U.D.C. 547.303/.306

The Properties of Orthoesters and Their Applications in Organic Synthesis

V.V.Mezheritskii, E.P.Olekhnovich, and G.N.Dorofeenko

A systematic and general account is given of data on the properties of orthoesters and their applications in organic synthesis. The mechanisms of certain reactions involving orthoesters have been considered or revised.
The bibliography includes 278 references.

CONTENTS

I. INTRODUCTION

Despite the fact that the esters of orthocarboxylic acids cannot always be compared as regards the number of known examples with certain widely familiar classes of organic compounds, their importance in many synthetic methods is very great. It is sufficient to say that the application of orthoesters made it possible to develop extremely simple methods for the introduction of the formyl or acyl residue into an aromatic ring, at a double bond, and in the α-methyl and methylene groups of carbonyl and heterocyclic compounds. Acylation and also alkylation of oxygen, sulphur, nitrogen, phosphorus, and silicon atoms of a wide variety of organic and inorganic substances has been achieved with the aid of orthoesters.

It is noteworthy that hitherto orthoformates (in particular ethyl orthoformate) have found the greatest number of applications, which is due to their high reactivity in many reactions and greater availability compared with other orthoesters.

The advances achieved in the chemistry of aliphatic orthoesters were described in Post's review[1] published in 1943. In 1953, the properties of ethyl orthoformate were briefly reviewed[2]. Certain examples of the applications of orthoesters have been compared in familiar monographs on organic chemistry[3-5]. However, there are no reviews in the Soviet literature dealing with this problem.

The vigorous development of the chemistry of orthoesters in recent years led to the accumulation of extensive factual data, a systematic and general account of which is required. Moreover, the mechanisms of certain reactions have been re-examined and revised in the light of recent studies.

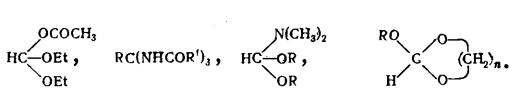
In the present review, we attempted to cover the known types of reactions of orthoesters without endeavouring to give an exhaustive description of data for individual reactions.

II. THE STRUCTURE AND REACTIVITY OF ORTHOESTERS

Organic orthoesters have the general formula (I) and are the esters of orthoacids which do not exist in a free state:

$$\underset{(I)}{RC(XR')_3}.$$

Oxygen or sulphur function as the heteroatom X. The group R can be an alkyl, aryl, or aralkyl residue or a functional group (COOR, OR, etc.). The group R′ is as a rule aliphatic, although aryl orthoformates are known[6]. There exist mixed orthoesters containing groups R′ of different types. These include, for example, diethoxymethyl acetate (II)[7]. Certain amino-derivatives of orthoacids [orthoamides(III)][8], acetals of dimethylformamide (IV)[9], cyclic orthoesters (V)[10], etc. resemble orthoesters as regards the nature of the reactions in which they are involved.

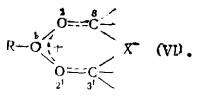


(II) (III) (IV) (V)

Orthoesters are highly reactive owing to the electron deficient central carbon atom caused by the $-I$ effect of the electronegative groups XR. The presence of a positive charge on the central atom results in their affinity for nucleophilic agents and the transition state is stabilised fairly readily by the elimination of HXR (an alcohol or mercaptan).

Orthoesters can be activated by protic and aprotic acids. The catalytic effect of acids is due to their interaction with orthoesters, which gives rise to the formation

under the reaction conditions of an extremely reactive carboxonium ion (VI), which has been isolated as a salt [10]:



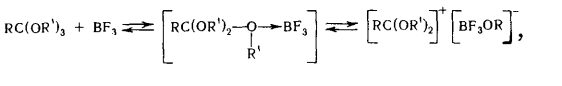
(VI).

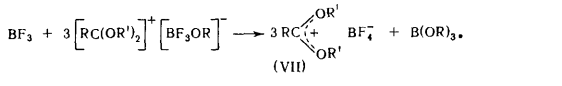
As a result of [electron] delocalisation, the dialkoxycarboxonium cation carries a partial positive charge both on the oxygen atoms and on the carbon atoms linked to them (1,3,3′). As a result of such charge distribution, the carboxonium ion exhibits a dual reactivity. In those cases where the nucleophilic centre of the reacting species is attacked by the central carbon atom of the carboxonium ion, insertion into the molecule of the acetal fragment $RC(OR')_2$, i.e. acylation, takes place. On the other hand, when the attack is by the 3- or 3′-carbon atom of the alkyl group, alkylation takes place. Acylation can occur both at a carbon atom in organic compounds (the formation of a C–C bond) and at a heteroatom (O, S, N, P, etc.). Alkylation is as a rule directed only to a heteroatom which is involved in a multiple bond (=O, ≡N, =S, etc.). However, cases of alkylation at S–H or O–H bonds are known [11,12], as well as cases where an alkyl group combines with a halide ion [13,14]. Under certain conditions acylation and alkylation reactions can occur simultaneously and behave therefore as competing or parallel processes [15]. Under conditions of acid catalysis, the orthoesters of alkanecarboxylic acids give a lower yield of condensation products with amines [16] and ketones [7] than orthoformates. This can be accounted for by the compensation of the positive charge of the carboxonium ion produced by the $+I$ effect of the alkyl group.

The specific effect of the structure of the orthoester on its reactivity is discussed in the individual sections of the review.

III. REACTIONS OF ORTHOESTERS WITH INORGANIC ACIDS

Orthoesters react with protic and aprotic acids, metal halides, and certain oxides. Acids and metal halides (calcium, magnesium, platinum, antimony, etc. halides) tend to form complexes which are sometimes fairly stable and can be isolated. Meerwein [10] showed that orthoesters form complexes with BF_3 and $SbCl_5$, which in certain cases can ionise at the C–O bond with formation of a carbonium ion and the complex anions $(ROBF_3)^-$ or $(ROSbCl_5)^-$, disproportionating to the stable anions BF_4^- and $SbCl_6^-$:

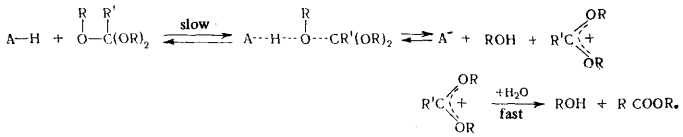




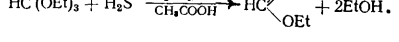
(VII)

The anion disproportionation stage is rate-limiting. The capacity of the complexes for ionisation increases with electron density at the central atom and with increase of the stability of the carboxonium ion (VII) formed. In the general case, the stability of carboxonium ions decreases with the number of oxygen atoms bound to the charged carbon atom, owing to the decrease of the contribution of the oxonium forms to the corresponding carboxonium structure:

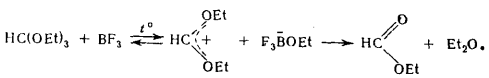
The hydrolysis of orthoesters is one of the most thoroughly investigated reactions. Many studies have been made on the elucidation of its mechanism. In the light of recent data [18–20], the hydrolysis of orthoesters is an example of general acid catalysis reaction and may be regarded as an example of bimolecular electrophilic S_E2 substitution at the oxygen atom:



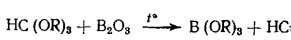
The reaction of ethyl orthoformate with hydrogen sulphide takes place similarly to hydrolysis [21]:



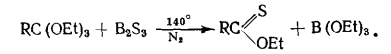
When ethyl orthoformate is heated in the presence of very small amounts of BF_3, it undergoes catalytic decomposition into ethyl formate and ethyl ether [22]:



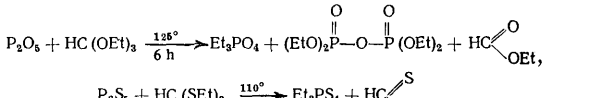
Acidic oxides are alkylated by orthoesters at the oxygen atom. Evidently this process also involves the formation of a carboxonium ion, since the reaction products include ethers and esters. When a 1 : 3 mixture of boron trioxide and an alkyl orthoformate is heated, trialkyl borates are formed [23] in yields of about 50%:



Under more severe conditions, boron trisulphide also reacts with orthoesters:



Reactions of ethyl orthoformate and ethyl thio-orthoformate with phosphorus pentoxide and pentasulphide have been described [25]:



The reactions of orthoesters with metal and non-metal halides have been investigated. These reactions usually result in the substitution of halogen atoms by alkoxy-groups. The reaction products may include alkyl halides, ethers, and carboxylic acid esters. Thus Arbuzov and Bogonostseva [26], who investigated the reaction of phosphorus trichloride with ethyl orthopropionate, observed that, by altering the proportions of the reactants, it is possible to replace in succession all three halogen atoms in the PCl_3 molecule by ethoxy-groups.

In the presence of $AlCl_3$, germanium tetrachloride reacts with orthoformates [27] to form substances having the general formula $Cl_nGe(OR)_{4-n}$, where $n = 0-3$.

The capacity of orthoesters to give rise to alkyl halides in the presence of halide ions has been used in the synthesis of ethyl fluoride[14], which is formed in 90% yield.

A novel method of synthesising alkyl iodides, proposed by Dangiyan[13], is based on the interaction of alkyl orthoformates with elemental iodine in the presence of various metals (Mn, Zn, Mg, Fe, Al).

The reactions of orthoesters with halogen-containing organic derivatives of the elements have been investigated. A method of preparing alkoxysilanes by the reaction of halogenosilanes with alkyl orthoformates in the presence of $AlCl_3$ has been described[28]:

$$R_mH_nSiX_{4-(m+n)} + HC(OR')_3 \xrightarrow{AlCl_3} R_mH_nSi(OR')_{4-(m+n)}$$

($m = 0, 1, 2, 3$; $n = 0, 1, 2, 3$; $m + n \leqslant 3$, X = halogen). Chlorocyanoalkylsilanes[29], boron-containing chloroalkylsilanes[30], and 1,1,1-trihalogenophospholens[31] are alkoxylated similarly.

A convenient method for the alkylation of phosphorodithioic acid ester consists in heating in with the orthoesters of alkanecarboxylic acids:

$$(EtO)_2P(=S)SH + RC(OR')_3 \rightarrow (EtO)_2P(=S)SR' + R'OH + RC(=O)OR'.$$

The alkylation reaction also constitutes the basis of the synthesis of alkyl hypophosphites from hypophosphoric acid[12]:

$$H_2P(=O)OH + RC(OR')_3 \xrightarrow{N_2} H_2P(=O)OR' + R'OH + RC(=O)OR'.$$

An interesting method of formylation at a phosphorus atom consists in heating a mixture of orthoformate and dialkyl metaphosphate[32]:

$$(RO)_2P(=O)H + HC(OR')_3 \rightarrow (RO)_2P(=O)CH(OR')_2 + R'OH.$$

IV. EXCHANGE OF ALKOXY-GROUPS AND ALKYLATION REACTIONS

1. Exchange of Alkoxy-groups of Orthoesters

Transesterification reactions leading to partial or complete replacement of alkoxy- or alkylthio-groups of the orthoesters by new RO or RS groups may be regarded as the simplest reactions of orthoesters. These reactions take place when orthoesters are treated with alcohols, phenols, carboxylic acids, carboxylic acid anhydrides, and mercaptans and are typical examples of nucleophilic substitution at a saturated carbon atom.

Transesterifications with alcohols, phenols, and mercaptans as a rule requires an active catalyst, while in the case of carboxylic acids the latter probably are sufficiently acidic to catalyse the reaction. The reactions involve a carboxonium ion:

$$RC(XR')_3 + H^+ \rightleftharpoons RC^+(XR')_2 + R'XH,$$

$$RC^+(XR')_2 + R''YH \rightleftharpoons R''-\overset{+}{Y}(H)-C(XR')_2R \xrightleftharpoons{-H^+} RC(XR')_2YR'',$$

$$RC(XR')_2(YR'') \xrightleftharpoons{+R''YH} RC(XR')(YR'')_2 \xrightleftharpoons{+R''YH} RC(YR'')_3.$$

The exchange of alkoxy-groups constitutes the basis of the synthesis of higher alkyl orthoformates, which are obtained in yields of 75–95%.[33,34]

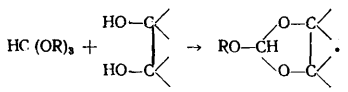
The corresponding orthoformates are also produced when a mixture of ethyl orthoformate is refluxed with ethyl or butyl alcohol in the presence of $ZnCl_2$.[35] If zinc chloride is replaced by sulphuric acid, another reaction takes place:

$$HC(SEt)_3 + 3BuOH \xrightarrow{H_2SO_4} 3EtSH + HC(=O)OBu + (Bu)_2O.$$

β-Chloroalkanols react with orthoformates, giving rise to a 54–88% yield of β-chloroalkyl orthoesters[36]. Aryl orthoformates have been obtained similarly[6,37].

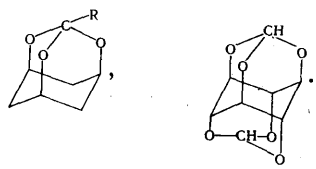
Mercaptans can react with orthoesters even at room temperature. The products are thio-orthoesters produced in nearly quantitative yields[38].

Compounds containing two or three hydroxy-groups also react with orthoesters, giving rise to the corresponding cyclic derivatives. Ethylene glycol and its derivatives [methylethylene glycol, glycerol α-chlorohydrin, pinacol, cyclohexane-1,2-diol, (+)-tartaric and mesotartaric acids, etc.] give rise to 2-alkoxy-1,3-dioxolanes on heating with methyl or ethyl orthoformates[39,40]:

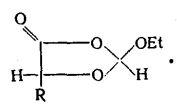


Glycerol and polyhydric alcohols behave similarly.

In the presence of BF_3, *cis*-phloroglucitol reacts with ethyl orthoformate and ethoxycarbonyltriethoxymethane[41,42], the oxa-analogues of adamantane being formed in yields in excess of 70%:



The syntheses of cyclic orthoesters of sugars[43], steroids[44], and other complex compounds have been described. On heating in benzene in the absence of a catalyst, ethyl orthoformate reacts with hydroxyacids[45]. 2-Ethoxy-1,3-dioxolan-4-ones (VIII) were obtained in high yields by this procedure:



(VIII)

In the presence of BF_3, oxiran or methyloxiran adds to methyl or ethyl orthoformate with formation of adducts differing in the proportion of alkoxy-groups[46]:

$$HC(OR)_3 + CH_2(O)CH_2 \xrightarrow{BF_3} HC(OR)_n[(OCH_2CH_2)_mOR]_{3-n}.$$

(n=0, 1, 2; m=1, 2, 3)

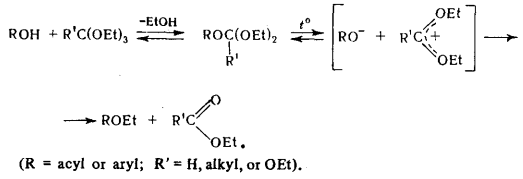
Post and Erickson[47] observed that, when carboxylic acid anhydrides are allowed to react with orthoesters, an alkoxy-group is replaced by an acyloxy-group:

$$RC(OEt)_3 + (R'CO)_2O \rightarrow RC(OEt)_2OCOR' + R'C(=O)OEt.$$

This reaction takes place only at elevated temperatures and is irreversible.

2. Alkylation Reactions

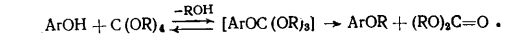
Orthoesters are used to alkylate carboxylic acids, phenols, and certain amines. When acids and phenols are alkylated, the usual transesterification of the orthoesters probably takes place initially. This is followed by the thermal dissociation of the newly formed RO–C linkage and alkylation of the RO^- anion by a carboxonium ion (see Section II):



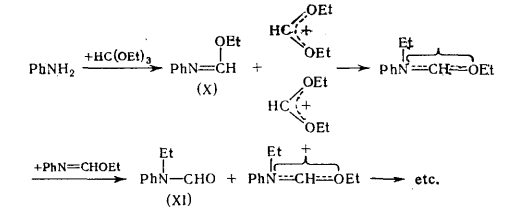
(R = acyl or aryl; R' = H, alkyl, or OEt).

The esterification of carboxylic acids by orthoesters is very promising for preparative purposes [49]. The method is applicable to the esterification of aliphatic, aromatic, and sterically hindered acids as well as certain acids which are difficult to esterify.

Smith [37] obtained alkyl ethers of phenols by refluxing mixtures of the corresponding phenol with a small excess of orthocarbonate:



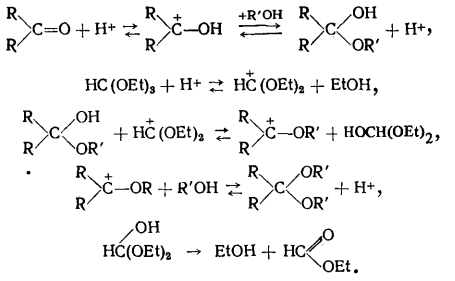
An interesting reaction was discovered by Roberts and Vogt [50], who showed that, when aniline is heated with ethyl orthoformate in the presence of sulphuric acid above 140°C, the aniline is *N*-alkylated. The ethyl ether of *N*-phenylformamide (X) is formed initially and then *N*-ethylformanilide (XI):



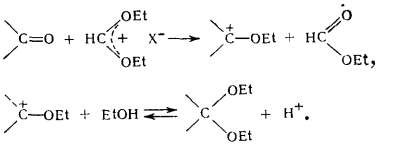
Compound (X) can be converted into (XI) also in the absence of orthoesters but the presence of the latter increases the yield of (XI). When compound (X) is treated with sulphuric acid and isopentyl orthoformate, a mixture of *N*-ethyl- and *N*-isopentyl-formanilides is formed. Toluene-*p*-sulphonic acid also catalyses this reaction but the yield of compound (XI) is low, while the reaction with HCl does not occur at all. These findings are consistent with the sequence of reactions expressed by the above mechanism, which takes into account the intermolecular nature of the conversion of compound (X) into (XI). The method of Roberts and Vogt can be recommended for the synthesis of *N*-monoalkylanilines via the corresponding formanilides in high yields [51,52].

V. SYNTHESIS OF ACETALS AND ENOL ETHERS

The method of synthesising acetals and ketals from the corresponding carbonyl compounds, orthoformates, and alcohols was developed by Claisen [53] and was subsequently widely adopted. The formation of acetals and ketals is an acid-catalysed reaction; it is assumed that the alcohol and not the orthoester behaves as a donor of alkoxy-groups [54]:



Kabuss [55] and Dimroth and Heinrich [56] observed that diethoxycarbonium salts obtained by Meerwein's method [10] from ethyl orthoformate are highly active alkylating agents. In particular, when these salts are mixed with aldehydes or ketones, the latter are *O*-ethylated with formation of ethoxycarbonium salts in nearly quantitative yields. This means that direct interaction between dialkoxycarbonium ions and the carbonyl compound is possible:



Naturally it is probable that the reaction proceeds simultaneously via the two mechanisms indicated with formation of the same final products.

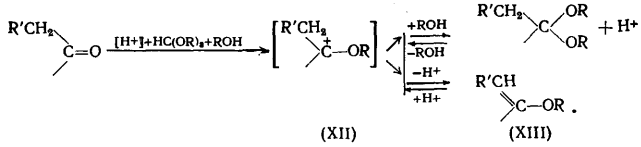
Hydrochloric, sulphuric, phosphoric, and toluene-*p*-sulphonic acids, ammonium chloride, sulphate, or nitrate, iron chloride, and other reagents are used as catalysts for the synthesis of acetals and ketals. Catalysts such as ammonium sulphate and nitrate and the hydrochlorides of mono-, di-, and tri-ethylamines are more effective than ammonium chloride. Magnesium and zinc chlorides give satisfactory results. Alkali metal chlorides are ineffective. Organic acids also exhibit catalytic activities but much weaker than inorganic acids. Their catalytic activity decreases in the sequence oxalic acid > formic acid > > acetic acid.

Ethyl orthoformate is usually employed to synthesise acetals. Other alkyl orthoformates give lower yields and ethyl orthoacetate does not react at all [57]. Benzaldehyde and its substituted derivatives form acetals in nearly quantitative yields regardless of the nature of the substituent [53,58]. Ketals of aliphatic-aromatic ketones such as acetophenone are obtained in yields up to 90% [54,59]. Acetals of aliphatic [58] and $\alpha\beta$-unsaturated aldehydes and ketones are formed in lower yields (which do, however, reach 80%) [60,61].

The rate of formation of ketals decreases with increase of the molecular weight of the ketone. Ketones with a branched hydrocarbon chain react more slowly than those with straight-chain alkyl groups and t-butyl methyl ketone does not react at all with orthoformate ester [3,62].

The questions concerning the synthesis of acetals and ketals have been described in detail in monographs by Post [1] and Houben [3] and partly in other publications [2,4,5].

The formation of enol ethers via an elimination reaction probably competes with the formation of acetals:

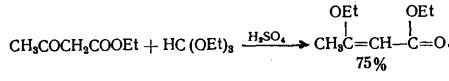


(XII) (XIII)

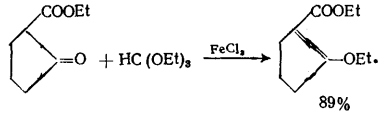
The mechanism shows that the synthesis of acetals and enol ethers invariably involves the intermediate formation of a carboxonium ion (XII). Since acetals and vinyl ethers are products of competing reactions, they are as a rule present together, their relative amounts depending on the process conditions and the structure of the carbonyl component.

The presence of an electronegative group at the α-carbon atom of the carbonyl compound increases the mobility of the α-methylene hydrogen atoms and thereby facilitates the conversion of the carbonium ion (XII) into the vinyl ether (XIII). The ease of formation of enol ethers is satisfactorily correlated with the tendency of the carbonyl compound to enolise. Favourable conditions for the formation of vinyl ethers are created when a mixture of orthoester and the carbonyl compound is heated for a long time in the presence of acids. In this instance, the action of toluene-*p*-sulphonic acid is most specific.

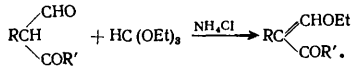
Enol ethers are formed extremely readily from β-dicarbonyl compounds, which is caused not only by the greater acidity of the α-methylene hydrogen atoms but also by the appearance of the group $O{=}C{-}C{=}C{-}OR$, which contains conjugated double bonds. Thus β-ethoxycrotonate is obtained from acetoacetic ester in the presence of several drops of sulphuric acid [63]:



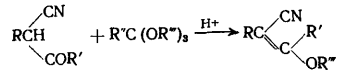
Esters of cyclic β-ketoacids react similarly [64]:



Enol ethers are formed even more readily from β-ketoaldehydes [65,66]:

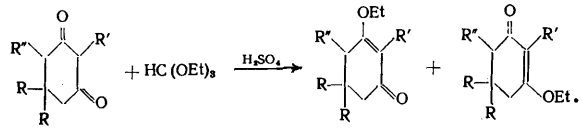


The highly electronegative cyano-group can activate the methylene group [67]:

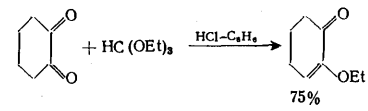


(R and R′ = H, alkyl, or aryl; R″ = H or alkyl; R‴ = alkyl).

Cyclic ketones show a greater tendency towards the formation of enol ethers than open-chain compounds. A general method for synthesising monoenol ethers of substituted cyclohexane-1,3-diones has been described [68]:

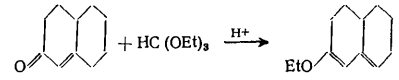


The monoenol ether of cyclohexane-1,2-dione can be obtained in solution in benzene saturated with hydrogen chloride [69]:



The conjugation of the keto-group with a benzene ring facilitates the formation of cyclic enol ethers. Thus an enol ether is formed from α-tetralone even at room temperature [70].

When enol ethers are produced from non-aromatic polycyclic compounds, the new double bond is formed in such a way that a conjugation chain is created (or preserved). This usually involves the migration of the existing double bond. As an example, one may quote the reaction of ethyl orthoformate with $\Delta^{1,9}$-2-octalone [71]:

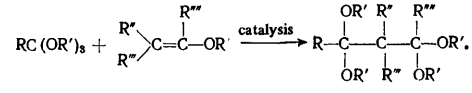


The formation of enol ethers with simultaneous migration of the double bond is very typical of steroids [72,73].

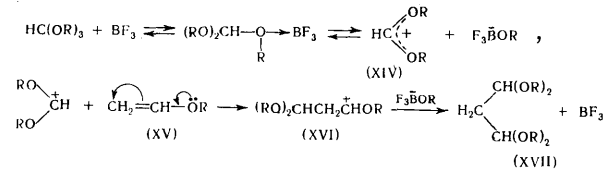
VI. REACTIONS WITH VINYL ETHERS AND THEIR ANALOGUES

The reaction of orthoesters with vinyl ethers has been described in detail in a highly informative review by Povarov [74]. This section gives a brief description of the general properties of this reaction, attention being concentrated on the reaction of orthoesters with analogues of vinyl ethers involving a similar mechanism.

The overall reaction of orthoesters with vinyl ethers can be represented schematically as follows:



This process, which takes place in the presence of acid catalysts (BF_3, $ZnCl_2$, $FeCl_3$, etc.), can have an ionic mechanism similar to that proposed for the analogous reaction of acetals [75]:



In the course of this reaction, as in many of the cases discussed above, a reactive dialkoxycarbonium ion (XIV) is formed and attacks the β-carbon atom of the vinyl ether (XV), the double bond of which is activated owing to the $+M$ effect of the alkoxy-group. As a result, the acetal fragment ($-HC(OR)_2$) is inserted into the molecule of the vinyl ether with subsequent addition of the alkoxy-group to the carbonium ion (XVI). The final products (XVII) are tetra-acetals of β-dicarbonyl compounds.

The cationic polymerisation of vinyl ethers is an undesirable competing process. Moreover, the carbonium

ion (XVI) can react further with the vinyl ether, which results in the formation of high-molecular-weight adducts. However, since the reactivity of the cation (XIV) is usually higher than that of the cation (XVI), the reaction proceeds preferentially with formation of the tetra-acetal (XVII) even when the molar ratio of the components is 1 : 1 and does not depend very markedly on the amount of the orthoester [76]. Nevertheless, in order to ensure higher yields of the monoadducts (XVII), it is better to employ an excess of the orthoester. In the presence of an excess of the vinyl ether, adducts with higher molecular weights can also be isolated, for example 1,1,3,5,5-pentaethoxypentane [76]:

$$HC(OEt)_3 + 2CH_2{=}CHOEt \xrightarrow{BF_3} EtOCH[CH_2CH(OEt)_2]_2.$$

Povarov [74] showed on the basis of the literature data that orthoesters are intermediate between saturated and $\alpha\beta$-unsaturated acetals as regards reactivity in the above reactions and resemble aromatic acetals. Therefore orthoesters form readily and in high yields monoadducts with unsubstituted and β-substituted vinyl ethers. In the reaction with the more reactive α-alkyl-substituted vinyl ethers, the yield of monoadducts falls approximately by a factor of two and the yield of polymeric products increases. Finally, in the reaction with the highly reactive alkoxydienes, cationic polymerisation predominates and adducts of orthoesters are not formed at all. As was to be expected, in the reactions with vinyl ethers (see Section II) orthoformates are more reactive than orthoacetates [77].

Among the wide variety of tetra-acetals obtained by the reaction of orthoesters with vinyl ethers, one should distinguish the tetra-acetals of malonic dialdehyde, which are difficult to obtain by other methods and which are important intermediates in many syntheses of heterocyclic systems. A simple method of preparation of the tetra-acetals of malonic dialdehyde from readily available compounds consists in the condensation of vinyl acetate with ethyl orthoformate, which involves the exchange of the acetoxy-group for an ethoxy-group [78]:

$$HC(OEt)_3 + CH_2{=}CHOCOCH_3 \xrightarrow{FeCl_3} H_2C\begin{matrix}CH(OEt)_2\\CH(OEt)_2\end{matrix}\ (60\%).$$

Thio-orthoesters react similarly with vinyl ethers [79] and vinyl sulphides [80]:

$$HC(SEt)_3 \xrightarrow{CH_2{=}CHOR} (EtS)_2CHCH_2CH\begin{matrix}OR\\SEt\end{matrix}$$

$$HC(SEt)_3 \xrightarrow{CH_2{=}CHSR} (EtS)_2CHCH_2CH\begin{matrix}SR\\SEt\end{matrix}.$$

Nitrogen analogues of orthoesters and enamides undergo a similar reaction [81]:

$$HC(NHCOOEt)_3 + R'CH{=}CHNHCOOEt \rightarrow R'CH[CH(NHCOOEt)_2]_2.$$

The reaction of orthoesters with ketones in the presence of Friedel–Krafts catalysts leads to the formation of dialkylacetals of β-keto-aldehydes [15,82]. The enolic form of the ketone (XVIII) plays the role of the vinyl ether in this reaction. The essential features of the reactions can be traced using as an example the interaction between ethyl orthoformate and acetophenone, which gives rise to the diethylacetal of benzoylacetaldehyde (XX):

$$HC(OEt)_3 + HClO_4 \rightleftarrows \overset{+}{H}C(OEt)_2ClO_4^- + EtOH,$$

$$PhC(OH){=}CH_2\ (XVIII) + \overset{+}{H}C(OEt)_2 \rightleftarrows Ph{-}\overset{+}{C}H{-}CH_2CH(OEt)_2\ (XIX) \xrightleftharpoons{-H^+} PhCOCH_2CH(OEt)_2\ (XX,\ 30\%).$$

A characteristic feature of this reaction is that the intermediate cation (XIX) is not stabilised by the addition of an RO radical, as for vinyl ethers, but by the dissociation of a proton. This gives rise to a dimethylacetal of the β-dicarbonyl compound instead of the tetra-acetal. The formation of ketals is a competing reaction.

All the above reactions of orthoesters with ketones in an acidic medium can be described by an overall general mechanism. For simplicity, the reversibility of the reaction is not indicated:

$$-H_2C{-}C(=O){-}H \xrightarrow{+\overset{+}{C}H(OR)_3} -H_2C{-}\overset{+}{C}(OR){-}H \xrightarrow{+ROH} -H_2C{-}C(OR)_2{-}H \xrightarrow{-H^+} -HC{=}C(OR){-}H \quad \text{pathway } A.$$

$$-H_2C{-}\overset{+}{C}(OH){-}H \xrightarrow{+ROH} -H_2C{-}C(OR)(OH){-}H \quad (+\overset{+}{C}H(OR)_3),$$

$$-CH{=}C(OH){-} \xrightarrow{+\overset{+}{C}H(OR)_3} (RO)_2CH{-}CH(\overset{+}{C}(OH){-})- \xrightarrow{-H^+} -HC(CH(OR)_2)C(=O){-} \quad \text{pathway } B.$$

Thus the dual reactivity of dialkoxycarbonium ions is revealed by the fact that they are capable of *O*-alkylation (pathway *A*) with formation of ketals (or enol ethers) and of *C*-formylation, or more precisely of inserting the fragment $HC(OR)_2$ with formation of β-ketoacetals (pathway *B*).

The nature and relative amounts of the final products are greatly influenced by the amount of the acidic reagent. In the presence of catalytic amounts of acids, the reaction could be carried out with a limited number of ketones [17]. Apart from the diethylacetal of benzoylacetaldehyde (XX), low yields are obtained also of the diethylacetals of *p*-methoxy- and *p*-ethoxy-benzoylacetaldehydes.

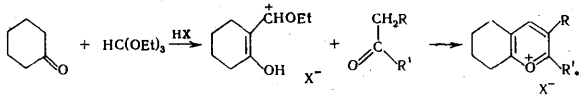
The reaction with aliphatic and alicyclic ketones usually cannot be arrested at the stage of a monoadduct of type (XX), more far-reaching transformations taking place. Thus the condensation of two molecules of a ketone with an orthoester in the presence of molar amounts of acid results in the formation of a 1,5-diketone, which cyclises under the reaction conditions to a pyrylium cation:

$$RCOCH_3 + HC(OR')_3 \xrightarrow{H^+} RCOCH_2CH(OR')_2 \xrightarrow{+RCOCH_3} \rightarrow \text{(OR', CH, CH}_2\text{, CH}_2\text{, RCO, OCR)} \xrightarrow[-R'OH;\ -H_2O]{+HX} \text{(pyrylium)}\ X^-.$$

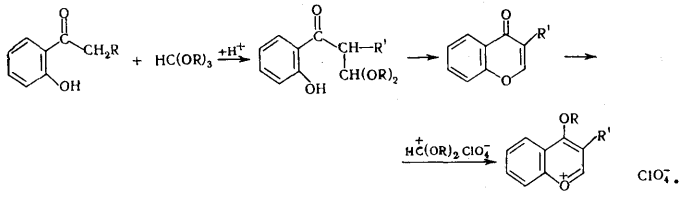
This reaction has served as a basis for a method of synthesising pyrylium salts, which is of general validity. The acid reagents employed are 70% perchloric and 98% sulphuric acids, boron trifluoride-ether, dry hydrogen chloride, aluminium chloride, iron(III) chloride, and others [83].

It has been shown [17] that orthoformates are the most reactive in this process. The yields of pyrylium salts decrease with increase in the chain length of the alkyl substituents in the orthoformate molecule. Orthoesters of alkanecarboxylic acids form [pyrylium] salts in low

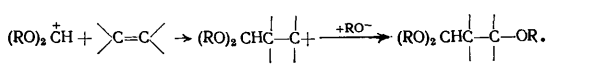
yields. Aliphatic-aromatic, alicyclic, and certain aliphatic ketones enter into the reaction. The yields of pyrylium salts are as a rule high. Cross-condensation was achieved with alicyclic ketones [84]:



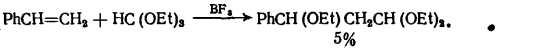
When alkyl *o*-hydroxyaryl ketones are employed, the intermediate acetals of β-ketoaldehydes are probably initially cyclised to chromones, which are alkylated and converted into 4-alkoxychromylium salts. The latter are hydrolysed to give high yields of chromones and isoflavones (including natural products of this structure [17,85,86]:



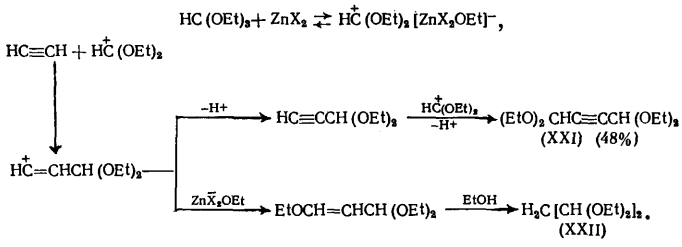
The mechanism of the reaction of vinyl ethers with orthoesters can be quite legitimately applied to the reaction of orthoesters with olefins. The only difference is that the addition to one of the carbon atoms at the double bond is not due to the activating and directing influence of the alkoxy-group, as in vinyl ethers, but is due to the polarisation of the double bond induced by the carbonium cation:



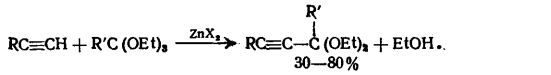
Orthoesters are known [87] to add to isobutene and cyclopentadiene. In the presence of BF_3, styrene condenses with ethyl orthoformate [77] and ethyl thio-orthoformate [87]:



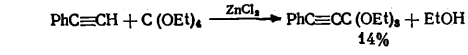
Acetylene reacts with ethyl orthoformate in the presence of zinc halides [88,89], the main reaction product being the tetraethylacetal of acetylenedialdehyde (XXI)—the tetraacetal of malonic dialdehyde (XXII) is formed as a side product:



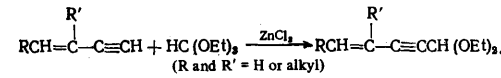
The reaction is of general validity. Alkyl- and arylacetylenes react with ethyl orthoformate, ethyl orthoacetate, and ethyl orthovalerate to form the diethylacetals of the corresponding acetylenic aldehydes and ketones:



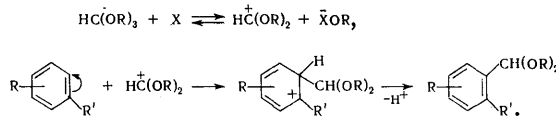
Highest yields (up to 80%) are achieved when ethyl formates are employed. In the reaction involving the orthoesters of alkanecarboxylic acids, the yields decrease approximately by a factor of two. Ethyl orthocarbonate gives rise to acetylenic orthoesters in low yields, for example:



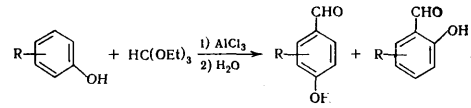
Substituted vinylacetylenes also enter into the reaction with ethyl orthoformate [90]:



The group of reactions including the interaction of dialkoxycarbonium ions with benzenoid of heterocyclic systems is of very great interest. They proceed via a general mechanism involving electrophilic substitution of an aromatic compound:

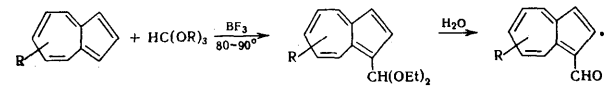


A new method of formylating phenols by orthoformic ester in the presence of aluminium chloride was proposed in 1963: [91]

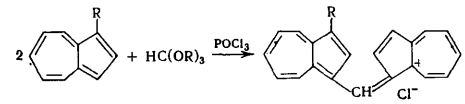


The method was tested on a large series of phenols, methylphenols, and naphthols [92]. Owing to its simplicity, it has substantial advantages over the methods of formylating the above compounds employed previously.

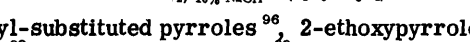
In the presence of acid catalysts (BF_3, $AlCl_3$, $SnCl_4$), azulene and its alkyl-substituted derivatives react with alkyl orthoformates to form the corresponding derivatives of azulene-3-aldehyde [93]:



In the presence of $POCl_3$, the interaction of ethyl orthoformate or ethyl thio-orthoformate with azulenes leads to azulenemonomethine dyes [94]:



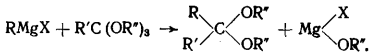
When ferrocene is treated with an excess of orthoester in the presence of $AlCl_3$, the following reaction takes place [95]:



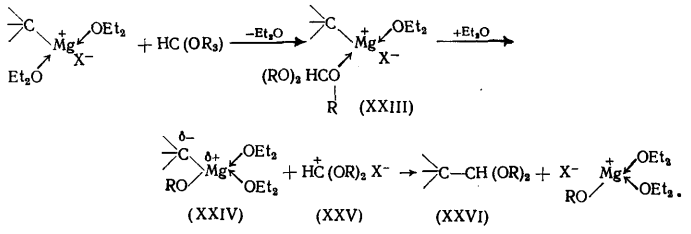
Alkyl-substituted pyrroles [96], 2-ethoxypyrroles [97], indoles [98], and 2-ethoxyindoles [99] react with ethyl orthoformate in the presence of acids (HCl, HBr, BF_3) to form monomethine derivatives.

VII. REACTIONS WITH ORGANOMETALLIC COMPOUNDS

Orthoesters react with organometallic compounds as follows:



Orthoformates give rise to acetals and the esters of other orthocarboxylic acids form ketals. In the reaction with orthocarbonic esters, the reaction products are other orthocarbonic esters. Probably the first reaction stage involves the formation of a coordination complex (XXIII) of the organometallic compound with the orthoester as a result of the replacement of a solvent molecule [1,100]. Subsequently the complex decomposes into the alkoxylated organometallic compound (XXIV) and the dialkoxycarbonium salt (XXV). Interaction between these intermediates yields the acetal (XXVI):



An organomagnesium compound plays the role of an acid activator of the orthoester in this reaction.

The method of acylation with orthoesters described above was proposed by Chichibabin [101]. The synthesis is carried out by refluxing a 1 : 1 mixture of components in ether or in higher-boiling solvents. For the reaction to be successful, it is sometimes necessary to evaporate the solvent after the addition of the orthoester to the solution of the organometallic compound. Frequently, instead of the acetals themselves, one isolates the corresponding aldehydes and ketones by hydrolysing the reaction mixture. The reaction may not stop at the acetal formation stage, since under certain conditions the latter are also capable of exchanging an alkoxy-group for an organic substituent of the organometallic compounds. Methyleneacetals and acetals of aliphatic aldehydes react with greater difficulty, aromatic aldehydes react more readily, and the reaction involving ketals is easiest [3]. In certain cases, all the alkoxy-groups of the orthoesters may be replaced, which results in the formation of a hydrocarbon [102].

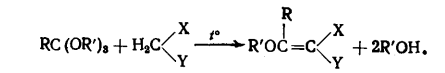
The first alkoxy-group is replaced most readily, the reaction being exothermic. The replacement of the second and even more so the third alkoxy-group requires an elevated temperature.

Aliphatic organometallic compounds form acetals in lower yields than aromatic derivatives. The yields of aliphatic acetals decrease with increase of the aliphatic chain length. Orthoformates are more reactive in this process than the orthoesters of alkenecarboxylic acid. In general, the method is convenient for the synthesis of aliphatic [1,103], aliphatic-aromatic [104], unsaturated [105], acetylenic [106], aromatic [107], and heterocyclic [108] aldehydes and ketones. More detailed information about this reaction and its conditions has been given in two monographs [1,109].

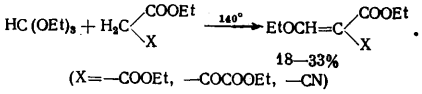
VIII. REACTIONS OF ORTHOESTERS WITH SUBSTANCES CONTAINING AN ACTIVE METHYLENE GROUP

1. Interaction of Orthoesters with Aliphatic Methylene Derivatives

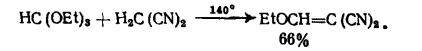
Orthoesters react with compounds containing an active methylene group via the mechanism



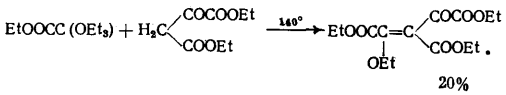
The substituents X and Y must be electronegative (COOR, COR, C≡N, and NO_2) and may be the same or of different types. The reaction proceeds on heating (140–150°C) the methylene derivatives with a small excess of the orthoester. The interactions of ethyl orthoformate with acetoacetic, oxaloacetic, and cyanocetic esters have been described [110]:



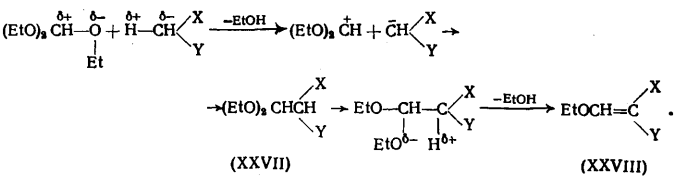
Ethyl orthoformate [110] and ethyl orthoacetate [111] show the greatest reactivity in this reaction (with malononitrile) forming the corresponding ethoxymethylene derivatives in high yields:



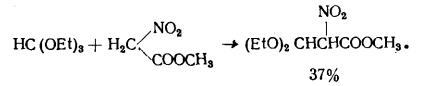
Triethoxyethyl acetate reacts with oxaloacetic ester [110]:



Post and Erickson [112] and also Jones [110] believe that the elimination of an alcohol from the orthoester must be preceded by additional polarisation of the C–O bond in the orthoester under the influence of the acidic hydrogen atoms of the methylene compound. One cannot rule out the possibility that at certain stages the reaction is ionic:



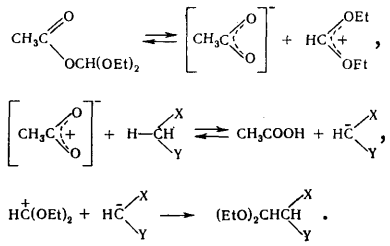
In certain cases, the intermediate acetal (XXVII) was isolated as the final reaction product. Thus, on heating ethyl nitroacetate with a small excess of ethyl orthoformate, the diethylacetal of methoxycarbonylnitroacetaldehyde is formed [113]:



When the acetal is heated to 170°C, a second alcohol molecule is split off and an ethoxymethylene derivative (XXVIII) (X = NO_2; Y = COOEt) is formed.

The diethylacetal of 2,2-dinitropropionaldehyde was synthesised similarly in 18% yield. Owing to the low yields of alkoxymethylene compounds, this method has little preparative value. A version of the synthesis first proposed by Claisen [114] and giving excellent results is employed in laboratory practice for the synthesis of alkoxymethylene compounds. In this procedure, a mixture of the orthoester and the methylene compound is refluxed in the presence of an excess of acetic anhydride which behaves as an activator of the orthoester, forming the reactive diethoxymethyl acetate and, moreover, shifts the reaction in the required direction by combining with the alcohol split off from the orthoester.

The higher reactivity of diethoxymethyl acetate in this reaction compared with ethyl orthoformate is due to the fact that the acetate anion is more stable than the alkoxide anion. Therefore diethoxy methyl acetate should undergo thermal dissociation to a considerable degree and the resulting acetate anion can deprotonate the methylene group:



Jones [115], who carefully separated all the products of the reaction of ethyl orthoformate with oxaloacetic ester in acetic anhydride and who determined their amount, proposed a mechanism involving successive transformations which accounts for all the compounds isolated (ethyl acetate, ethyl formate, acetic acid, and exothymethyleneoxaloacetic ester). The quantitative proportions of products which he found are in good agreement with the proportions calculated according to the mechanism proposed:

$$HC(OEt)_3 + (CH_3CO)_2O \rightarrow CH_3COOCH(OEt)_2 + CH_3COOEt,$$

$$CH_3COOCH(OEt)_2 + H_2C\langle^{X}_{Y} \rightarrow CH_3COOH + (EtO)_2CHCH\langle^{X}_{Y},$$

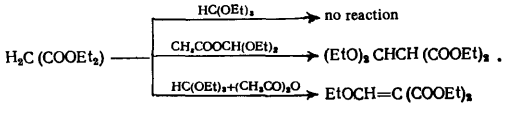
(XXIX)

$$(XXIX) \rightarrow EtOCH{=}C\langle^{X}_{Y} + EtOH,$$

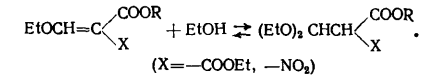
$$EtOH + (CH_3CO)_2O \rightarrow CH_3COOH + CH_3COOEt,$$

$$CH_3COOCH(OEt)_2 \xrightarrow{t^\circ} CH_3COOEt + HCOOEt.$$

Jones's mechanism also reflects two important factors which were already mentioned above. Firstly, the activating effect of acetic anhydride is shown only in the stage where the acetal (XXIX) is formed. Secondly, in the succeeding stage where the alcohol is split off by compound (XXIX) acetic anhydride serves only to bind the alcohol, displacing the reaction thereby to the right. These postulates are confirmed by the fact that diethyl malonate, a relatively inactive methylene compound, does not react with orthoesters in the absence of acetic anhydride [110] but does react with diethoxymethyl acetate to form only the acetal of formylmalonate [116], and ethoxymethylenemalonate is formed only on heating in the presence of an excess of acetic anhydride [117]:

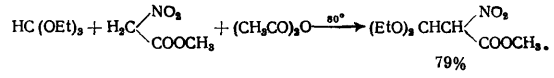


The assertion that acetic anhydride behaves as an alcohol-binding agent in the formation of the ethoxymethylene derivative from compound (XXIX) is consistent with the reversibility of this stage in the absence of acetic anhydride [116,118]:



(X=—COOEt, —NO_2)

It is also noteworthy that the acetic acid formed in the course of the reaction naturally catalyses the elimination of the alcohol from compound (XXIX). Under mild conditions, compound (XXIX) can be isolated even in the presence of acetic anhydride [118]:



The syntheses of ethoxymethylene derivatives in acetic anhydride from oxaloacetic ester, trifluoroacetic ester, ethyl acetylpyruvate [115], nitroacetic ester [119], acetylacetone [113], ethoxyacetylacetone [120], acetoacetic ester [113,121], ethyl acetonedicarboxylate [122], cyanoacetic ester [123,124], substituted amides of cyanoacetic acid [125,126], malononitrile [127,128], and benzoylacetic ester [129,130] have been described.

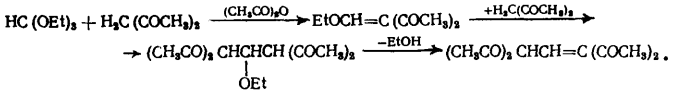
The reactivity of methylene compounds in reactions with orthoesters is higher the greater the electronegativity of the groups X and Y. The group C–N has the highest electronegativity, COR is less electronegative, and COOR is least electronegative.

The reaction with relatively unreactive methylene compounds requires catalysis. Thus prolonged refluxing in the presence of zinc chloride gives diethyl ethoxymethylenemalonate in high yield [131,132].

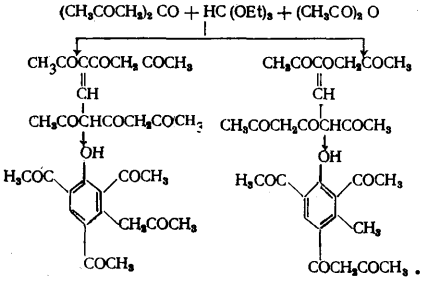
In view of the possibility of creating a system of conjugated bonds, it is possible to carry out the reaction of orthoformate esters with ethyl pyruvate [133]. The interaction of orthoesters with cyclopentene-1,3-dione [134] and indan-1,3-dione [135] has been described.

A patent has been taken out [136] for a method of synthesising alkoxymethylene compounds by the reaction of orthoesters with methylene derivatives in the presence of small amounts of glacial acetic acid as the catalyst with continuous distillation of the alcohol formed.

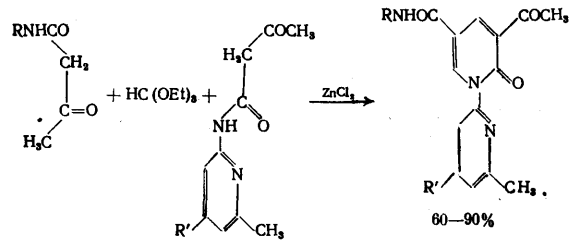
After prolonged heating of orthoesters with methylene compounds in acetic anhydride, one orthoester molecule condenses with two diketone or ketoester molecules [114]:



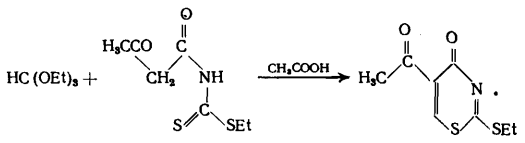
When diacetylacetone interacts with ethyl orthoformate in acetic anhydride, a mixture of isomers, cyclising under the reaction conditions into the corresponding phenols, is formed [137]:



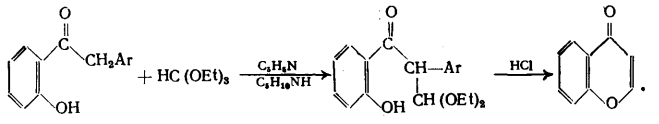
On refluxing in alcohol in the presence of $ZnCl_2$, cyclic products were obtained from substituted amides of acetoacetic acid [138]:



In the presence of a further reactive functional group in the molecule of the methylene derivative, internal cyclisation can occur [139]:

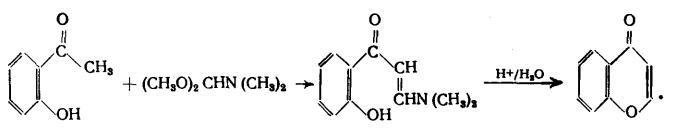


The methylene group in compounds containing a ketobenzyl group is also fairly reactive in the interaction with orthoesters in the presence of basic catalysts. A method of synthesising isoflavones by the condensation of orthoformate ester with benzyl *o*-hydroxyaryl ketones on heating in pyridine in the presence of piperidine was developed on this basis in 1949:[140]



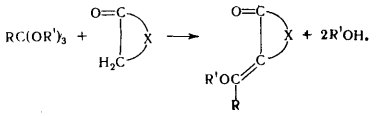
Subsequently the method found extensive application in the synthesis of a wide variety of natural isoflavones and their analogues, which are obtained in high yields.

A modification of the method has been used to synthesise chromone, the orthoester being replaced by the dimethylacetal of dimethylformamide, which functions simultaneously as a reactant and a basic catalyst [9]:

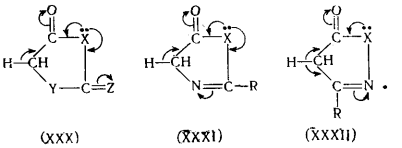


2. Condensation of Orthoesters with Heterocyclic Ketomethylene Compounds

Five- and six-membered ketomethylene compounds with one or two heteroatoms enter into the reaction with orthoesters. This results in the formation of heterocyclic alkoxyalkylidene derivatives:



A wide variety of five-membered heterocyclic systems, which enter into this reaction, correspond to one of the structures [135] presented below:



(XXX) (XXXI) (XXXII)

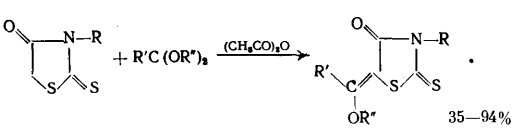
In the first two types [(XXX) and (XXXI)], the hydrogen atoms of the methylene group are activated mainly by the adjacent electronegative keto-group and to a considerable degree also by the fragment Y (XXX, Y = O, S, or NR) or $-N=C\langle$ (XXXI) owing to the $-I$ effect. The group X (O, S, or NR) lowers the electronegativity of the keto-group ($+M$ effect) and has a passivating influence on the methylene group. Passivation in structures (XXX) and (XXXI) is weakened by the influence of a second electronegative group (mesomeric with X) $-C=Z$ or $\rangle C=N-$.

In heterocyclic compounds of type (XXXII), the methylene group is activated simultaneously by the two highly electronegative fragments $-C=O$ and $-C=N$, which leads to a much higher reactivity of compounds of this type compared with (XXX) and (XXXI). Therefore, pyrazolones and isoxazolones (XXXII, X = N or O), for example, react readily with orthoesters in the absence of acetic anhydride, while compounds described by formulae (XXX) and (XXXI) have to be refluxed in acetic anhydride [135].

Steric factors are also important in the reactions of orthoesters, other than orthoformates, with ketomethylene compounds in which the atom adjoining the methylene group has a substituent. This effect can be demonstrated for 3-ethyl-2-thiothiazolidin-5-one, which condenses with ethyl orthoformate to form a planar 4-ethoxymethylene derivative, but does not react with ethyl orthoacetate. An analogous phenomenon has been observed for 1,3-disubstituted 2-thiohydantoins (XXX, X and Y = NR, Z = S) and other compounds with structure (XXX) and a bulky group Y.

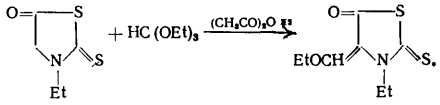
Pyrazolones (XXXII, X = NR) and isoxazolones (XXXII, X = O), which are more reactive, interact with ethyl orthoacetate and ethyl orthopropionate but the alkoxyalkylidene-derivatives formed are unstable for steric reasons. Ethyl thio-orthoformate cannot be made to react with the above types of ketomethylene compounds. Acetic anhydride plays the same role in this reaction as in the case of the acyclic methylene compounds discussed above.

A general method has been developed for the synthesis of 3-substituted 5,1′-alkoxyalkylidene-2-thionothiazolidin-4-ones by refluxing 3-R-rhodanine (R = aryl, alkyl, benzyl, cyclohexyl, allyl, and ethoxycarbonylmethyl) in the presence of an excess of orthoester and acetic anhydride [135,141,142]:

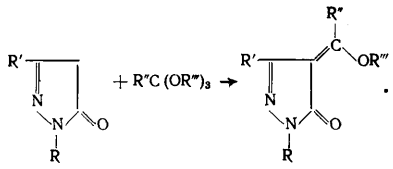


The highest yields of products are achieved with methyl and ethyl orthoacetates, while methyl and ethyl orthoformates and ethyl orthopropionate give somewhat less

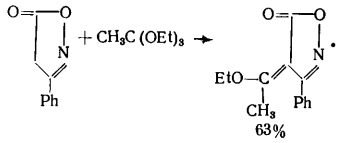
satisfactory results. When a mixture of 3-ethyl-2-thionothiazolidin-5-one is heated with ethyl orthoformate and acetic anhydride, the following reaction takes place [135]:



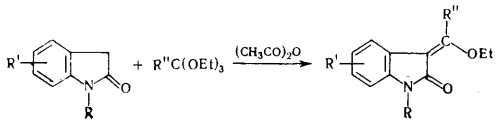
On refluxing with orthoesters in acetic anhydride [142] or in its absence [143], 1,3-disubstituted 5-pyrazolones readily form 4-alkoxyalkylidene derivatives:



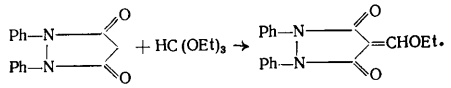
In the absence of acetic anhydride, 3-phenyloxazol-5-one reacts similarly with ethyl orthoacetate to form the unstable 4,1′-ethoxyethylidene-3-phenyloxazol-5-one [135]:



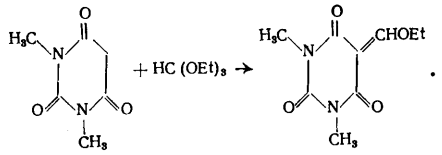
The condensation of orthoesters with oxindole [144] and its derivatives [145], in which the presence of a benzene ring causes additional activation of the methylene group, has been described:



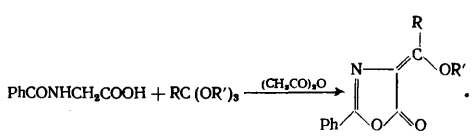
Diketomethylene heterocycles are also extremely reactive in the reaction with orthoesters. Ethyl orthoformate interacts with 1,2-diphenylpyrazole-3,5-dione [146]:



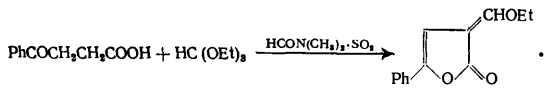
1,3-Dimethylbarbituric acid behaves similarly:



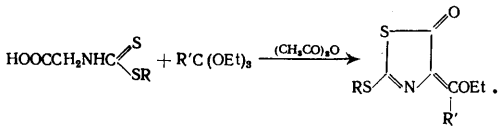
Frequently alkoxyalkylidene derivatives are synthesised in one stage from acyclic compounds. In such cases the condensation involving the methylene group is preceded by cyclisation with formation of a ketomethylene heterocycle. Thus, when hippuric acid was refluxed with orthoesters in acetic anhydride, 4,4′-alkoxyalkylidene-2-phenyloxazol-5-ones were obtained [147,148]:



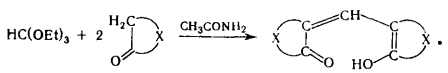
Benzoylpropionic acid reacts with ethyl orthoformate in the presence of a dimethylformamide–sulphur trioxide complex [149]:



N-(Ethylthiothionomethyl)glycine has been used [135] to synthesise 4,1′-alkoxyalkylidene-2-alkylthiothiazol-5-ones:

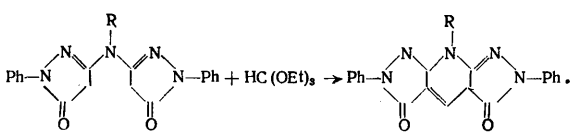


The reaction of orthoesters with ketomethylene heterocyclic compounds can lead to the so called oxonal dyes under certain conditions. Catalysis by a weak base (amides, pyridine) is sometimes used for such syntheses. Zenno [150] developed a method of synthesising oxonol dyes from ethyl orthoformate and certain ketomethylene heterocycles (3-methyl-1-phenylpyrazol-5-one, 3-ethylrhodanine, and barbituric, thiobarbituric, 1,3-diethylbarbituric, and 4-aminobarbituric acids) in the presence of acetamide:



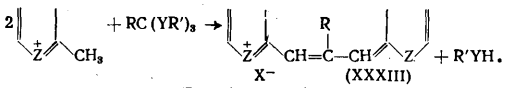
Oxonol dyes have also been obtained from 2-phenylthiazolidin-4-one [151] and certain 3-substituted 2-phenylpyrazolones [152].

The capacity of orthoesters to react with ketomethylene heterocycles can be used to cyclise certain compounds of suitable structure [153]:



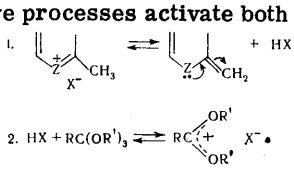
IX. SYNTHESES OF CYANINE DYES

Organic compounds containing a methyl group conjugated with a positively charged atom of a heterocyclic cation can react with orthoesters to form carbocyanine dyes (XXXIII):



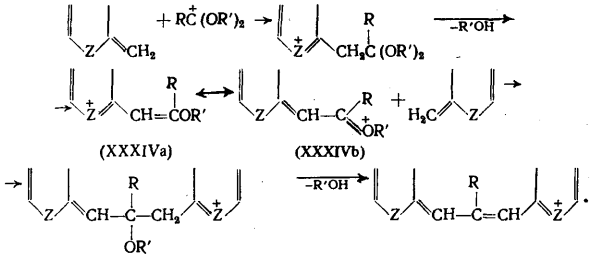
(Z=—NR, O,S; Y=O, S)

It is believed [154] that initially the charged system dissociates into a methylene base and an acid (HX), which reacts with the orthoesters to form a carboxonium salt. These consecutive processes activate both reactants:



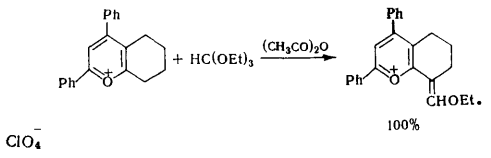
Dissociation is also promoted by solvents such as pyridine and acetic anhydride.

The aim of further reactions is clear from the following scheme:

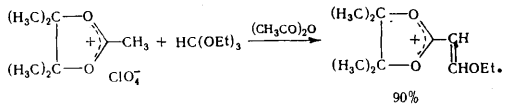


The scheme is valid also for thio-orthoesters.

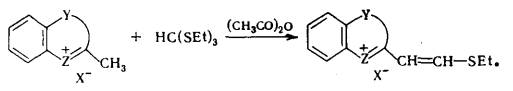
Mizuno and Tanabe [155] showed that the synthesis of cyanines does indeed proceed via an intermediate alkylidene derivative (XXXIV), which is also suggested by the sharp decrease of the yield of cyanine dyes in the presence of a large excess of orthoesters. In certain cases, alkoxyalkylidene compounds can be isolated as the main reaction product. Thus, when tetrahydrobenzopyrylium and tetrahydroxanthylium salts and their derivatives were heated briefly in acetic anhydride in the presence of ethyl orthoformate, the corresponding ethoxymethylene derivatives of these compounds were obtained [156,157]:



Ethoxymethylenedioxolanium salts are formed under similar conditions [158]:



This reaction is particularly characteristic of thio-orthoesters. For example, ethyl thio-orthoformate reacts with quaternary salts of 2-methylbenzothiazole, 2-methylbenzoxazole, and quinaldine on refluxing in acetic anhydride [159]:

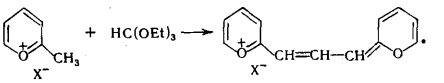


A wide variety of orthoesters are used in the synthesis of cyanine dyes. Orthoformates and thio-orthoformates form carbocyanines containing an unsubstituted trimethine chain (XXXIII, R = H) and orthoesters of higher acids give rise to dyes substituted at the central carbon atom of the chain. A wide variety of five-, six-, and seven-membered condensed systems condensed with other rings or charged monocyclic systems with one-, two-, or more heteroatoms can be involved in the reactions with orthoesters. Simple mononuclear heterocycles form cyanine dyes with greater difficulty than heterocycles condensed with aromatic rings.

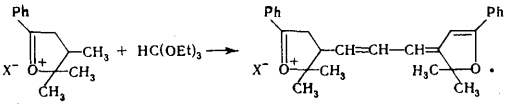
The greatest number of studies on the synthesis of cyanine dyes concern heterocycles of the thiazole series. Both monocyclic thiazolium salts [160] and salts condensed with benzene [161] and heterocyclic [162] rings have been used in the condensation reaction. The use of substituted imidazolium and benzimidazolium salts in this reaction has been described [163]. Pilyugin and coworkers synthesised cyanines from a wide variety of *N*-alkyl- and *N*-aryl-substituted quinaldinium [164] and benzoquinaldinium [165] quaternary salts. Lepidine derivatives [166] and other compounds containing the pyridine ring [167] enter into the reaction.

Trimethinecyanines are formed from benzoxazole [168], thienopyridine [169], 1,2,4-triazine [170], 1,4,7,9-tetra-azaindenes [171], 1,7-diazaindene [172], azepine [173], and tetrazole [174].

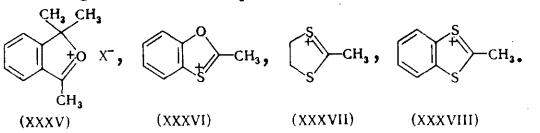
Oxonium heterocycles or their thio-analogues are used in the synthesis of cyanine dyes. Thus α- or γ-alkyl-substituted pyrylium [175] and benzopyrylium [176] salts and 9-methylxanthylium salts [177] readily form trimethine dyes on heating with ethyl orthoformate in pyridine or in a mixture of acetic anhydride and acetic acid:



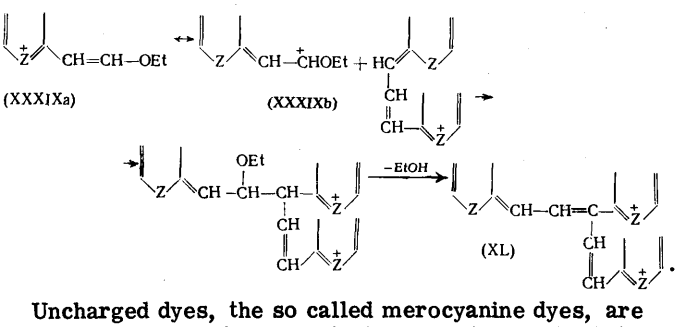
Non-aromatic furylium salts can also take part in the reaction [178]:



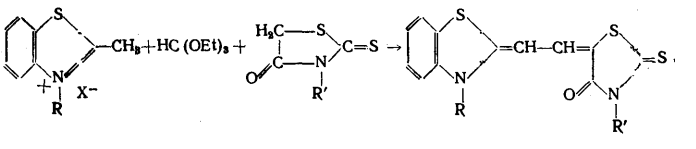
On heating in acetic acid or in a mixture of acetic anhydride and pyridine, ethyl orthoformate reacts with benzofurylium (XXXV) [179], benzoxanthylium (XXXVI) [180], dithiylium (XXXVII) [180] and benzodithiylium (XXXVIII) salts, forming trimethine dyes:



Trinuclear neocyanine dyes, for which Konig's formula (XL) [154] was recently shown to be correct [155], are almost invariably formed as side products in the synthesis of trimethinecyanines. The mechanism of the formation of neocyanines was investigated by Japanese workers [155], who observed that the yield of neocyanines is lower the higher the yield of trimethinecyanines. This indicates competition between two modes of binding of the alkoxymethylene cation (XXXIX):

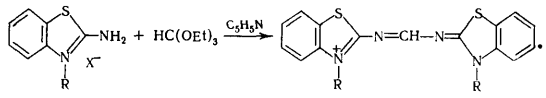


Uncharged dyes, the so called merocyanine dyes, are obtained when one of the reactants is a heterocyclic ketomethylene derivative and the other is a quaternary salt of a nitrogen-containing heterocycle [182]. For example:



Ethyl orthoformates react similarly with barbituric or thiobarbituric acid and quaternary salts of nitrogen-containing heterocycles (α-picoline, 2,6-lutidine, quinaldine, and 2-methylbenzothiazole)[183].

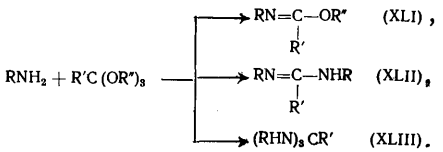
Orthoesters are suitable for the synthesis of azacyanines—compounds in which one or several methine groups are substituted by nitrogen atoms[184,185]:



X. REACTIONS OF ORTHOESTERS WITH AMINO-DERIVATIVES

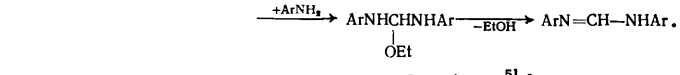
1. Synthesis of Acyclic Products

When orthoesters react with substances containing an amino-group (amines, amides, substituted ureas, and hydrazines, hydrazides, etc.) products of three types may be obtained depending on the reaction conditions and the structure and relative amounts of the components:



The first two reactions, which lead to imidoesters [imidates] (XLI) and amidines (XLII) respectively, are general, while the formation of nitrogenous analogues of orthoesters (XLIII) is possible only from certain compounds of suitable structure and constitutes a special case. Since the synthesis of imidoesters and amidines with the aid of orthoesters has been discussed in a number of reviews[186-188], we shall consider only the fundamental studies carried out recently.

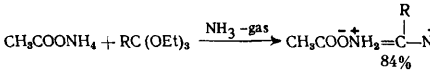
Spectroscopic studies on the reaction of aniline with ethyl orthoformate showed[189] that imidoesters are intermediates in the synthesis of amidines:



The formation of *N*-arylformimidoesters[51] becomes possible under the conditions of acid catalysis when the activation of orthoformate by the acid causes the rate of formation of the formimidoester to predominate over the rate of its conversion into diarylformamidine.

Roberts et al.[190] developed a general method for the synthesis of *N*-phenylformimidoesters by the reaction of alkyl orthoformate with aniline.

Ammonium acetate reacts with ethyl orthoformate and ethyl orthoacetate to form amidinium acetates[191]:

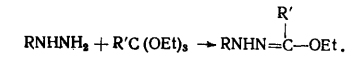


Dimethylformamidine is obtained by passing gaseous methylamine through ethyl orthoformate[192]. The synthesis of higher *NN*-dialkylformamidines in the presence of boron trifluoride-ether has also been described[193].

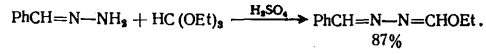
Heterocyclic bases react with orthoesters too. *N*-Heterocyclic derivatives of formimidoesters of the pyrazole[194], imidazole[194], isoxazole[195], isothiazole[196], and pyridine[197] series have been obtained.

Syntheses of formamidines from 5-aminopyrazole[198], 3-amino-2-pyrazoline[199], 2-aminopyrimidine[200], and 3-aminoisoxazole[201] have been described.

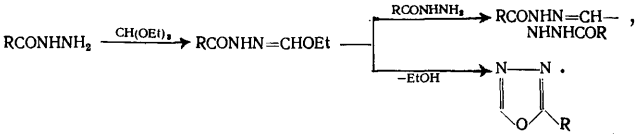
On heating with orthoesters, arylhydrazines[202] give high yields of ethoxyalkylidenehydrazines:



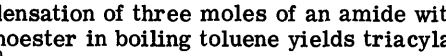
The reaction of benzaldehyde hydrazone with a fourfold excess of ethyl orthoformate in the presence of sulphuric acid yields ethoxymethylenephenylmethylenehydrazine, which contains conjugated double bonds[203]:



The reaction of carboxylic acid hydrazides with ethyl orthoformate, which can give rise to cyclic products in addition to ethoxymethylenehydrazides and hydrazidomethylenehydrazides takes place in a more complex manner[204,205]:



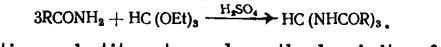
Owing to the reduced reactivity of the amino-group in acid amides, their reactivity in relation to orthoesters is much lower than that of amines, hydrazines, and hydrazides. Whereas ethyl orthoformate still reacts with acetamide and benzamide, giving low yields of diacylformamidines[206], ethyl orthoacetate can no longer be made to react in this way[207]:



The reactivity of urea and its derivatives is similar to that of acid amides. On refluxing with ethyl orthoformate, urea and its alkyl and arylalkyl derivatives yield high-melting sparingly soluble products—*NN*-dicarbamoylformamidines[208].

The condensation of ethyl orthoformate with urethanes in the presence of acids has been described[209].

The condensation of three moles of an amide with one mole of orthoester in boiling toluene yields triacylaminomethanes[210]:



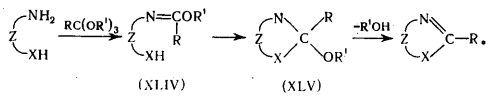
Electronegative substituents reduce the basicity of the amide and the yields of products are low.

2. Synthesis of Cyclic Compounds

When the molecule contains two amino-groups, the reaction usually leads to the formation of cyclic amidines. Cyclic systems with different heteroatoms are obtained when other functional groups are introduced into the reaction apart from the amino-group. The cyclisation is achieved by heating the components with or without the distillation of the alcohol.

It was sometimes possible to isolate the intermediates (XLIV) and (XLV) in the cyclisation reaction. The elimination of the alcohol from the alkoxy-derivative

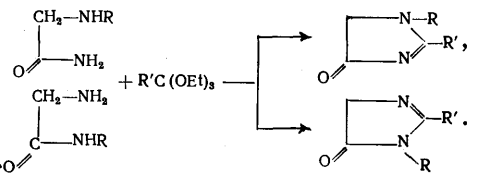
(XLV) is the rate-determining stage of the cyclisation process:



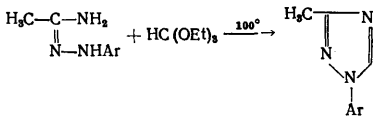
(XLIV) (XLV)

Usually X is a substituted or a free amino-group, oxygen, or sulphur. The group Z can be a carbochain or heterochain bridge and also constitutes part of a carbocyclic or heterocyclic system.

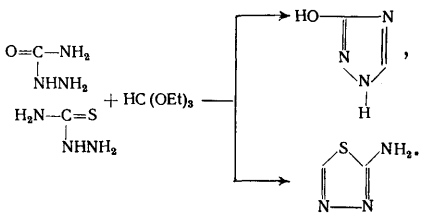
A general method of synthesising 4-imidazolones and 5-imidazalones is based on the cyclisation of *N*- or *N'*-substituted glycine amides [211]:



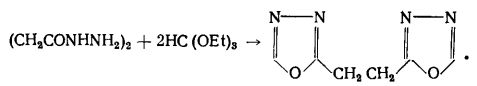
Acetamide arylhydrazones react with ethyl orthoformate to form 1-aryl-3-methyl-1,2,4-triazoles [212]:



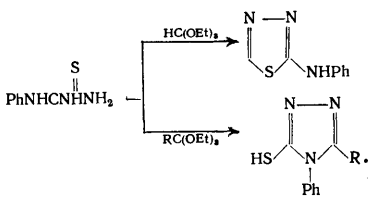
It is interesting that semicarbazide [213] and thiosemicarbazide [214] hydrochlorides form different types of heterocycles:



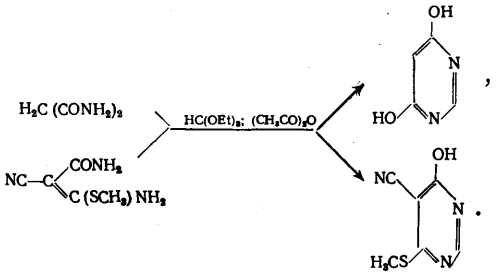
The synthesis [215] of heterodiazoles on refluxing hydrazides and thiohydrazides of alkyl- and aryl-substituted and heterocyclic carboxylic acids with orthoesters has been described. Succinic acid dihydrazide undergoes biscyclisation on treatment with ethyl orthoformate [204]:



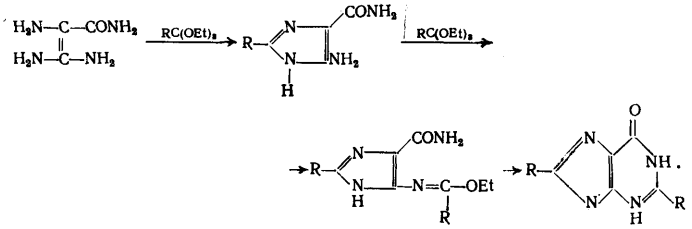
Owing to differences in the reactivities of orthoformates, the reaction of 4-phenylthiosemicarbazide with ethyl orthoformate or the orthoesters of alkanecarboxylic acids (ethyl orthoacetate and ethyl orthopropionate) gives two types of heterocycles[216]:



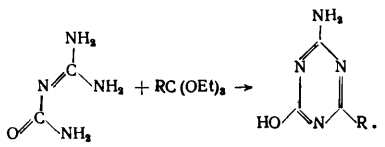
Malonodiamide [213] and 3-amino-2-cyano-3-methylthioacrylic acid cyclise in the presence of acetic anhydride [217]:



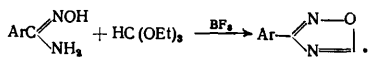
Hypoxanthine[218] and a number of its substituted derivatives [219] are obtained under similar conditions. The reaction proceeds via the formation of intermediates, which have been isolated:



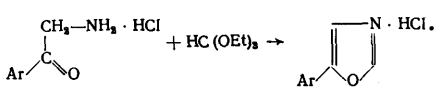
Guanylurea [220] can be condensed with orthoesters and the dimethylacetal of dimethylformamide with formation of substituted 1,3,5-triazines:



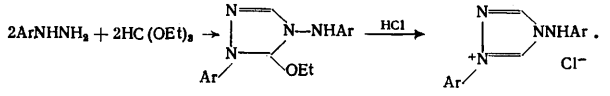
A convenient method for the synthesis of 3-aryl-1,2,4-oxadiazoles consists in heating the amidoximes of arylcarboxylic acids with ethyl orthoformate in the presence of boron trifluoride-ether [221]:



Oxazoles can be prepared from the hydrochlorides of substituted ω-aminoacetophenones and ethyl orthoformate [222]:

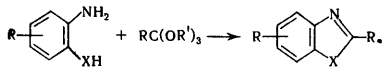


Arylhydrazines with electron-donating substituents in the benzene ring yield derivatives of 1,2,4-triazole on interaction with ethyl orthoformate [202]:



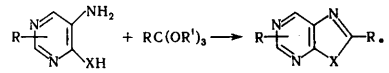
Condensed heterocyclic systems can be synthesised when the functional groups involved in cyclisation occupy the 1- and 2-positions in the benzene or heterocyclic ring.

When ring-substituted *o*-phenylenediamines[223], *o*-aminophenols[224], and *o*-aminothiophenols[225] react with orthoesters, the products are derivatives of benzimidazole, benzoxazole, and benzothiazole respectively:

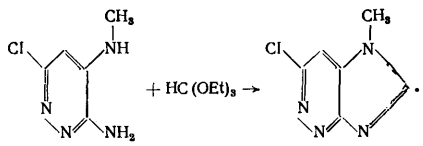


(X = NH; O; S; NR)

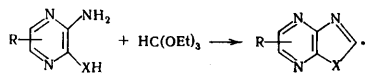
Heterocyclic compounds containing purine and thiazolopyrimidine groups were synthesised similarly from a wide variety of derivatives of 4,5-diamino,[226] 4-R-amino-5-amino-[227], and 5-amino-4-mercapto-pyrimidines[228]:



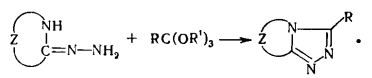
A substituted imidazopyridazine is obtained when 3-amino-6-chloro-4-methylaminopyridazine is heated with ethyl orthoformate[229]:



Syntheses of imidazopyrazines have been described[216,230]



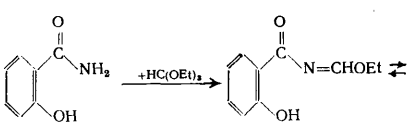
Heterocyclic systems containing three nitrogen atoms in the ring are formed when the hydrazones of a wide variety of heterocyclic keto-derivatives react with orthoesters:



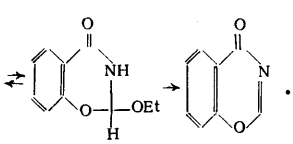
The hydrazones of 2-benzimidazolone, 2-benzoselenazolone[216], 2-quinolone[216], derivatives of 2-pyrimidinone[231], 4-quinazolone[232], 2-quinoxalinone[233], and imidazopyridazinone[234] can participate in this reaction.

When the amides of aromatic or heterocyclic carboxylic acids containing an active functional group in the *ortho*-position are introduced into the reaction with orthoesters, the products are six-membered heterocyclic keto-derivatives with two heteroatoms in the ring.

When the amide of salicyclic acid was refluxed with ethyl orthoformate, an intermediate iminoether (XLVI), which is a tautomer of the cyclic product (XLVII), was isolated[213,235]:



(XLVI)

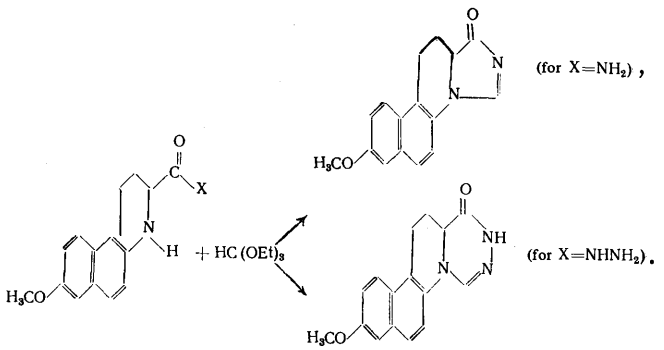


(XLVII)

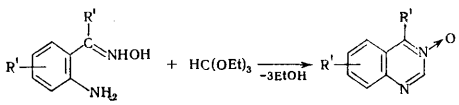
The reaction of the amide of anthranilic acid with ethyl orthoformate gives 4-quinazolone[213].

Apart from the amides of aromatic acid, a wide variety of heterocyclic *o*-substituted carbamides are used for similar cyclisations. The use of imidazole[236], isoxazole[237], 1,2,3-triazole[238], quinoline[239], pyrimidine[240], and pyrazine[241] derivatives has been described.

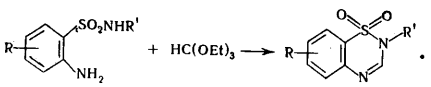
This principle has also been employed to synthesise di- and tri-azasteroid systems[242]:



On being refluxed with an excess of ethyl orthoformate, *o*-amino-derivatives of aldoximes and ketoximes give rise to quinazoline $N_{(3)}$-oxides[243]:

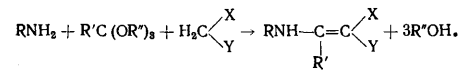


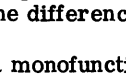
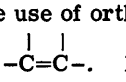
Aromatic sulphonamides with *o*-amino-substituents react with *o*-aminocarbamides, the difference being that in this case *SS*-dioxide rings are formed[244]:

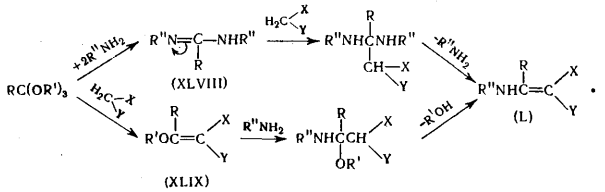


XI. THREE-COMPONENT CONDENSATIONS

This group combines single-stage reactions of orthoesters with amino-compounds (arylamines, heterocyclic amines, urea, and substituted ureas) and substances which can react as CH acids. For example:



At first sight this reaction resembles the Mannich reaction. The difference is that the Mannich reaction gives rise to a monofunctional aminoalkyl group  , while the use of orthoesters yields the bifunctional enamine unit  . Probably the reaction proceeds simultaneously via two similar mechanisms:



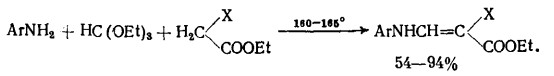
(XLVIII)

(XLIX)

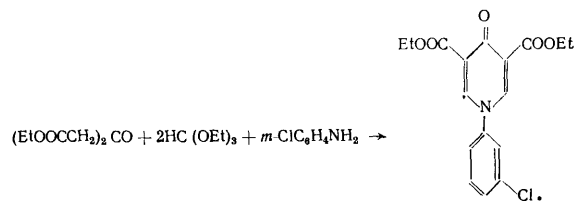
(L)

The yields of the intermediates (XLVIII) and (XLIX), where these are obtained specially by heating the components in pairs (the amine and the orthoester or the CH acid and the orthoester) are frequently much lower than the yield of the final product (L) obtained when all three starting materials are involved simultaneously in the reaction. Evidently the reason for this phenomenon may consist in a favourable mutual influence of the starting materials on one another. On the one hand, the formation of the alkoxyalkylidene compound (XLIX) should undoubtedly be facilitated by the catalytic action of the base (amine), while the acidity of the methylene component is a factor promoting the activation of the orthoester and therefore facilitating both reactions. Moreover, the products of the interaction of any pair of the starting compounds are removed from the sphere of the reversible reaction owing to the interaction with the third component.

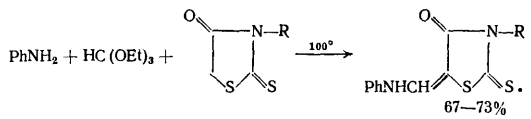
Three-component condensation was achieved for the first time by Snyder and Jones [244], who developed a method for synthesising β-arylamino-substituted acrylic esters by the reaction of compounds containing an active methylene group with aromatic amines and ethyl orthoformate:



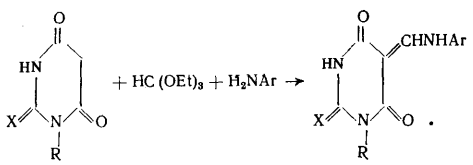
Later a general method was developed for the synthesis of a wide variety of enamines by the reaction of orthoesters with compounds containing an active methylene group and with arylamines [245]. The reaction of acetonedicarboxylic acid esters with ethyl orthoformate and *m*-chloroaniline gives a substituted pyridone [244]:



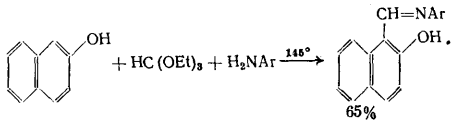
Ketomethylene heterocyclic derivatives may serve as the CH acid components in the reaction with aromatic amines and ethyl orthoformate [246]:



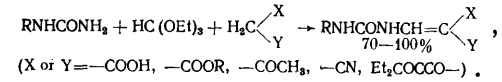
On heating with ethyl orthoformate and aromatic amines, barbituric [247], thiobarbituric [247], and 1,3-dimethylbarbituric [248] acids form arylaminomethylenebarbiturates:



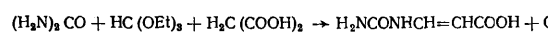
Aromatic phenolic systems can also behave as the CH acid components [249]. In this case the products are not enamines but Schiff bases:



Apart from aromatic amines, substituted ureas participate in this reaction. Whitehead [250,251] developed a general method for synthesising ureidoethylenes by the reaction of ethyl orthoformate with urea, *N*-cyclohexylurea, *N*-alkylureas, and *N*-arylalkylureas and compounds containing an active methylene group:

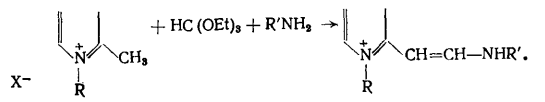


It was shown that the activity of the methylene component in this reaction decreases in the sequence COOH > CN > > $COCH_3 \gg COOC_2H_5$. Malonic acid and oxaloacetic ester, which are the most reactive, react even at room temperature; the reactions with acetylacetone, cyanoacetamide, acetoacetic ester, and cyanoacetic ester require heating for 8–12 h, while in the case of malononitrile refluxing for 1–2 h is sufficient. When malonic acid is allowed to react with ethyl orthoformate and urea on heating, the condensation involves the simultaneous decarboxylation of one of the carboxy-groups:

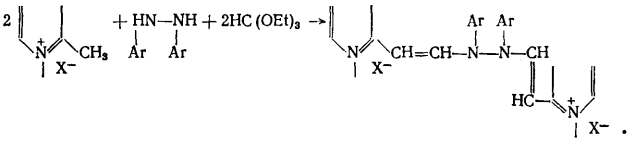


Other examples of the reaction of ethyl orthoformate with urea [252] or alkylureas [253–255] and cyanoacetic ester [256], malononitrile [255,257], nitroacetic ester [258], α-nitroacetonitrile [254], oxaloacetic ester [252], acetylpyruvate [252] and acetylacetothienone [259] have also been described.

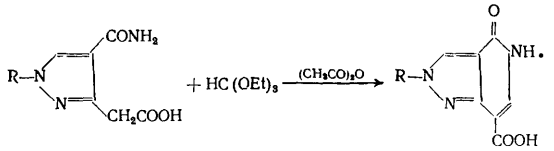
Knott [260] and Dzenno [261] showed that methyl-substituted quaternary salts of nitrogen-containing heterocycles (α-picoline, 2,6-lutidine, quinaldine, and 2-methylbenzothiazole) can take part in the reaction with ethyl orthoformate and aromatic amines (aniline, toluidine, *m*-aminophenol, *p*-aminoacetophenone):



Symmetrical disubstituted hydrazines, benzidine, and certain other diamines form bisdiaminodivinyl derivatives [262]:



When the molecule contains an amino- and an active methylene group simultaneously, internal condensation with formation of a cyclic product takes place [263]:



XII. OTHER REACTIONS OF ORTHOESTERS

The reactions of orthoesters with individual compounds, which do not fit the classification adopted in the review, are considered in this section.

In the presence of zinc chloride or boron trifluoride, ethyl orthoformate reacts with keten [264,265] according to the following mechanism:

$$HC(OEt)_3 + BF_3 \rightarrow \overset{+}{HC}(OEt)_2 + BF_3\bar{O}Et,$$

$$(EtO)_2\overset{+}{C}H + CH_2{=}C{=}O \rightarrow (EtO)_2CHCH_2\overset{+}{C}{=}O \xrightarrow{BF_3\bar{O}Et} (EtO)_2CHCH_2C(=O)OEt.$$

The interaction of orthoesters on heating with aliphatic, alicyclic, and aromatic isocyanates and also with polyisocyanates in the presence of acidic condensing agents (BF_3, $ZnCl_2$, $AlCl_3$) involves a similar mechanism [266,267]:

$$\overset{+}{RC}(OEt)_2 + R'N{=}C{=}O \rightarrow RC(OEt)_2NR'C^{+}{=}O \xrightarrow{X\bar{O}Et} \underset{70-90\%}{RC(OEt)_2NR'C(=O)OEt}.$$

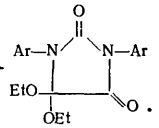
Acid catalysis is also essential for the reaction of ethyl orthoformate with diketen [77]:

$$HC(OEt)_3 + \underset{H_3C}{\overset{O-C=O}{\overset{|}{C}{=}CH}} \xrightarrow{BF_3} CH_3\overset{OEt}{\overset{|}{C}}{=}CHC(=O)OEt.$$

In the absence of acids, the reaction of isocyanates with orthoesters proceeds via a different mechanism. Thus Whitehead and Traverso [268] found that, when aryl isocyanates are refluxed (for 12–24 h) in the presence of an excess of ethyl orthoformate, 1,3-diaryl-5,5-diethoxyhydantoins are formed:

$$ArN{=}C{=}O \xrightarrow{HC(OEt)_3} ArNHCOC(OEt)_3 \xrightarrow{ArNCO}$$

$$\rightarrow ArNHCON(Ar)COC(OEt)_3 \rightarrow$$



In the presence of Lewis acids, diazoacetic ester and diazoacetone react with orthoesters to form addition products [269]:

$$RC(OR')_3 + \begin{cases} \xrightarrow{N_2CHCOOEt} (R'O)_2C(R)-CHCOOEt \\ \xrightarrow{N_2CHCOCH_3} (R'O)_2C(R)-CHCOCH_3 \end{cases}$$

The reaction proceeds with evolution of nitrogen and the yields of products are 37–99%.

The α-methylene group of the orthoesters of alkanecarboxylic acids [270] and phenylacetic acid [271] is readily brominated, the other groups remaining unaffected:

$$RCH_2C(OCH_3)_3 + Br_2 \xrightarrow[80\%]{C_5H_5N} RCH_2Br(OCH_3)_3.$$

The bromo-derivatives of orthoesters can be used to prepare keten acetals [270]:

$$RCHBrC(OCH_3)_3 + Na \rightarrow \underset{68\%}{RCH{=}C(OCH_3)_2} + NaBr + CH_3ONa.$$

Orthoesters containing in the α-position an activating group, such as phenyl [271] or the cyano-group [272], are a convenient source from which keten acetals may be obtained. In this case the alcohol may be split off both as a result of pyrolysis at 220–230°C and under the conditions of acid catalysis, the reaction being reversible in the presence of acids:

$$RCH_2C(OR')_3 \underset{H^+}{\overset{H^+}{\rightleftarrows}} RCH{=}C(OR)_2 + R'OH.$$

$$(R{=}{-}C_6H_5, {-}CN)$$

In certain cases, catalysis by strong bases was employed in the synthesis of keten acetals from orthoesters [273].

The formation of carbenes on treatment of di(methylthio)- or dialkoxy-carbonium salts of ethyldi-isopropylamine in methylene chloride at −10°C was reported recently [274]. The carbene dimerises under the reaction conditions, forming tetrasubstituted ethylenes:

$$(RO)_2\overset{+}{C}H \xrightarrow[-H^+]{i\text{-}Pr_2NEt} [(RO)_2C:] \xrightarrow{+(RO)_2\overset{+}{C}H} [(RO)_2\overset{+}{C}CH(OR)_2] \xrightarrow[-H^+]{} (RO)_2C{=}C(OR)_2.$$

The interaction of aromatic aldehydes with nitrogenous analogues of orthoesters is unusual [275]. The aminal of arylglyoxal (LI) formed initially subsequently disproportionates via the Cannizzaro reaction:

$$ArCHO + HC(OCMe_3)(NMe_2)_2 \xrightarrow{180^\circ} ArCOCH(NMe_2)_2,$$

(LI)

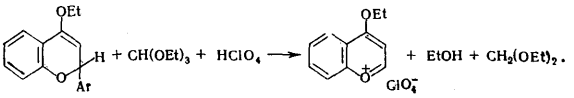
$$(LI) \rightarrow \begin{cases} ArCOC(NMe_2)_3 \\ ArCOCH_2NMe_2 + HC(OCMe_3)(NMe_2)_2 \rightarrow ArCOC(NMe_2){=}CHNMe_2. \end{cases}$$

The interaction of hydrocyanic acid [276] and acetonitrile [277] with orthoesters leads to the replacement of the alkoxy-group by a cyano-group:

$$RC(OR')_3 + R''CN \rightarrow RC(OR')_2CN + R''OR'.$$

$$(R''{=}H, CH_3)$$

In the presence of acidic agents, orthoesters can behave as hydride ion acceptors [278]:



The examples quoted in the present review by no means exhaust all the applications of orthoesters in organic synthesis.

REFERENCES

1. H. W. Post, "The Chemistry of the Aliphatic Orthoesters", Reinhold Publishing Corp., New York, 1943.
2. "Triaetylorthoformiat", Chem. Pharm. Tech. (Dordrecht), 8, 280 (1953).
3. J. Houben, "Methoden in organischen Chemie" (Translated into Russian), Inostr. Lit., Moscow–Leningrad, 1934, Vol. 3, No. 1.
4. C. Weygand and G. Hilgetag, "Organische-chemische Experimentierkunst" (Translated into Russian), Izd. Khimiya, Moscow, 1968.
5. L. Fieser and M. Fieser, "Organic Chemistry" (Translated into Russian), Izd. Mir, Moscow, 1970.
6. H. Stetter and E. Reske, Chem. Ber., 103, 643 (1970).
7. H. Post and E. Erickson, J. Org. Chem., 2, 260 (1937).
8. H. Bredereck, R. Gompper, F. Effenberger, H. Keck, and H. Heise, Chem. Ber., 93, 1398 (1960).
9. B. Föhlisch, Chem. Ber., 104, 348 (1971).
10. H. Meerwein, Angew. Chem., 67, 374 (1955).
11. R. McConnell and H. Coover, US P. 2972628 (1961).
12. S. Fitch, J. Amer. Chem. Soc., 86, 61 (1964).
13. M. Dangiyan, Byul. Arm. Otd. Akad. Nauk SSSR, 63 (1942).
14. K. Mason, J. Sperry, and E. Stern, J. Chem. Soc., 2558 (1963).
15. V. V. Mezheritskii and G. N. Dorofeenko, Khim. Geterotsikl. Soed., Collection 2, 232 (1970).
16. R. Roberts, D. Thomas, and D. Noyes, J. Amer. Chem. Soc., 77, 3801 (1955).
17. G. N. Dorofeenko, V. V. Mezheritskii, E. P. Olekhnovich, and A. L. Vasserman, Zhur. Org. Khim., 9, 395 (1973).

18. R. De Wolfe and R. Royston, J. Amer. Chem. Soc., 76, 4379 (1954).
19. R. De Wolfe and J. Jensen, J. Amer. Chem. Soc., 85, 3264 (1963).
20. C. Bunton and R. De Wolfe, J. Org. Chem., 30, 1371 (1965).
21. R. Mayer and H. Berthold, Z. Chem., 3, 310 (1963).
22. J. M. McKenna and F. Sowa, J. Amer. Chem.Soc., 60, 124 (1938).
23. C. Bowman, US P. 2976315 (1961).
24. J. Lalancette and Y. Beauregard, Tetrahedron Letters, 5169 (1967).
25. K. Brannock, J. Amer. Chem. Soc., 73, 4953 (1951).
26. B. A. Arbuzov and I. P. Bogonostseva, Izv. Akad. Nauk SSSR, Ser. Khim., 484 (1953).
27. R. Pike and A. Dewidar, Rec. Trav. chim., 83, 119 (1964).
28. L. Shorr, J. Amer. Chem. Soc., 76, 1390 (1964).
29. E. Peppe, US P. 2985679 (1961).
30. N. Schwartz, E. O'Brien, S. Karlan, and M. Fein, Inorg. Chem., 4, 66 (1965).
31. K. Hunger and F. Korte, Tetrahedron Letters, 2855 (1964).
32. A. I. Razumov and V. V. Moskva, Zhur. Obshch. Khim., 34, 3195 (1964).
33. R. Roberts, D. Thomas, P. Noyes, J. Amer. Chem. Soc., 77, 3801 (1955).
34. R. Rossi, P. Pino, F. Piacenti, L. Lardicci, and G. Delbino, Gazzetta, 97, 1194 (1967).
35. W. Mochel, C. Agre, and W. Kanford, J. Amer. Chem. Soc., 70, 2268 (1948).
36. H. Stetter and E. Reske, Chem. Ber., 103, 639 (1970).
37. B. Smith, Acta Chem. Scand., 10, 1006 (1956).
38. A. V. Bogdanova, M. F. Shostakovskii, A. N. Dolgikh, and G. I. Plotnikova, USSR P. 138248 (1961); Ref. Zhur. Khim. 3L104 (1962).
39. R. Mehrotra and R. Narain, Indian. J. Appl. Chem., 28, 53 (1965).
40. H. Baganz and L. Domaschke, Chem. Ber., 91, 650 (1958).
41. H. Stetter and K. Steinacker, Chem. Ber., 86, 790 (1953).
42. O. Vogl, B. Anderson, and D. Simons, Tetrahedron Letters, 415 (1966).
43. K. Freidenberg and W. Jacob, Chem. Ber., 80, 325 (1947).
44. R. Gardi, R. Vitali, and A. Ercoli, Tetrahedron Letters, 448 (1961).
45. R. Narain and R. Mehrotra, Indian J. Chem., 4, 538 (1966).
46. O. Dermer and F. Slezak, J. Org. Chem., 22, 701 (1957).
47. H. Post and E. Erickson, J. Org. Chem., 2, 260 (1937).
48. J. Scheeren and W. Stevens, Rec. Trav. chim., 85, 793 (1966).
49. H. Cohen and J. Mier, Chem. Ind. (London), 349 (1965).
50. R. Roberts and R. Vogt, J. Amer. Chem. Soc., 78, 4778 (1956).
51. F. Hussein and K. Al-Dulaimi, J. Chem. U. A. R., 9, 287 (1966).
52. R. M. Roberts and P. J. Vogt, "Organic Synthesis" (Translated into Russian), Inostr. Lit., Moscow, 1960, Vol. 10, p. 80.
53. L. Claisen, Ber., 47, 3171 (1914).
54. C. MacKenzie and J. Stocker, J. Org. Chem., 20, 1695 (1955).
55. S. Kabuss, Angew. Chem., 78, 714 (1966).
56. K. Dimroth and P. Heinrich, Angew. Chem., 78, 714 (1966).
57. H. Post, J. Amer. Chem. Soc., 55, 4176 (1933).
58. J. Klein and E. Bergman, J. Amer. Chem. Soc., 79, 3452 (1957).
59. G. Bianchetti, C. P. Dalla, and D. Pocarr, Rend. Ist. Lombardo Sci. e Letter. Sci. mat., fis. chim. e geol., 99, 259 (1965).
60. H. Fischer and E. Baer, Helv. Chim. Acta, 18, 516 (1935).
61. T. Wieland and E. Neeb, Annalen, 600, 161 (1956).
62. V. Evlampiev, Chem. Zentr., 999, III (1923).
63. G. Hesse and H. Moell, Naturwiss., 40, 411 (1953).
64. R. Mayer and B. Gebhardt, Chem. Ber., 3, 1212 (1960).
65. L. N. Yakhontov and M. V. Rubtsov, Zhur. Obshch. Khim., 26, 2844 (1956).
66. G. S. Gusakova, E. A. Panferov, and E. P. Polubneva, Zhur. Obshch. Khim., 29, 2768 (1959).
67. N. Whittaker and P. Russel, BRD P. 888692 (1953).
68. E. Meek, J. Turnbull, and W. Wilson, J. Chem. Soc., 811 (1953).
69. W. Kern, W. Heitz, and H. Wirth, Makromol. Chem., 42, 177 (1961).
70. A. Birch and D. White, J. Chem. Soc., 4086 (1964).
71. E. Tamelen and W. Proost, J. Amer. Chem. Soc., 76, 3632 (1954).
72. K. Nakama, M. Sawai, and Y. Suzuki, Japanese P. 11423 (1961); Chem. Abs., 58, 10271 (1963).
73. R. Gardi, P. Castelli, and A. Ercoli, Tetrahedron Letters, 497 (1962).
74. L. S. Povarov, Uspekhi Khim., 34, 1489 (1965) [Russ. Chem. Rev., No. 8 (1965)].
75. R. Hoaglin and D. Hirsh, J. Amer. Chem. Soc., 71, 3468 (1949).
76. T. V. Protopopova and A. P. Skoldinov, Zhur. Obshch. Khim., 27, 57 (1957).
77. L. A. Yanovskaya, S. S. Yufit, and V. F. Kucherov, Izv. Akad. Nauk SSSR, Otd. Khim. Nauk, 1246 (1960).
78. M. Haltquist, US P. 2459076; Chem. Abs., 43, 4291 (1949).
79. J. Copenhaver, US P. 2500486 (1946); Chem. Abs., 44, 5379 (1950).
80. A. N. Dolgikh, A. V. Bogdanova, and M. F. Shostakovskii, Izv. Akad. Nauk SSSR, Otd. Khim. Nauk, 340 (1964).
81. A. V. Stavrovskaya, T. V. Protopopova, and A. P. Skoldinov, Zhur. Org. Khim., 7, 267 (1971).
82. V. V. Mezheritskii and G. N. Dorofeenko, Zhur. Org. Khim., 3, 1533 (1967).
83. G. N. Dorofeenko and N. A. Lopatina, Khim. Geterotsikl. Soed., 160 (1971).
84. G. N. Dorofeenko and E. D. Olekhnovich, Zhur. Org. Khim., 6, 192 (1970).
85. G. N. Dorofeenko, V. V. Mezheritskii, and N. A. Lopatina, Khim. Geterotsikl. Soed., Collection 2, 238 (1970).
86. L. V. Mezheritskaya and G. N. Dorofeenko, Zhur. Obshch. Khim., 40, 2459 (1970).
87. J. Copenhaver, US P. 2677708; Chem. Abs., 49, 1812 (1955).
88. B. Howk and I. Sauer, J. Amer. Chem. Soc., 80, 4607 (1958).
89. R. Epsztein and I. Marszak, Bull. Soc. chim. France, 313 (1968).
90. V. B. Mochalin and N. G. Ivanova, Zhur. Obshch. Khim., 31, 3896 (1961).

91. H. Gross, A. Rieche, and G. Matthey, Chem. Ber., 96, 308 (1963).
92. T. Amakasu and K. Sato, Bull. Chem. Soc. Japan, 40, 1428 (1967).
93. W. Treibs, Tetrahedron Letters, 4707 (1967).
94. G. Bach, E. Poppe, and W. Treibs, Naturwiss., 45, 517 (1958).
95. R. Schaah, J. Org. Chem., 27, 107 (1962).
96. A. Treibs, E. Herrman, E. Meissner, and A. Kuhn, Annalen, 602, 153 (1957).
97. H. Plieninger, H. Bauer, and A. Katritzky, Annalen, 654, 165 (1962).
98. E. Leete, Acta. Chem. Scand., 14, 2064 (1960).
99. H. Plieninger and D. Wild, Chem. Ber., 99, 3063 (1966).
100. C. Wood and M. Comley, J. Soc. Chem. Ind., 42, 429T (1923).
101. A. E. Chichibabin, Ber., 38, 563 (1905).
102. A. E. Chichibabin and L. Elgazin, Ber., 47, 1851 (1914).
103. G. Bachman, "Organic Syntheses" (Translated into Russian), Inostr. Lit., Moscow, 1949, Vol. 2, p. 295.
104. J. Cymerman-Craig, E. Davis, and J. Lake, J. Chem. Soc., 1874 (1954).
105. W. Young and J. Roberts, J. Amer. Chem. Soc., 68, 649 (1946).
106. P. Montijn, H. Schmidt, J. Boom, H. Bos, L. Brandsma, and J. Arens, Rec. Trav. chim., 84, 271 (1965).
107. H. Norman, Bull. Soc. chim. France, 728 (1957).
108. F. Popp and W. McEwen, J. Amer. Chem. Soc., 80, 1181 (1956).
109. S. T. Ioffe and A. N. Nesmeyanov, "Metody Elementoorganicheskoi Khimii" (Methods of the Chemistry of Organic Derivatives of the Elements), Izd. Akad. Nauk SSSR, Moscow, 1963, p. 336.
110. R. Jones, J. Amer. Chem. Soc., 74, 4889 (1952).
111. J. Pascual and M. Ballester, Anales real. Soc. españ. Fís. Quím., 45B, 87 (1949).
112. H. Post and E. Erickson, J. Amer. Chem. Soc., 55, 3851 (1933).
113. H. Post and E. Erickson, J. Org. Chem., 2, 260 (1937).
114. L. Claisen, Ber., 40, 3903 (1907).
115. R. Jones, J. Amer. Chem. Soc., 73, 3684 (1951).
116. R. Fuson, W. Parham, and L. Reed, J. Org. Chem., 11, 194 (1946).
117. G. Duffin and J. Kendall, J. Chem. Soc., 893 (1948).
118. N. A. Tikhonova, K. K. Babievskii, and V. M. Belikov, Izv. Akad. Nauk SSSR, Ser. Khim., 877 (1967).
119. A. Taylor, B. P. 842797 (1960).
120. E. Stiller, US P. 2422598 (1947); Chem. Abs., 41, 5903 (1947).
121. H. Yasuda, J. Pharm. Soc. Japan, 79, 836 (1959).
122. G. Errera, Ber., 31, 1682 (1898).
123. E. De-Bollemont, Bull. Soc. chim. France, 25, 18 (1901).
124. T. Cuvigny and H. Norman, Bull. Soc. chim. France, 2423 (1961).
125. G. Shaw, J. Chem. Soc., 1834 (1955).
126. R. Ralph and G. Shaw, J. Chem. Soc., 1877 (1956).
127. T. Passalacqua, Gazzetta, 43, 11, 566 (1913).
128. M. Nishimura, K. Ito, M. Tsurushima, and N. Inoue, Japanese P. 15961; Chem. Abs., 62, 10344 (1965).
129. R. Weis and K. Woidich, Monatsh., 47, 427 (1926).
130. J. Chatterjea and K. Prasael, J. Indian Chem. Soc., 32, 371 (1955).
131. W. E. Parham and L. J. Reed, "Organic Syntheses" (Translated into Russian), Inostr. Lit., Moscow, 1953, Vol. 4, p. 596.
132. K. Gunderman, Annalen, 578, 48 (1952).
133. R. Kuhn and P. Lutz, Biochem. Z., 338 (1963).
134. T. Miki, K. Higara, T. Asako, and H. Masuya, Chem. Pharm. Bull. (Japan), 15, 670 (1967).
135. E. Knott, J. Chem. Soc., 1482 (1954).
136. L. Nicholl, P. Tarsic, and H. Blohm, US P. 2824121 (1958); Chem. Abs., 52, 11909 (1958).
137. A. Kiang and S. Tan, J. Chem. Soc., 5646 (1964).
138. M. Scidel, G. Van-Tuyle, and W. Weiz, J. Org. Chem., 35, 1475 (1970).
139. R. Warrener and E. Cain, Tetrahedron Letters, 3225 (1966).
140. V. Sathe and K. Venkataraman, Current Sci., 18, 373 (1949).
141. Lo Chien-Pen and W. Croxall, J. Amer. Chem. Soc., 76, 4166 (1954).
142. P. Tripathy and M. Rout, J. Sci. Ind. Res., B20, 177 (1961).
143. J. Kendall and D. Fry, B. P. 544647 (1940); Chem. Abs., 37, 1046 (1943).
144. H. Behringer and H. Weissauer, Chem. Ber., 85, 774 (1952).
145. G. Walker, J. Amer. Chem. Soc., 77, 3844 (1955).
146. F. Eiden, Arch. Pharm., 295/67, 533 (1962).
147. J. Kendall and G. Daffin, B. P. 633736 (1949); Chem. Abs., 44, 7175 (1950).
148. P. Tripathy and M. Rout, J. Indian Chem. Soc., 36, 625 (1959).
149. Y. Rao and R. Filler, Chem. Ind. (London), 280 (1964).
150. H. Zenno, J. Pharm. Soc. Japan, 73, 1063 (1953).
151. F. N. Stepanov and Z. Z. Moiseeva, Zhur. Obshch. Khim., 25, 1977 (1955).
152. C. M. Smith, US P. 2903452.
153. B. Graham, W. Reckhow, and A. Weissberger, J. Amer. Chem. Soc., 76, 3993 (1954).
154. W. Konig, Ber., 57, 685 (1924).
155. Y. Mizuno and Y. Tanabe, J. Pharm. Soc. Japan, 73, 227 (1953).
156. W. Stewens and R. Wizinger, Helv. Chim. acta, 44, 1708 (1961).
157. G. N. Dorofeenko and E. P. Olekhnovich, Khim. Geterotsikl. Soed., (in the press)
158. G. N. Dorofeenko and L. V. Mezheritskaya, Khim. Geterotsikl. Soed., (in the press).
159. J. Kendall and J. Majer, J. Chem. Soc., 687 (1948).
160. E. D. Sych, Ukrain. Khim. Zhur., 22, 80, 217 (1956); 24, 79 (1958).
161. A. N. Kiprianov and I. P. Fedorova, Zhur. Obshch. Khim., 28, 1023 (1958).
162. A. V. Stetsenko and V. I. Ivanova, Ukrain. Khim. Zhur., 22, 772 (1956).
163. L. M. Yagupol'skii and V. I. Troitskaya, Zhur. Obshch. Khim., 29, 2730 (1959).
164. G. G. Pilyugin and E. P. Opanasenko, Uch. Zap. Chernovitskogo Gos. Univ., 21, 68 (1956).
165. I. P. Chernyuk, G. G. Pilyugin, and A. N. Gorelikov, Zhur. Org. Khim., 1, 923 (1965).
166. G. T. Pilyugin and Ya. O. Gorichuk, Khim. Geterotsikl. Soed., 122 (1967).
167. M. Pailer and E. Kuhn, Monatsh., 84, 85 (1953).
168. L. Basaglia and B. Mariani, Chimica e Industria, 46, 633 (1964).
169. V. G. Zhiryakov and P. I. Abramenko, Zhur. Obshch. Khim., 35, 150 (1965).
170. C. Cogrossi, B. Mariani, and S. Renato, Chimica e Industria, 46, 530 (1964).

171. B. Mariani and R. Sgarbi, Chimica e Industria, 46, 630 (1964).
172. G. Ficken and J. Kendall, J. Chem. Soc., 3202 (1959).
173. L. K. Mushkalo and S. K. Mikhailenko, Ukrain. Khim. Zhur., 30, 202 (1961).
174. A. Sieglitz, L. Berlin, and H. Hamal, US P. 2770620 (1956); Chem. Abs., 51, 5608 (1959).
175. H. Strzelecka, Ann. Chim., 1, 201 (1966).
176. H. Brockmann, H. Junge, and R. Muhman, Ber., 77, 529 (1944).
177. R. Wizinger and U. Arni, Chem. Ber., 92, 2309 (1959).
178. A. Fabrycy, Chimia, 15, 552 (1961).
179. A. Fabrycy, Roczniki. Chem., 34, 1837 (1960).
180. R. Wizinger and D. Durr, Helv. Chim. Acta, 46, 2167 (1963).
181. T. Soder and R. Wizinger, Helv. Chim. Acta, 42, 1733 (1959).
182. F. Hamer, R. Rathbone, and B. Winton, J. Chem. Soc., 1113, 1126 (1949).
183. H. Dzenno, J. Pharm. Soc. Japan, 73, 301 (1953).
184. A. I. Kiprianov and T. M. Verbovskaya, Zhur. Obshch. Khim., 33, 479 (1963).
185. S. Hung, F. Bruhne, and E. Breither, Annalen, 667, 72 (1963).
186. A. Pinner, "Die Imidoäther ihre Derivate", Verlag Oppenheim, Berlin, 1892.
187. R. Shriner and F. Neuman, Chem. Rev., 35, 351 (1944).
188. R. Roger and D. Neilson, Chem. Rev., 61, 179 (1961).
189. R. Roberts and R. De Wolfe, J. Amer. Chem. Soc., 76, 2411 (1954).
190. R. Roberts, D. Thomas, and P. Noyes, J. Amer. Chem. Soc., 77, 3801 (1955).
191. E. Taylor and W. Ehrhart, J. Amer. Chem. Soc., 82, 3138 (1960).
192. F. Fischer, W. Neumann, and J. Roch, Annalen, 633, 158 (1960).
193. G. Lehman, H. Seefluth, and G. Hilgetag, Chem. Ber., 97, 299 (1964).
194. E. Taylor and P. Loeffler, J. Amer. Chem. Soc., 82, 3147 (1960).
195. E. Taylor and E. Garcia, J. Org. Chem., 29, 2116 (1964).
196. K. Hartke and L. Peshkar, Angew. Chem., 79, 56 (1967).
197. R. Lorenz, B. Tullar, C. Kolsch, and S. Archer, J. Org. Chem., 30, 253 (1965).
198. S. Cheechi and M. Ridi, Gazzetta, 87, 597 (1957).
199. G. Duffin and J. Kendall, B. P. 743505 (1956).
200. K. Banno and M. Hayamiza, Japanese P. 16E461, No. 6489 (1963); Chem. Abs., 59, 11387 (1963).
201. H. Kano and E. Yamazaki, Tetrahedron, 20, 159 (1964).
202. C. Runti and C. Nisi, J. Med. Chem., 7, 814 (1964).
203. I. Hagedorn and H. Wunkelman, Chem. Ber., 99, 850 (1966).
204. C. Runti, L. Sindellari, and C. Nisi, Ann. Chim. (Italy), 49, 1649 (1959).
205. M. Vincent, J. Mailard, and M. Banard, Bull. Soc. chim. France, 1580 (1962).
206. T. Oda, N. Tanimoto, and S. Matsuda, J. Chem. Soc. Japan, 59, 610 (1955).
207. R. Roberts, J. Amer. Chem. Soc., 71, 3848 (1949).
208. C. Whitehead, J. Amer. Chem. Soc., 75, 671 (1953).
209. A. V. Stavrovskaya, T. V. Protopopova, and A. P. Skoldinov, Zhur. Org. Khim., 3, 1749 (1967).
210. H. Bredereck, F. Effenberger, and H. Treiber, Chem. Ber., 96, 1505 (1963).
211. M. Leplawy, D. Jones, G. Kenner, and R. Sheppard, Tetrahedron, 21, 39 (1960).
212. N. N. Vereshchagina and I. Ya. Postovskii, Nauch. Dokl. Vys. Shkoly, Khim. i Khim. Tekhnol., 341 (1959).
213. C. Runti, V. D'Osualdo, and F. Ulian, Ann. Chim. (Italy), 49, 1668 (1959).
214. Kanaoka, J. Pharm. Soc. Japan, 75, 1149 (1955).
215. C. Ainsworth, US P. 2733245 (1956).
216. G. Reynolds and J. Van Allan, J. Org. Chem., 24, 1478 (1959).
217. K. Dornow and K. Dehmer, Chem. Ber., 100, 2577 (1967).
218. E. Richter and E. Taylor, Angew. Chem., 67, 303 (1955).
219. E. Richter, J. Loeffler, and E. Taylor, J. Amer. Chem. Soc., 82, 3144 (1960).
220. A. Piskala, Coll. Czech. Chem. Comm., 32, 3966 (1967).
221. M. Arbasino and P. Grünanger, Chimica e Industria, 45, 1238 (1963).
222. N. P. Demchenko and A. P. Grekov, Zhur. Obshch. Khim., 32, 1219 (1962).
223. J. Hoover and R. Day, J. Amer. Chem. Soc., 77, 4324 (1955).
224. Tanabe, Rept. Fac. Pharmacy Kanazawa Univ., 5, 61 (1955).
225. W. Ried and W. Storbeck, Arch. Pharm., 295/67, 143 (1962).
226. J. Montgomery, J. Amer. Chem. Soc., 78, 1928 (1956).
227. R. Robins and Lin Hsi Hu, J. Amer. Chem. Soc., 79, 490 (1957).
228. L. Marchal and R. Promed, Bull. Soc. chim. belges, 66, 407 (1957).
229. H. Murakami and R. Castle, J. Heterocycl. Chem., 4, 555 (1967).
230. F. Muehlman and A. Day, J. Amer. Chem. Soc., 78, 242 (1956).
231. K. Sirakawa, J. Pharm. Soc. Japan, 79, 903 (1959).
232. I. P. Postovskii, N. N. Vereshchagina, and S. L. Mertsalov, Khim. Geterotsikl. Soed., 130 (1966).
233. S. Den-itsu and T. Shoichiro, J. Amer. Chem. Soc., 82, 4044 (1960).
234. B. Stanovnik and M. Tisler, Tetrahedron Letters, 2403 (1966).
235. T. Trie, E. Kurosawa, and T. Hanada, J. Chem. Soc. Japan, 79, 1401 (1958).
236. C. Leese and G. Timmis, J. Chem. Soc., 3818 (1961).
237. E. Taylor and E. Garcia, J. Org. Chem., 29, 2116 (1964).
238. E. Richter and E. Taylor, J. Amer. Chem. Soc., 78, 5848 (1956).
239. E. Taylor and W. Kalenda, J. Amer. Chem. Soc., 78, 5108 (1956).
240. H. Mautner, J. Org. Chem., 23, 1450 (1958).
241. E. Taylor, J. Carbon, and R. Hoff, J. Amer. Chem. Soc., 75, 1904 (1953).
242. R. Emrys, J. Chem. Soc., 5907 (1964).
243. R. Haraoka, T. Kamiya, and K. Kariyone, Japanese P. 11645 (1966); Ref. Zhur. Khim., 14Zh327P (1967).
244. H. Snyder and R. Jones, J. Amer. Chem. Soc., 68, 1253 (1946).
245. R. Boyle, P. Susi, and J. Milionis, US P. 3079366 (1963).

246. L. G. Bogolyubskaya, V. A. Bogolyubskii, and Z. P. Sytnik, Zhur. Org. Khim., 2, 1315 (1966).
247. H. Dzenno, J. Pharm. Soc. Japan, 73, 1066 (1963).
248. J. Clark-Lewis and M. Thompson, J. Chem. Soc., 2401 (1959).
249. E. Knott, J. Chem. Soc., 976 (1947).
250. C. Whitehead, J. Amer. Chem. Soc., 75, 671 (1953).
251. C. Whitehead, US P. 2774760 (1956).
252. Esida, Kato, and Oda, J. Chem. Soc. Japan, Ind. Chem. Sect., 56, 161 (1953).
253. D. Brown, J. Appl. Chem., 6, 358 (1955).
254. D. Brown, J. Appl. Chem., 9, 203 (1959).
255. B. B. Kehn and C. Whitehead, "Organic Syntheses" (Translated into Russian), Inostr. Lit., Moscow, 1959, Vol. 9, p. 14.
256. F. Weygand and O. Swoboda, Z. Naturforsch., 369 (1956).
257. M. Prystas and F. Sorm, Coll. Czech. Chem. Comm., 31, 3990 (1966).
258. M. Prystas and J. Gut, Coll. Czech. Chem. Comm., 28, 2501 (1963).
259. T. Nishiwaki, Tetrahedron, 23, 2979 (1967).
260. E. Knott, B. P. 609812 (1948); Chem. Abs., 43, 2642e (1949).
261. H. Dzenno, J. Pharm. Soc. Japan, 73, 589 (1953).
262. H. Dzenno, J. Pharm. Soc. Japan, 73, 592 (1953).
263. E. Taylor and K. Hartke, J. Amer. Chem. Soc., 81, 2456 (1959).
264. W. Gresham, US P. 2449471 (1948); Chem. Abs., 43, 1055 (1949).
265. F. Šorm and J. Smrť, Chem. Listy, 47, 413 (1953).
266. H. Brachel and R. Merten, Angew. Chem., 74, 872 (1962).
267. H. Brachel, BRD P. 1156780 (1964).
268. C. Whitehead and J. Traverso, J. Amer. Chem. Soc., 80, 962 (1958).
269. A. Schönberg and K. Praefcke, Tetrahedron Letters, 2043 (1964).
270. S. McElvain, R. Kent, and C. Stevens, J. Amer. Chem. Soc., 68, 1922 (1946).
271. S. McElvain and C. Stevens, J. Amer. Chem. Soc., 68, 1917 (1946).
272. S. McElvain and J. Schroeder, J. Amer. Chem. Soc., 71, 47 (1949).
273. S. McElvain and R. Clarke, J. Amer. Chem. Soc., 69, 2661 (1947).
274. R. Olofson, S. Walinsky, J. Marino, and J. Jernow, J. Amer. Chem. Soc., 90, 6554 (1968).
275. H. Bredereck, G. Simchen, G. Kanaun, and R. Wahl, Chem. Ber., 103, 2980 (1970).
276. J. Erickson, J. Amer. Chem. Soc., 73, 1338 (1951).
277. H. Bredereck, G. Simchen, and W. Kantlehner, Chem. Ber., 104, 924 (1971).
278. G. N. Dorofeenko and V. V. Tkachenko, Zhur. Org. Khim., 7, 2633 (1971).

Institute of Physical and
Organic Chemistry at
Rostov-on-Don State
University