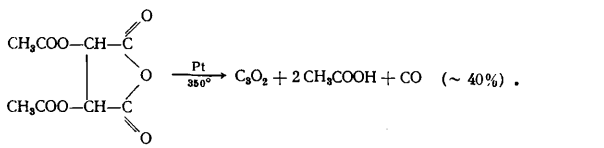
a. Diels was the first to obtain carbon suboxide on heating diethyl malonate with phosphorus pentoxide [1]. Subsequently the ester was replaced by malonic acid itself. In the latter case the yield of carbon suboxide amounted to 18–20% after a number of improvements [7,33,42]. The maximum yield of carbon suboxide from diethyl malonate was obtained by Korshak and coworkers (30–37%). [34]

Staudinger proposed two methods for the synthesis of carbon suboxide:



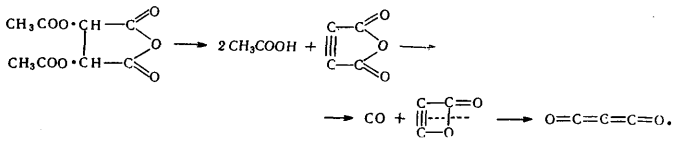
So far an 80% yield of carbon suboxide has been obtained only by the second method. However, an important disadvantage of this method is that carbon suboxide is not obtained in a free form but in ethereal solution. This restricts the scope of the method. Furthermore, the synthesis of the starting materials is relatively complex and very time-consuming. Another disadvantage of this entire group of methods for the synthesis of carbon suboxide is that malonic acid and its derivatives are used as the starting materials, and they themselves are capable of "malonylation". For this reason, the second group of reactions is of considerable interest.

b. The most practical method for the preparation of carbon suboxide proved to be the pyrolysis of the anhydride of diacetyltartaric acid, proposed by Ott and Schmidt [46]:



Subsequently Hurd and Pilgrim showed that the high-temperature non-catalytic pyrolysis of the anhydride leads to approximately the same results (quartz tube, 750°). [47]

The following mechanism has been proposed for the synthesis of carbon suboxide from the anhydride of diacetyltartaric acid:



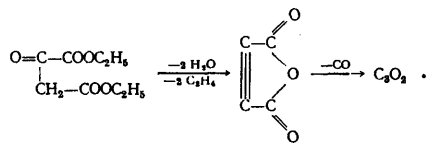
This mechanism of the pyrolysis is confirmed by the formation of carbon suboxide in the pyrolysis of acetylenedicarboxylic acid under analogous conditions [48] and also by the absence of radioactivity from the carbon suboxide obtained from the anhydride of acetyltartaric acid labelled with ^{14}C in the acetyl groups [48,49].

The technique of the pyrolysis has undergone various modifications. For example, it has been suggested that sand be used instead of mercury to force the acetyltartaric acid anhydride melt from the burette into the pyrolysis tube [50]. Later it was shown that it is more convenient to use the anhydride of diacetyltartaric acid in acetic anhydride [48].

Various data have been quoted for the temperature conditions of the pyrolysis and the yields: 625–650°C (40–49%);[47] 570–600°C (41%);[51] 700–725°C (40%);[48] 700–750°C (43–46%).[52]

A large number of dicarbonyl compounds have been pyrolysed in connection with research into new reactions involving the formation of carbon suboxide. Carbon suboxide forms in the pyrolysis of lactic acids, succinic acid derivatives, acetylenedicarboxylic acid and its esters, certain β-keto-esters, etc.[48,53,54] Among the reactions investigated, only the pyrolysis of diethyl oxaloacetate (yield 48%)[48] is of practical importance.

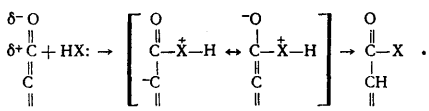
In the pyrolysis of diethyl [4-^{14}C]oxaloacetate it proved possible for the first time to obtain carbon suboxide labelled with ^{14}C. The molecular radioactivity (MR) of carbon suboxide was found to be smaller by a factor of two than that of the initial diethyl oxaloacetate. This shows that the 1-^{12}C and 4-^{14}C atoms of the carbon skeleton of oxaloacetic acid participate in the decarboxylation to an equal extent. This finding suggests that the process proceeds similarly to the pyrolysis of the anhydride of diacetyltartaric acid[48]:



The formation of carbon suboxide has also been observed on passing a weak electric discharge through carbon monoxide[56] or a mixture of carbon monoxide and carbon dioxide[57] in an ozoniser ($4CO \rightarrow C_3O_2 + CO_2$) and on irradiating a mixture of carbon monoxide and carbon dioxide with ultraviolet light[57].

IV. CHEMICAL PROPERTIES OF CARBON SUBOXIDE

The first investigators of carbon suboxide already noted its unsaturated character and tendency towards addition reactions. At the present time the most thoroughly investigated reactions of carbon suboxide are those with various nucleophilic reagents: amines, alcohols, mercaptans, etc. It must be supposed that in this case the addition begins with the penetration of the unshared electron pair of the nucleophilic reagent into the electron gap of the extreme carbon atom of carbon suboxide:



The proton can add either to the oxygen or the carbon atom. In the first case the unstable enol isomerises to the carbonyl form. The fact that addition to oxygen is possible is confirmed, for example, by the participation of carbon suboxide in organometallic synthesis[60].

While the mechanism of addition to ketones has been frequently discussed in the literature[58,59], the same process involving carbon suboxide has been almost entirely neglected[60]. There is hardly any point in considering the problem of whether addition takes place at the carbonyl or ethylene bond, since the extreme carbon atom of carbon suboxide is simultaneously a carbonyl and an ethylenic atom. In any case, it is the atom subject to primary nucleophilic attack.

1. Reactions with Hydroxy- and Mercapto-Compounds

Carbon suboxide reacts with water and alcohols, forming malonic acid and its esters respectively:

$$2\,ROH + O{=}C{=}C{=}C{=}O \rightarrow ROCOCH_2COOR\ .$$

At room temperature the reaction of carbon suboxide with water is fairly slow but is accelerated at 60–70°C in the presence of catalytic amounts of hydrochloric acid. The yield of malonic acid is quantitative[61]. This reaction has been used to prepare 4-D-malonic acid. On carrying out the reaction of carbon suboxide with deuterium oxide in solution in benzene[62] or carbon tetrachloride[63], deuteriated malonic acid was obtained. On the other hand, when the reaction was carried out in deuterium oxide at 50°C, the final product was only deuteriated acetic acid[64].

Methyl and ethyl alcohols react with carbon suboxide even at room temperature. Starting with propyl alcohol, heat and catalysts are required[61]. Phenol reacts only in the presence of catalysts[61,65]. Nitro-alcohols can be "malonylated" with the aid of carbon suboxide only when aluminium chloride is used as the catalyst[50]. Reactions of carbon suboxide with hydroxylamine and oximes, involving the mechanism common to hydroxy-compounds, have been described[47,66].

In the reaction with hydroxy-compounds acid catalysts were mainly used: sulphuric acid, *p*-toluenesulphonic acid[65], and hydrogen chloride[61]; their role probably consists in the additional polarisation of the carbonyl group of carbon suboxide and hence in an increase of the electrophilicity of the carbonyl carbon:

$$=C{=}C{=}\overset{\curvearrowright}{O} + H^+ \longrightarrow =C{=}\overset{+}{C}{-}OH\ .$$

The effect of basic catalysis on addition reactions of carbon suboxide has not been considered, although some experiments on those lines have been performed. Hegar[51] carried out the reaction of carbon suboxide with aqueous solutions of phenol and butanol in the pH range 1–14 at 0°C. Under these conditions he obtained exclusively the phenyl ester of malonic acid, the maximum yield occurring at pH 11. It has recently been established that in the reaction of carbon suboxide with alcohols the corresponding alkoxides are good catalysts. The yield of malonate esters is then nearly quantitative[67]. We believe that both these findings confirm the applicability of basic catalysis to reactions of carbon suboxide with weak nucleophilic reagents, in which there is a possibility of the formation of an anion with much more pronounced nucleophilic properties.

With diols carbon suboxide forms polyesters, the molecular weight of which is several thousands[34,52]. Carbon suboxide reacts fairly readily with formic and acetic acids, mixed anhydrides of malonic acid being formed[42]. The reaction of carbon suboxide with anhydrous oxalic acid is accompanied by the evolution of carbon monoxide and dioxide and leads to the formation of the lactone of β-hydroxyisopropylmalonic acid, a solid product, whose structure has not been established, being produced with malonic acid[18,66].

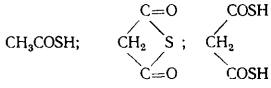
Mercaptans react with carbon suboxide under somewhat more severe conditions than do alcohols. The corresponding esters of dithiomalonic acid are formed[52]:

$$2\,RSH + O{=}C{=}C{=}C{=}O \longrightarrow RS{-}\overset{O}{\overset{\|}{C}}{-}CH_2{-}\overset{O}{\overset{\|}{C}}{-}SR\ .$$

However, when diethylaminoethanol and diethylaminoethanethiol are "malonylated" with the aid of carbon suboxide the

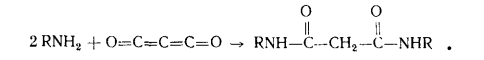
reaction takes place much more readily with the mercaptan[69]. These data are satisfactorily consistent with analogous work in the chemistry of keten[58] and also with work on the introduction of the malonyl acid group into proteins with the aid of carbon suboxide[70], which can probably be accounted for by the marked nucleophilic properties of the SH group[71].

Depending on the relative amounts of the reagents, the reaction of carbon disulphide with carbon suboxide gives rise to a number of compounds[68,72]:



2. Reactions with Primary Amines

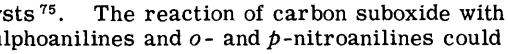
In consequence of their pronounced nucleophilic properties, amines react extremely readily with carbon suboxide:



This group of reactions of carbon suboxide has been investigated more thoroughly than others, which makes it possible to follow at least qualitatively the effect of the properties of the amine on its reactivity with respect to carbon suboxide. Since carbon suboxide is a Lewis acid and amines are bases, the reaction can be regarded as an acid–base process. Then the basicity of the amine can be regarded as a criterion of its reactivity. This makes it possible to estimate to some extent the effect of substituents in the amine on the course of the reaction[73].

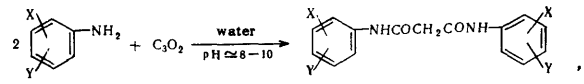
Unsubstituted primary amines. These react with carbon suboxide under mild conditions and with almost quantitative yields. The reaction is a rule performed in an indifferent solvent at the normal temperature or below 0°C. The reactions of carbon suboxide with acyclic, alicyclic, and aromatic amines have been investigated[74,75]. As was to be expected, the phenyl group lowers somewhat the rate of reaction, which, however, does not prevent the use of the reaction between carbon suboxide and aniline for the quantitative determination of the latter[48].

Substituted primary amines. Pauw[74] showed that the reaction of carbon suboxide with *o*-, *m*-, and *p*-alkylanilines, -halogenoanilines, and -alkoxyanilines results in high yields of the corresponding malonic acid diamides[76]. On introduction into the benzene ring of electrophilic substituents, the reduction of the basicity of the amine becomes so appreciable that, for example, *o*-, *m*-, and *p*-aminoacetophenones and aminobenzoic acid esters virtually do not react with carbon suboxide in the absence of catalysts[75]. The reaction of carbon suboxide with *o*- and *p*-sulphoanilines and *o*- and *p*-nitroanilines could not be achieved even on prolonged heating and in the presence of various catalysts[74,77]. In the series of C-substituted aliphatic amines, reactions of carbon suboxide with β-substituted ethylamines[78], βγ-halogenopropylamines[79], and amino-acids and their esters[74,78,80,81,82] have been carried out:



where X = Cl, Br, OH, OR, SH, SR, ArC=O, COOR, COOH, C≡N, and CH_2=(allylamine).

The acylation of amines with carbon suboxide is as a rule performed in an organic solvent. However, as a result of the difference between the rates of the reactions of amines and water, it is in many cases possible to use water successfully as the reaction medium[77]:

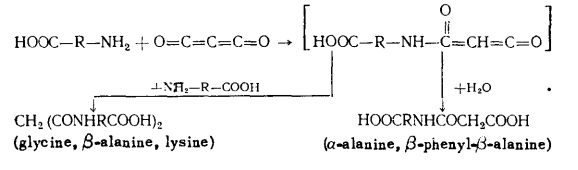


where

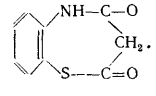
X	*o*-, *m*-, *p*-COOH	*o*-, *m*-, *p*-OH	*m*-, *p*-COOH
Y	H	H	*p*-, *m*-OH

The "malonylation" of halogenoalkylamines (β-chloroethylamine, etc.), which are unstable in the form of the free bases, takes place with high yields when the base is produced from the aqueous solution of its salt by adding alkali during the reaction[78].

Aliphatic amino-acids also readily react with carbon suboxide in aqueous media at pH 8–10.[78,80,81,82]. However, when α-alanine and β-phenylalanine were "malonylated", it proved possible to isolate from the reaction medium only the monoamides of malonic acid[73,78]. It should be noted that the formation of monoamides has been observed in the acylation of amino-acids in which the amino-group is linked to a secondary carbon atom. This course of the reaction may be associated with the fact that the presence of the substituent (methyl or phenyl) gives rise to steric hindrance to the reaction of the intermediate aldoketone with a second amino-acid molecule. As a result, the rates of the reactions with a second amino-acid molecule and water become comparable:



When the C-substituent of the amine is itself reactive with respect to carbon suboxide (OH, SH), it may be expected that the reaction will take place in several ways. However, whereas, as stated above, β-hydroxyethylamine and β-mercaptoethylamine, which are fairly strong bases, react with carbon suboxide via the amino-group, in reactions involving the "malonylation" of *o*-aminothiophenol, in which the basicity of the amino-group is greatly reduced, a cyclic addition product (2,3-benzo-1-thia-4-azacycloheptane-5,7-dione) is obtained[73,83]:



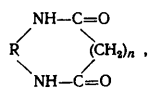
Secondary amines. As a result of their high basicity, it would seem that these should react with carbon suboxide fairly readily in accordance with the general mechanism. However, Pauw[74] failed to identify the products of the reaction of carbon suboxide with dimethyl- and diethyl-amines. Subsequently this reaction ceased to attract the attention of investigators. The reaction of carbon suboxide with secondary cyclic amines (cyclic imines) has been more widely investigated. Ethyleneimine reacts with carbon suboxide, giving *NN'*-malonylbisethyleneimine in good yield only in "absolute" ethyl ether between -60° and -70°C.[64] At higher temperatures there is a possibility of the formation of polymeric products[51]. It is noteworthy that attempts to "malonylate" ethyleneimine by the usual method (malonyl dichloride in the presence of triethylamine

in benzene) proved unsuccessful[85]. Higher polymethyleneimines, up to heptamethyleneimine inclusive, also react fairly readily with carbon suboxide; the yields of products range from 60% up to quantitative[84,86]. When the reaction is performed in the presence of water, there is a possibility of the formation of *N*-acetyl derivatives. Thus in the "malonylation" of ethyleneimine the formation of a product undergoing rapid decomposition, possibly *N*-acetylethyleneimine, was observed[51,73], the yield of *N*-acetylpiperidine being 82%.[86]

Substituted oxazolidines and thioazolidines react with carbon suboxide similarly[83,87]. The yields range from 50 to 80%, thiazolidine and 2,2-dimethylthiazolidine undergoing "malonylation" even in an aqueous medium. All these compounds are fairly strong bases ($pK_b < 10$). With still less basic amines ($pK_b > 10$), for example benzo-condensed heterocycles, the reaction is carried out in the presence of catalysts — sulphuric acid[51] and aluminium chloride[73,84]. Under these conditions 1,2,3,4-tetrahydroquinoline reacts with carbon suboxide fairly rapidly, the yield of products being 72%,[84] while without catalysts the yield of *NN'*-malonylbistetrahydroquinoline is only about 30% and the reaction takes several days[88]. Diethyl malonate also reacts in the presence of aluminium chloride but under more severe conditions. The product is 1,8-malonyl-1,2,3,4-tetrahydroquinoline[89].

Tertiary amines. Diels and Hansen[72] showed that quinoline, codeine, nicotine, and certain other heterocyclic compounds with a tertiary nitrogen atom react with carbon suboxide, forming coloured products of unknown structure. The powerful catalytic action of tertiary amines (particularly pyridine and triethylamine)[51] on the polymerisation of carbon suboxide has been frequently noted. Quaternary ammonium bases have a similar effect[51].

Diamines. In contrast to diols, these react with carbon suboxide, forming either linear polyamides or cyclic diamides, depending on the reaction conditions. When the reaction was carried out in ethereal solutions with gradual addition of carbon suboxide to the reaction mixture, cyclic addition products were obtained even with hexa- and deca-methylenediamines[74,90,91]:

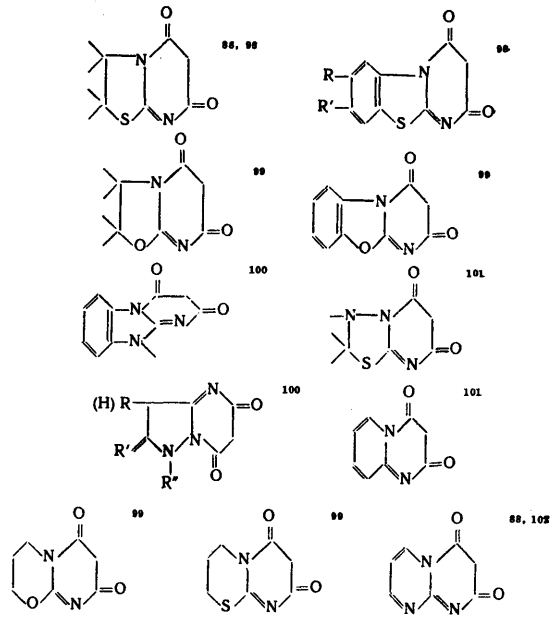


where R = $(CH_2)_n$ with n = 2–6 and 10. Under more severe conditions (heat, pressure), the products are polyamides[34,51]:

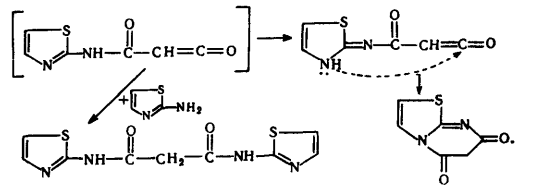
$$[-NH-RCOCH_2CO-]_n,$$

where R = $(CH_2)_6$ and $(CH_2)_{10}$.

Amino–imino tautomers. Recently the capacity of carbon suboxide to react with compounds capable of amino–imino tautomerism with formation of various heterocyclic systems condensed with 2,4-dioxopyrimidine has been attracting much attention. Syntheses of heterocyclic systems of this kind using malonic ester and malonyl dichloride have been described, but the reactions often require severe conditions[92–95]. In certain cases, when diethyl malonate is used as the "malonylating" agent, only linear acylation products were obtained[93], while carbon suboxide gives cyclic products, for example with 2-aminothiazole[88,96,97]. The study of the reaction of carbon suboxide with a number of amino–imino tautomers led to the synthesis of the following heterocyclic systems[88,98–102]:

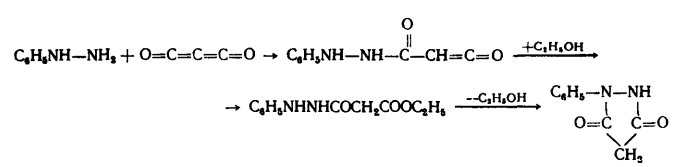


In the reaction involving the introduction of the malonyl group with carbon suboxide into certain amino–imino tautomers it was noted that the formation of cyclic products is accompanied by the formation of linear malonic acid diamides. Thus in the reaction of carbon suboxide with 2-aminothiazole the yields of the cyclic and acyclic products were 42.5 and 57.5% respectively[103]. Only the linear diamides were obtained in the reaction of carbon suboxide with 3-aminopyrazoles[100]. This course of the reaction can be satisfactorily explained by the different degrees of aromaticity of the initial heterocycles and hence their different capacities for isomerisation and cyclisation in the stage involving the formation of the intermediate aldoketen:



3. Reactions with Hydrazine and its Derivatives

The first studies on the reaction of carbon suboxide with hydrazines were performed by Van Alphen[90]. The aim was to prepare pyrazolidine-3,5-dione. However, with hydrazine itself, a polymeric product, probably of a linear structure, was obtained. Initially it was possible to obtain a cyclic addition product only with *N*-phenylhydrazine. The reaction proceeds through a stage involving the formation of *N*-malonylphenylhydrazine, the cyclisation of which yields 1-phenyl-3,5-dioxopyrazolidine. This mechanism of the reaction has been confirmed by other workers[91]:



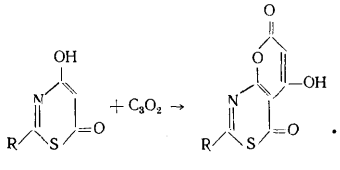
Later Van Alphen also obtained a series of 1,2-disubstituted 3,5-dioxopyrazolidines via carbon suboxide [104]. Reactions leading to the formation of 3,5-dioxopyrazolidines are also known for other "malonylating" agents (malonyl dichloride, diethyl malonate) [105,106], but yields are fairly low.

Reactions of carbon suboxide with substituted hydrazines [107,108] and hydrazobenzene [108] have been described comparatively recently. It has been stated that the reactions can take place without catalyst at temperatures close to 0°C. In the reaction of carbon suboxide with unsubstituted pyrazolidine cyclic addition of carbon suboxide with formation of 1,2-(3,5-dioxopyrazolidino)pyrazolidine also takes place [109].

4. Reactions with Amides and Diamides

It was believed that, in view of their greatly reduced basicity, amides are unreactive with respect to carbon suboxide. However, Ziegler [88] showed that the reactions of benzamide and 3,4-dimethylbenzamide with carbon suboxide on heating for several hours at 60–80° in tetrahydrofuran give bismalonyl derivatives in 65% yield. The reaction with the amides of thioacids takes place in a different way. In contrast to the usual amides, they react in the thiol form with formation of 2-substituted 4-hydroxy-1,3--thiazin-6-one. [88,110]

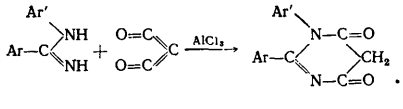
According to Ziegler, on heating with an excess of carbon monoxide, there is a possibility of further addition of carbon suboxide with formation of hydroxypyrone structures, which in turn can again combine with carbon suboxide:



Diamides (urea and thiourea) are acylated with carbon suboxide to barbituric and thiobarbituric acids. Van Alphen observed this only with the aid of qualitative reactions for barbituric acid [90], but after improvement of the method the yields reached 75–85% [91,110] and 56%. [91] *N*-Acetylthiourea reacts in the thiol form with formation of 2-acetyl-4-hydroxy--1,3-thiazin-6-one (yield 90%). [110]

5. Reactions with Amidines

The interaction of carbon suboxide with amidines in which the basicity of the NH groups is approximately the same (for example, with an *N*-arylbenzamidine) leads to the formation of high yields of 1,2-aryl-4,6-dioxotetrahydropyrimidines [111–114]:



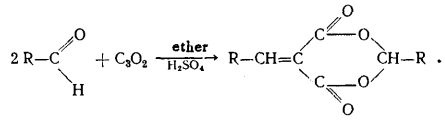
Unsubstituted amidines can react with carbon suboxide according to different mechanisms. Benzamidine reacts with carbon suboxide only via one amino-group, forming *NN'*-malonylbisbenzamidine, while *p*-toluamidine reacts via the amino- and imino-groups, yielding 2-(*p*-tolyl)--1,6-dioxotetrahydropyrimidine [112]. The use of malonyl dichloride [115] and dialkyl malonates [116,117] in these syntheses instead of carbon suboxide results in lower yields.

6. Reactions with Schiff Bases

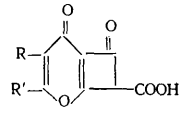
The study of these reactions was undertaken with the aim of preparing azetidine-2-ones containing an active keten grouping, which would make possible their use in the synthesis of biologically active substances with β-lactam rings. However, the reaction of carbon suboxide with benzylideneaniline takes place only under severe conditions (heating to 200°) which leads to the autocondensation of the intermediate aldoketen; only a complex compound with cyclobutane rings forms [118].

7. Reactions with Carbonyl Compounds

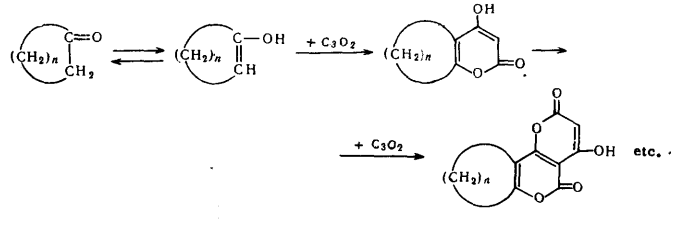
While keten readily reacts with aldehydes to form β-lactones [120], carbon suboxide behaves in a different way in reactions with aldehydes [51,119]. The reactions have been performed with benzaldehyde, *p*-toluic aldehyde, *p*-chlorobenzaldehyde, and cinnamaldehyde. In all cases high yields were obtained of the arylidene esters of substituted malonic acids, whose structure was demonstrated by synthesis and by infrared spectroscopy:



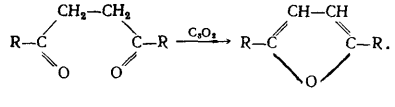
On reaction with carbon suboxide, β-diketones and β-keto-esters form compounds with the general formula [121]:



The probable mechanism of this reaction is the interaction of carbon suboxide with the enol form of the dicarbonyl compound and the subsequent addition of a second carbon suboxide molecule to the hydroxypyrone. A similar addition of carbon suboxide to cyclic ketones, which tend to enolise if only to a slight extent, has been described by Ziegler [88]. However, he also attributes the cyclopyrone structure to products of further addition of carbon suboxide:



Like keten [118], in reactions with γ-diketones carbon suboxide behaves as a dehydrating agent, which leads to the closure of the furan ring [51]:



8. Carbon Suboxide in the Friedel–Crafts Reaction

In the presence of equimolar amounts of anhydrous aluminium chloride carbon suboxide enters into the Friedel–Crafts reaction with benzene, naphthalene, and their homologues [122,123], with formation of aryl methyl ketones:

$$ArH + C_3O_2 \rightarrow [R{-}COCH{=}C{=}O] \xrightarrow[-CO_2]{+H_2O} Ar{-}\overset{\overset{O}{\|}}{C}{-}CH_3 .$$

Although it proved impossible to isolate the intermediate aldoketen, convincing proof of its existence has been secured. Without preliminary hydration, the reaction mixture with benzene was treated with aniline or absolute alcohol. Benzoylacetanilide and ethyl benzoylacetate were then isolated [124]:

$$\left[C_6H_5{-}\overset{\overset{O}{\|}}{C}{-}CH{=}C{=}O\right] \begin{array}{l} + C_6H_5NH_2 \rightarrow C_6H_5COCH_2CONHC_6H_5 \\ + C_2H_5OH \rightarrow C_6H_5COCH_2COOC_2H_5 . \end{array}$$

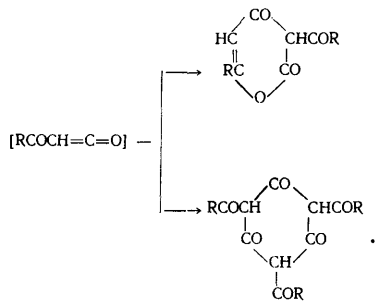
9. Reactions with Organometallic Compounds

The participation of carbon suboxide in organomagnesium [125-128] and organolithium [129] syntheses has been described. Depending on the reaction conditions and the relative amounts of the reactants, β-diketones [127,129] or methyl ketones [125,126,128] can be obtained:

1. $C_3O_2 + 2\,Mg\begin{matrix}R\\X\end{matrix} \rightarrow XMgO{-}\overset{R}{\underset{|}{C}}{=}C{=}\overset{R}{\underset{|}{C}}{-}OMgX \xrightarrow{2H_2O} R(OH)C{=}C(OH)R \rightarrow$
$\rightarrow RCCOCH_2COR$

2. $C_3O_2 + Mg\begin{matrix}R\\X\end{matrix} \rightarrow XMgO{-}\overset{R}{\underset{|}{C}}{=}C{=}C{=}O \xrightarrow[-CO_2]{H_2O} R{-}COCH_3 .$

It has been shown [125,126] that the intermediate aldoketen can react further by another mechanism with formation of cyclic dimers and trimers:



The capacity of carbon suboxide to enter into the Reformatskii reaction has been demonstrated by Dashkevich and Siraya [130]:

$$Zn + BrCH_2COOC_2H_5 + C_3O_2 \rightarrow C_2H_5OCOCH_2{-}C(ZnBr){=}C{=}C{=}O \xrightarrow{H_2O} \rightarrow C_2H_5OCOCH_2{-}COCH{=}C{=}O.$$

Since it proved impossible to isolate the aldoketen, the latter was hydrated, decarboxylated, and the acetoacetic ester obtained was subjected to ketone decomposition:

$$C_2H_5OCOCH_2COCH{=}C{=}O \xrightarrow{H_2O} C_2H_5OCOCH_2COCH_3 \rightarrow CH_3COCH_3 + CO_2 + C_2H_5OH.$$

Data on the reaction of carbon suboxide with sodium alkoxides in the corresponding alcohol [67] were presented above. It has been shown that, as the size of the alcohol radical increases, there is a corresponding increase in the amount of the sodium derivative of the dialkyl malonate formed:

$$RONa + C_3O_2 \rightarrow ROCOCNa{=}C{=}O \xrightarrow{HOR} ROCOCHNaCOOR,$$

where R = C_3H_7, C_4H_9, C_6H_{13}, C_7H_{15}, and C_8H_{17}. With ethyl and methyl alcohols, dialkyl malonates were obtained exclusively.

10. Reactions with Halides and Oxidation and Reduction of Carbon Suboxide

The addition of hydrogen halides to carbon suboxide results in the formation of malonyl halides [1]. From the reaction with ClBr in carbon tetrachloride the dichloride of dibromomalonic acid was isolated [124].

The oxidation and reduction of carbon suboxide have virtually not been investigated. In the attempt to reduce carbon suboxide with molecular hydrogen on nickel or palladium a mixture of products, consisting mainly of propene, together with acetic acid and small amounts of propane and water, was obtained [131] instead of the expected reduction products — propane-1,3-diol or propane.

According to the results of Staudinger, who studied the oxidation of ketens, carbon suboxide does not react with oxygen [132]. On cautious oxidation of carbon suboxide with a 2% solution of potassium permanganate, it proved possible to isolate a small amount of mesoxalic acid, which was identified via its phenylhydrazone [73]:

$$O{=}C{=}C{=}C{=}O \xrightarrow{2\%\ KMnO_4} \underset{OH}{\overset{O}{\|}}C{-}\underset{OH}{\overset{OH}{C}}{-}\overset{O}{\underset{\|}{C}} .$$

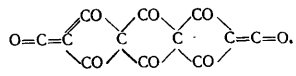
11. Polymerisation of Carbon Suboxide

The polymerisation of carbon suboxide was first observed by Diels [1]. The polymer which he described consisted of an amorphous powder whose colour ranged from dark red to black and which was readily soluble in water. Subsequently it has been frequently reported that the formation of the carbon suboxide polymer as a side-product accompanies all prolonged reactions of carbon suboxide, particularly at an elevated temperature and in the presence of catalysts.

Special experiments have also been made on the polymerisation of carbon suboxide. It has been shown that pure carbon suboxide is fairly stable (does not polymerise at 0° over a period of several weeks [51]), whereas the insufficiently purified compound polymerises over a period of only several hours. The effect of various catalysts on the rate of polymerisation has been studied. Organic bases (pyridine, triethylamine, quaternary ammonium bases), sulphuric acid, aluminium chloride, boron trifluoride [51,52], and phosphorus pentoxide [1,66] have been tested. When catalysts are added to liquid carbon suboxide, the polymerisation takes place vigorously, often with explosion; in a solvent the reaction takes place smoothly and gradually. Pyridine and triethylamine proved to be the best catalysts [51]. The polymer is also obtained in good yield (80%) when solutions of carbon suboxide in halogen-containing solvents are γ-irradiated [133].

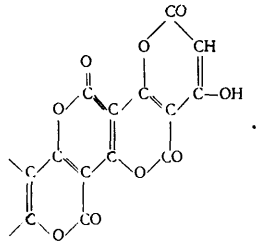
The problem of the structure of the carbon suboxide polymer has been the subject of lively discussion from the

moment of its discovery until the present time. Diels suggested that the red carbon suboxide polymer has a polycyclobutanedione structure[68]:



(I)

Later investigations of Schmidt and coworkers established that the polymer molecule includes also five- and six-membered lactone rings[134]. Ziegler suggested a poly-α-pyrone structure for the polymer[135]:



(II)

On the basis of the study of the infrared spectra of the polymer and its methyl ether, Hegar[51] rejects both structures (I) and (II), noting also that none of the polymers obtained had the composition $[C_3O_2]_x$. However, Blake and coworkers[136-138], who investigated the structure of the carbon suboxide polymer, again proposed a structure analogous to structure (II).

In the examination of the structures proposed one must bear in mind that the above investigators were scarcely likely to deal with identical compounds, since the conditions used in the preparation of the polymer were not the same. While Diels[1,68] and Hegar[51] obtained the carbon suboxide polymer at 0°C in the presence of chemical catalysts, Blake and coworkers[136] and other investigators[115] carried out the polymerisation at temperatures of the order of 100°C. Probably this is why the properties of the carbon suboxide polymers are so different[48]. It is also possible that the investigators dealt with structures analogous to both structure (I) and structure (II). Nor can one exclude the possibility of the formation of mixed structures, which may occur, for example, on further addition of carbon suboxide to the products of its interaction with enols; in this reaction two structures have been found to form, as in polymerisation — one with a carboxy-group analogous to structure (I)[51] and one with a polypyrone group, analogous to structure (II).[88]

In conclusion it should be noted yet again that further development of the chemistry of carbon suboxide is extremely promising both from the theoretical and practical points of view.

1. O.Diels and B.Wolf, Ber., 39, 689 (1906).
2. R.Grauer, Chimia (Switz.), 14, 11 (1960).
3. M.V.Vol'kenshtein, Uspekhi Khim., 4, 610 (1935).
4. A.Michael, Ber., 41, 925 (1908).
5. G.G.Le Fèvre, J.Chem.Soc., 1696 (1935).
6. A.Klemenc, R.Wechsberg, and G.Wagner, Z.phys.Chem., A170, 97 (1934).
7. O.Diels and P.Blumberg, Ber., 41, 82 (1908).
8. O.Diels and P.Blumberg, Ber., 41, 1233 (1908).
9. L.O.Brockway and L.Pauling, Proc.Nat.Acad.Sci.USA, 19, 860 (1933).
10. H.Boersch, Wiener Ber., [IIb], 144, 1 (1935).
11. R.L.Livingston, C.W.Ramachandra Rao, J.Amer.Chem. Soc., 81, 285 (1950).
12. H.Mackle and L.F.Sutton, Trans.Faraday Soc., 47, 937 (1951).
13. R.L.Lord and J.N.Wright, J.Chem.Phys., 5, 642 (1937).
14. A.D.Rix, J.Chim.phys., 22, 4291 (1954).
15. R.A.Long, F.S.Murfin, and R.L.Williams, Proc.Roy.Soc., 223A, 251 (1954).
16. W.Engler and K.Kohlrausch, Z.phys.Chem., B34, 214 (1936).
17. W.J.Lafferty, A.G.Maki, and F.K.Plyler, J.Chem.Phys., 40, 224 (1964).
18. A.P.Aleksandrov, V.I.Tyulin, and V.M.Tatevskii, Optika i Spektrosk., 7, 38 (1964).
19. A.O.Diallo and P.Barchewitz, J.Chim.phys., 61, 1296 (1964).
20. W.J.Lafferty and A.G.Maki, Chemistry, 37, 19 (1964).
21. K.S.Pitzer and S.J.Strickler, J.Chem.Phys., 41, 730 (1964).
22. G.Nagarajan, Indian J.Pure Appl.Phys., 2, 179 (1964).
23. R.M.Badger and R.C.Barton, Proc.Nat.Acad.Sci.USA, 20, 166 (1934).
24. H.R.Johnson and M.W.Stranberg, J.Chem.Phys., 20, 687 (1952).
25. T.T.Broun and R.L.Livingston, J.Amer.Chem.Soc., 74, 6084 (1952).
26. L.E.Sutton, "Tables of Interatomic Distances and Configuration in Molecules and Ions", London, 1958.
27. M.V.Vol'kenshtein, "Stroenie i Fizicheskie Svoistva Molekul" (The Structure and Physical Properties of Molecules), Izd.Akad.Nauk SSSR, 1965, p.198.
28. K.Venkateswarlu, M.G.Krishna Pillai, Z.phys.Chem. (Frankfurt), 18, 391 (1958).
29. K.Venkateswarlu and T.Thanalakshmi, Current Sci., 31, 186 (1962).
30. J.K.O'Loane, J.Chem.Phys., 21, 672 (1953).
31. M.J.Edwards and J.M.Williams, J.Chem.Soc., 855 (1927).
32. A.Klemenc, R.Wechsberger, and G.Wagner, Monatsh., 66, 337 (1935).
33. O.Diels and G.Meyerheim, Ber., 40, 357 (1907).
34. V.V.Korshak, S.V.Rogozhin, and V.I.Volkov, Vysokomol. Soed., 1, 804 (1959).
35. H.Stock and H.Stolzenberg, Ber., 50, 498 (1917).
36. K.A.Kobe, J.Chem.Educ., 8, 232 (1931).
37. H.Thompson, Trans.Faraday Soc., 27, 249 (1941).
38. A.Klemenc, R.Wechsberg, and G.Wagner, Z.Electrochem., 40, 488 (1934).
39. A.Klemenc and G.Wagner, Z.anorg.Chem., 239, 1 (1938).
40. V.P.Glushko (Editor), "Termodinamicheskie Svoistva Individual'nykh Veshchestv" (Thermodynamic Properties of Pure Substances), Izd.Akad.Nauk SSSR, 1962, Vol.1, pp. 474, 486.
41. H.Krepelka and V.Vebersik, Chem.Listy, 43, 25 (1949).
42. O.Diels and L.Lalin, Ber., 41, 3420 (1908).
43. H.Staudinger and S.Beresa, Ber., 41, 4461 (1908).
44. L.B.Dashkevich and I.Peterek, Trudy Leningrad.Khim.-Farmatsvet.Inst., 5, 27 (1958).
45. H.Staudinger and H.Klever, Ber., 41, 907 (1908).
46. E.Ott and K.Schmidt, Ber., 55, 2126 (1922).
47. C.D.Hurd and F.D.Pilgrim, J.Amer.Chem.Soc., 55, 757 (1933).
48. L.B.Dashkevich, V.A.Buevich, and B.E.Kuvaev, Zhur. Obshch.Khim., 30, 1946 (1960).
49. V.Maxia, S.Meloni, G.Parenti, M.Rollier, and M.Secci, Ric.Sci., 2, 273 (1962).
50. H.Feuer and R.Miller, J.Org.Chem., 24, 118 (1959).
51. G.Hegar, "Beitrag zur Chemie des Kohlensuboxids", Zürich, 1961.

52. G.Hagelloch and F.Fess, Ber, 84, 730 (1951).
53. E.Ott, Annalen, 401, 159 (1914).
54. L.B.Dashkevich and E.N.Kuvaeva, "Materialy Nauchnoi Konferentsii LKhFI" (Proceedings of the Scientific Conference of the Leningrad Institute of Chemistry and Pharmacy), 1960, p.41.
55. L.B.Dashkevich, Radiokhimiya, 2, 129 (1960).
56. A.Klemenc, H.Hinterberger, and H.Hofer, Naturwiss., 25, 249 (1937).
57. P.Harteck, W.Groht, and K.Faltings, Z.Electrochem., 44, 621 (1938).
58. T.Kvadbek, Khim. i Khim.Tekhnol., No.6, 52 (1957).
59. E.Müller, "Horizons in Organic Chemistry" (Translated into Russian), Inostr.Lit., Moscow, 1960, p.377.
60. L.B.Dashkevich, Trudy Leningrad.Khim.-Farmatsvet.Inst., 16, 39 (1962).
61. L.B.Dashkevich, Dokl.Akad.Nauk SSSR, 132, 1309 (1960).
62. C.L.Wilson, J.Chem.Soc., 492 (1935).
63. A.F.Potter and H.L.Ritter, J.Phys.Chem., 58, 1040 (1954).
64. L.B.Dashkevich, V.G.Beilin, and V.M.Siraya, Zhur. Obshch.Khim., 32, 2747 (1962).
65. I.H.Billman, Proc.Indiana Acad.Sci., 61, 120 (1952).
66. O.Diels, Angew.Chem., 39, 1025 (1926).
67. L.B.Dashkevich and V.A.Pechenyuk, Zhur.Obshch.Khim., 35, 284 (1965).
68. O.Diels, R.Beckmann, and G.Tönnies, Annalen, 439, 76 (1924).
69. L.B.Dashkevich and E.N.Kuvaeva, Trudy Leningrad.Khim.-Farmatsvet.Inst., 16, 59 (1962).
70. H.Fraenkel-Conrat, J.Biol.Chem., 146, 345 (1942).
71. M.Bender, "Mechanisms of the Catalysis of Nucleophilic Reactions of Carboxylic Acid Derivatives" (Translated into Russian), Izd.Mir., 1964, p.33 [Possibly translation from Chem.Rev., 60, 53 (1960) (Ed. of Translation)].
72. O.Diels and K.Hansen, Ber., 59, 2555 (1926).
73. V.G.Beilin, Candidate's Thesis, Leningrad, 1965.
74. A.Pauw, Rec.Trav.chim., 55, 215 (1936).
75. L.B.Dashkevich, Zhur.Obshch.Khim., 30, 3840 (1960).
76. L.B.Dashkevich, Trudy Leningrad.Khim.-Farmatsvet.Inst., 11, 94 (1960).
77. L.B.Dashkevich and E.N.Kuvaeva, Zhur.Obshch.Khim., 31, 1669 (1961).
78. L.B.Dashkevich and V.G.Beilin, Zhur.Obshch.Khim., 31, 1671 (1961).
79. L.B.Dashkevich and V.G.Beilin, Zhur.Obshch.Khim., 34, 2808 (1964).
80. W.F.Ross and H.N.Christensen, J.Biol.Chem., 137, 89 (1941).
81. W.R.Ross and L.S.Green, J.Biol.Chem., 137, 105 (1941).
82. A.A.Tracy and W.R.Ross, J.Biol.Chem., 146, 63 (1942).
83. V.G.Beilin, L.B.Dashkevich, and M.A.Strelkova, "Khimiya Dikarbonil'nykh Soedinenii" (The Chemistry of Dicarbonyl Compounds), Riga, 1966, p.11.
84. L.B.Dashkevich and V.G.Beilin, USSR P. 176285.
85. K.C.Tson, K.Hoegerle, and C.F.Suttelen, J.Med.Chem., 6, 435 (1963).
86. L.B.Dashkevich and V.G.Beilin, Zhur.Obshch.Khim., 32, 2423 (1962).
87. L.B.Dashkevich and M.G.Shepel', USSR P. 162146.
88. E.Ziegler and H.Biemann, Monatsh., 93, 34 (1962).
89. W.Reyser, Ber., 25, 1194 (1892).
90. J.Van Alphen, Rec.Trav.chim., 43, 823 (1924).
91. L.B.Dashkevich and V.M.Siraya, Zhur.Obshch.Khim., 32, 2330 (1962).
92. E.J.Masters and M.Bogert, J.Amer.Chem.Soc., 64, 2712 (1942).
93. C.F.Allen, J.van Allan, C.W.Wilson, J.Amer.Chem.Soc., 66, 1805 (1944).
94. M.Ohta, J.Pharm.Soc.Japan, 71, 1428 (1951).
95. S.Checchi, Gazzetta, 88, 591 (1958).
96. L.B.Dashkevich, Zhur.Obshch.Khim., 31, 3723 (1961).
97. M.A.Abramovich and N.M.Ginzburg, Trudy Leningrad. Khim.-Farmatsvet.Inst., 16, 63 (1962).
98. L.B.Dashkevich and E.N.Kuvaeva, Zhur.Obshch.Khim., 32, 3768 (1962).
99. L.B.Dashkevich and E.S.Korbelainen, Zhur.Obshch.Khim., 34, 3427 (1964).
100. L.B.Dashkevich, E.S.Korbelainen, E.N.Kuvaeva, and M.M.Samoletov, see Ref.83, p.42.
101. E.S.Korbelainen, "Materialy Nauchnoi Konferentsii LKhFI" (Proceedings of the Scientific Conference of the Leningrad Institute of Chemistry and Pharmacy), 1966, p.13.
102. L.B.Dashkevich and E.S.Korbelainen, "Khimiya Geterotsiklicheskikh Soedinenii" (The Chemistry of Heterocyclic Compounds), 1965, p.595.
103. A.F.Mokhie El'din, Candidate's Thesis, Institute of Chemistry and Pharmacy, Leningrad, 1965.
104. J.Van Alphen, Rec.Trav.chim., 44, 838 (1925).
105. H.P.Kaufmann, Angew.Chem., 40, 73 (1927).
106. T.Tsumaki, Bull.Chem.Soc.Japan, 6, 1 (1931).
107. V.Segers, Belg.P. 508085 (1952); C.A., 52, 9218 (1958).
108. J.M.Quintilla, Spanish P. 211285 (1953); C.A., 49, 14812 (1955).
109. L.B.Dashkevich and V.M.Siraya, "Materialy Vsesoyuznoi Konferentsii po Pyatichlennym Geterotsiklam" (Proceedings of the All-Union Conference on Five-Membered Heterocycles), Rostov-on-Don, 1962, p.35.
110. E.Ziegler and R.Wolf, Monatsh., 95, 1061 (1964).
111. L.B.Dashkevich, Dokl.Akad.Nauk SSSR, 145, 95 (1962).
112. L.B.Dashkevich and V.M.Siraya, Trudy Leningrad.Khim.-Farmatsvet.Inst., 16, 202 (1962).
113. L.B.Dashkevich, Zhur.Obshch.Khim., 32, 2346 (1962).
114. L.B.Dashkevich and V.M.Siraya, USSR P. 152465.
115. H.Frend, Annalen, 379, 27 (1910).
116. L.P.Ferris II and A.R.Ronzio, J.Amer.Chem.Soc., 62, 606 (1940).
117. A.Dox and L.Yoder, J.Amer.Chem.Soc., 44, 361 (1922).
118. L.B.Dashkevich and E.N.Kuvaeva, Trudy Leningrad.Khim.-Farmatsvet.Inst., 16, 55 (1962).
119. H.Hopff and G.Hegar, Helv.Chim.Acta, 44, 2016 (1961).
120. T.E.Zaugg, "Organic Reactions" (Translated into Russian), Inostr.Lit., Moscow, 1956, Vol.8, p.392.
121. C.D.Hurd, D.E.Edward, I.R.Roach, J.Amer.Chem.Soc., 66, 293 (1944).
122. J.Billmann, G.Thipp, R.Gash, J.Amer.Chem.Soc., 62, 770 (1940).
123. L.B.Dashkevich and L.G.Izrailev, Zhur.Obshch.Khim., 30, 3060 (1960).
124. L.B.Dashkevich, Doctoral Thesis, Institute of Chemistry and Pharmacy, Leningrad, 1966.
125. D.J.Cram and R.J.Zimmerman, J.Amer.Chem.Soc., 74, 2646 (1952).
126. J.Billmann and G.M.Smith, J.Amer.Chem.Soc., 74, 3174 (1952).
127. L.B.Dashkevich and E.I.Boksiner, Zhur.Obshch.Khim., 28, 2845 (1958).
128. L.B.Dashkevich and B.E.Kuvaev, Zhur.Obshch.Khim., 29, 2368 (1959).
129. L.B.Dashkevich and L.N.Kuz'menkov, Zhur.Obshch.Khim., 29, 2367 (1959).
130. L.B.Dashkevich and V.M.Siraya, Trudy Leningrad.Khim.-Farmatsvet.Inst., 16, 51 (1962).
131. K.Kobe and L.Reyerson, J.Phys.Chem., 35, 3025 (1931).
132. H.Staudinger, "Die Ketene", Stuttgart, 1912, p.139.
133. P.Gosselain, P.Dufour, and A.Vrancken, Belg.P.632558 (1963).
134. L.Schmidt, H.P.Boch, and U.Hoffmann, Z.anorg.Chem.,

296, 246 (1958).
135. E.Ziegler, H.Junen, and H.Biemann, Monatsh., 92, 926 (1961).
136. A.R.Blake, W.T.Eeles, P.P.Jenings, Trans.Faraday Soc., 60, 691 (1964).
137. A.R.Blake and A.F.Hyde, Trans.Faraday Soc., 60, 1775 (1964).
138. A.R.Blake, J.Chem.Soc., 3866 (1965).
139. A.W.Lunt and L.S.Mumford, J.Chem.Soc., 1711 (1929).

Leningrad Institute of
Chemistry and Pharmacy

U. D. C. 547.316.61

SYNTHESIS AND SOME PROPERTIES OF αω-DISUBSTITUTED (DIFUNCTIONAL) POLYENES

L. A. Yanovskaya

CONTENTS

I. Introduction 400
II. Synthesis of polyenes with the same substituents at the ends of the chain 400
III. Synthesis of polyenes with different substituents at the ends of the chain 406
IV. Some properties of polyenes 407

I. INTRODUCTION

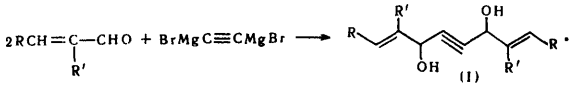
αω-Disubstituted (difunctional) polyenes are fairly widely distributed in nature. They include, for example, various branched and unbranched dicarboxylic acids (crocetin, bixin, corticrocin, descrocetin), which are the normal metabolites of certain plants and micro-organisms, polyene diketones (capsorubin — one of the pigments of cayenne, etc.). Many disubstituted difunctional polyenes are the degradation products of polyene antibiotics, such as, for example, fumagillin, lagosin, tetrin, etc. Finally, difunctional polyenes serve as the starting materials in the synthesis of other important natural compounds, for example, carotenoids (β-carotene, lycopene, etc.). In this connection synthetic methods have been investigated and developed for individual representatives of substances of this type, in the first place those with the isoprenoid structure; some of these have been described in reviews devoted to advances in the synthesis of carotenoids and vitamin A [1-3]. However, a complete description of the synthetic methods for αω-disubstituted (difunctional) polyenes has not been given so far. And yet in recent years considerable new advances have been achieved in this field, as a result of which the principal types of difunctional polyenes have become fully available. The advances in the synthetic field led to a number of theoretical findings based on the study of many properties of these compounds, particularly studies concerning the effect of the terminal substituents in the polyene chain on one another.

The present review is devoted to the advances in the synthesis of αω-disubstituted (difunctional) polyenes and certain properties of polyenes.

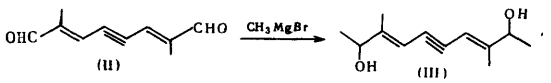
II. SYNTHESIS OF POLYENES WITH THE SAME SUBSTITUENTS AT THE ENDS OF THE CHAIN

Glycols

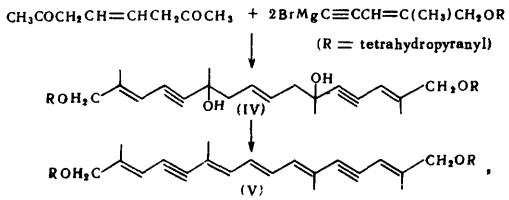
Primary and secondary glycols of the polyene and polyenyne series might serve as convenient starting compounds for the synthesis of other disubstituted (difunctional) polyenes, and therefore much attention has been devoted to their synthesis. The first and oldest method of preparing glycols consists in organometallic synthesis. This procedure leads mainly to secondary glycols. Best results have been obtained in the reaction of the simplest αβ-unsaturated monoaldehydes with the Iotsich complex. Thus when acrolein[4], methacrolein[5-11] or tiglic aldehydes[12] are allowed to act on bis(bromomagnesium)acetylene in ether, octa-1,7-dien-4-yne-3,6-diol (I, R = R′ = H), 2,7-dimethylocta-1,7-dien-4-yne-3,6-diol (I, R = H, R′ = CH_3), and 3,8-dimethyldeca-2,8-dien-5-yne-4,7-diol (I, R = R′ = CH_3) were obtained in yields of the order of 70%:



Dialdehydes and Grignard reagents can also be used in this reaction[12,13]. For example, the reaction of methylmagnesium bromide with 2,7-dimethylocta-2,6-dien-4-yne-1,8-dial (II) gave 3,8-dimethyldeca-3,7-dien-5-yne-1,9-diol (III):



However, attempts to synthesise primary glycols using the reaction between a Grignard reagent with the appropriate functional group and a diketone[14],



were not very successful because dehydration of compound (IV) gave the bistetrahydropyranyl ether (V) in a yield of only 8%.

The attempt to use for the synthesis of glycols the Grignard reaction between hex-4-en-1-yn-3-ol (VI) or hex-3-en-1-yn-5-ol (VII) and acetaldehyde was also unsuccessful. Although the corresponding reaction products, oct-6-en-3-yne-2,5-diol (VIII) and oct-5-en-3-yne-2,7-diol (IX) are formed in high yields[15], selective hydrogenation of the glycol (IX) by chemical or catalytic methods gave octa-3,5-diene-2,7-diol (X) in a very low yield. The hydrogenation