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ADVANCES IN THE SYNTHESIS OF PERFUMES POSSESSING AN ISOPRENOID STRUCTURE

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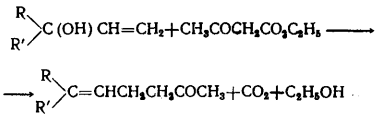
1. INTRODUCTION

Compounds of isoprenoid structure are known to occupy a special position in the chemistry of perfumes. This group includes a large number of natural compounds having valuable scents, as well as synthetic compounds which are not found in Nature.

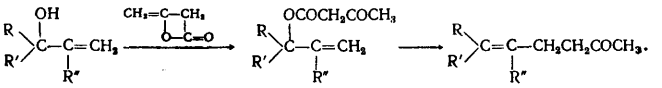
The evolution of scientific research in this field has been characterised during recent years not only by a continuation of the intensive search for new perfumes but also by considerable advances in developing industrial methods for the synthesis of many important compounds of this type from the simplest chemical raw materials. This work is examined in the present review.

2. TERPENOID AND SESQUITERPENOID COMPOUNDS

The direction of research on the synthesis of compounds of isoprenoid structure was greatly affected by the work of Carroll, who in 1940 proposed an elegant method for preparing unsaturated ketones by the treatment of tertiary allylic alcohols with acetoacetic ester in the presence of sodium ethoxide or of other alkaline reagents[1,2]:



This method†, subsequently developed by several other chemists, opened up wide possibilities for the preparation of the most important intermediates of isoprenoid structure. One of the most promising variants of Carroll's method is the use of diketen instead of acetoacetic ester. In this process the unsaturated ketone is obtained by condensation of the corresponding unsaturated vinylmethanol with diketen followed by pyrolysis of the resulting acetoacetate:



Among the compounds obtained in this way, 6-methylhept-5-en-2-one (I) [3] was described as early as 1943. A little later 5,6-dimethylhept-5-en-2-one (Ia) was obtained in a similar manner from 2,3-dimethylbut-1-en-3-ol (IIa) [5] (see Scheme 1, p.122).

During recent years various aspects of these reactions have been studied. A detailed investigation has been made of the conditions for the conversion of tertiary allylic alcohols into unsaturated ketones by the Carroll reaction[6-13]. Dreux and Colonge[7] suggested the use of aluminium isopropoxide as catalyst, and also studied the effect of the

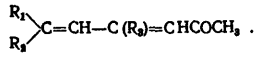
† For the reaction mechanism, see Refs. 1, 3, and 4.

structure of the initial alcohols on the yield of the unsaturated ketones. Nazarov and his collaborators[9-11] established that the alcohols can be made to react with acetoacetic ester even in the absence of a catalyst, if reaction is carried out under pressure or in high boiling solvents; high yields can be achieved if the ethyl alcohol formed is distilled off during the reaction (using a fractionating column)[9].

Results have been obtained showing that, during the reaction of acetoacetic ester with an unsaturated tertiary alcohol, formation of an unsaturated ketone involves the intermediate formation of an acetoacetate[11]; on the other hand, it has been shown that unsaturated ketones can be obtained from substituted vinylmethanols by the "diketen" method in a single stage without isolation of an acetoacetate[9,14].

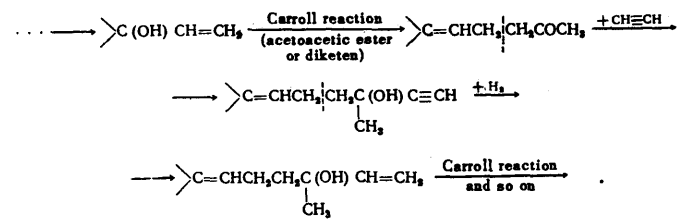
Amines — piperidine, pyridine, triethylamine, and several others[9-11] — are among new catalysts suggested for the formation of acetoacetate by the "diketen" method.

An interesting extension of the method was found in 1953 by Kimel and Sax[15], who showed that tertiary ethynylmethanols can be converted in this way into dienones. This allowed for the first time the transition to be made from dehydrolinalool (III), a product of the condensation of 6-methylhept-5-en-2-one (I) with acetylene, *via* its acetoacetate (IV) to pseudoionone (V), and also from dehydromethyllinalool (IIIa), obtained in a similar way from 5,6-dimethylhept-5-en-2-one (Ia), to pseudoirone (Va). Kimel and Sax's method was soon developed by Lacey[16,17] and applied to the synthesis of various dienones of general formula:



During subsequent years this method was subjected to a thorough and comprehensive investigation, special attention being paid to the development of various modifications of the synthesis of pseudoionone (V) and pseudoirone (Va). The possibility was noted of obtaining (V) and (Va) by the direct reaction of (III) and (IIIa) respectively with acetoacetic ester[4,11,12,18-24] or even by condensation with diketen followed by pyrolysis of the resulting acetoacetate (IV) or (IVa) respectively[8,11,15,25-27].

The elaboration of new methods for obtaining dienones of the type of pseudoionone and pseudoirone from acetylenic alcohols has played an extremely important part in the further development of the synthesis of compounds of terpenoid structure. At the present time an isoprenoid chain of any desired size can be constructed by repeated introduction of an acetonyl radical followed by condensation of the resulting ketone with acetylene and selective hydrogenation of the triple bond to a double bond:

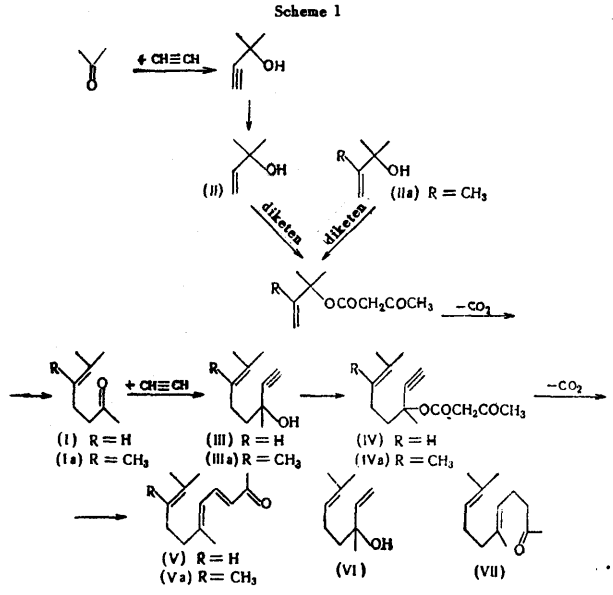


The condensation of acetylene with ketones in the presence of alkalis, leading to the formation of the corresponding ethynylmethanol, was discovered by Favorskii‡ as early as 1900.[28,29] Thanks to the detailed elaboration of this method by Nazarov and his coworkers[30-33], who studied the condensation of acetylene with many carbonyl compounds, no appreciable difficulty was encountered in carrying out the reaction under industrial conditions. Data on the condensation of acetylene with acetone (influence of solvents, nature and amount of alkaline agent, and added alcohols) have recently been reported in a paper by Japanese chemists[34], and also in Lacey and Jowitt's patent[35]. This reaction can also be carried out in solution in liquid ammonia in the presence of metallic sodium[6,8].

There is no difficulty in converting the ethynyl alcohol to the corresponding vinyl alcohol, the selective hydrogenation of the acetylenic to an ethylenic bond, under industrial conditions. This reaction has been quite well studied on many examples[30,33,36-43].

The above scheme for synthesising a terpenoid molecule has already found practical application in the USA, where Hoffmann-La Roche have constructed large works near New York for the synthesis of linalool, citral, and a group of isoprenoid vitamins[44-47]. From the general scheme for the production of terpenoid compounds in these works, we give below only that part which relates to the synthesis of pseudoionone (V) and pseudoirone (Va) (Scheme 1).

Scheme 1



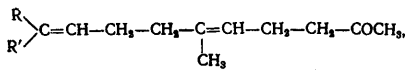
The yield of (V) is 35% based on the initial acetone and acetylene.

The above authors note the wide possibilities for the synthesis of terpenoid compounds opened up by the application of this method: thus linalool (VI) and dihydrolinalool can be obtained by the partial hydrogenation of dehydrolinaloool; condensation of linalool with diketen and subsequent decomposition of the resulting acetoacetate yields geranylacetone (VII), from which sesquiterpenoid alcohols and their ethers,

‡ For the significance of this work and also of other investigations by Favorskii on the synthesis of isoprenoid compounds see the recently published review by Yanovskaya and Kucherov[48].

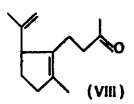
etc. can be obtained. The method can, of course, be extended to the synthesis of the most varied isoprenoid alcohols, aldehydes, ketones, and their derivatives, homologues, and analogues differing in chain length, substituents, or position of double bonds. In a detailed paper Kimel *et al.*[6] reported a considerable number of substances synthesised in this way, but unfortunately they did not describe the odour of previously unknown compounds.

A series of homologues and analogues of pseudoionone of general formula



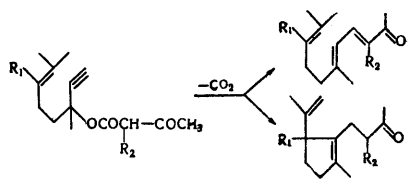
where R = CH_3 and R′ = H, Cl, CH_3, C_2H_5, iso-C_3H_7, and t-C_4H_9 and R = R′ = iso-C_3H_7, have recently been synthesised by Nazarov *et al.*[49,50] by the reaction of homologues and analogues of dehydrolinalool with acetoacetic ester, and also by condensation with diketen followed by pyrolysis of the resulting acetoacetates.

Pyrolysis of the acetoacetates of tertiary ethynyl alcohols is accompanied by a series of side-reactions, which considerably lower the yield of the desired dienones. This was responsible for the appearance of a large number of papers aimed at seeking better conditions for carrying out this stage[8,9,11,26,27,51], and also on the side-products which are formed. It was established that the most important side-products in the pyrolysis of dehydrolinalyl acetoacetate is a ketone§ (VIII) isomeric with pseudoionone and containing a cyclopentene ring[52-56]:



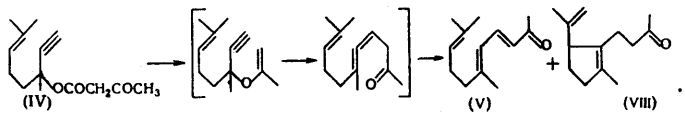
(VIII)

A similar formation of ketones having a cyclopentene group was noted also in the pyrolysis of substituted dehydrolinalyl acetoacetates[55]:



The ketone (VIII) was also detected as a side-product in the preparation of pseudoionone by the reaction of dehydrolinalool with acetoacetic ester[53].

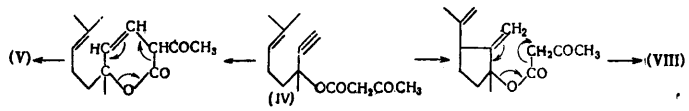
Possible schemes for the formation of pseudoionone and its isomeric ketone (VIII) by the pyrolysis of dehydrolinalyl acetoacetate have been discussed in several papers[54,56,57]. It is assumed, for example[26,55,56], that an allenone is formed as an intermediate product, and this undergoes further changes, *e.g.*[55]



(IV) (V) (VIII)

§ The formation in this reaction of a ketone isomeric with pseudoionone was noted also in a paper by Samokhvalov *et al*[27].

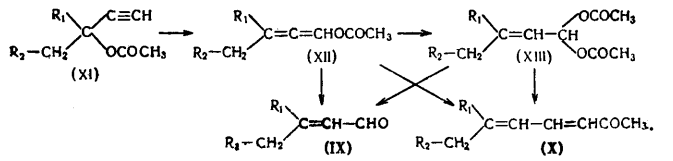
The following scheme has also been suggested[55]:



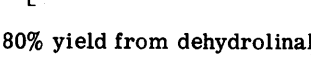
Nazarov and Krasnaya[58] studied the pyrolysis of acetoacetates prepared from tertiary enynyl and dienyl alcohols.

An interesting process, analogous to the Carroll reaction, was described by Daev and Dashunin, who showed that 5,6-dimethylhept-5-en-2-one (Ia) is formed by the reaction of pinacol with acetoacetic ester[59] or with diketen[60]. In the latter case the diacetoacetate of pinacol was obtained, which was subjected to pyrolysis at 200°.

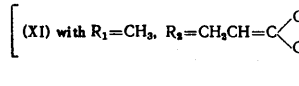
An extremely promising new possibility of passing from tertiary ethynyl alcohols to unsaturated aldehydes (IX) or the corresponding dienones (X) has been reported in recently published papers by Isler and his coworkers[61-63]. According to them, acetates of tertiary ethynyl alcohols (XI) isomerise, on being heated with acetic acid in the presence of copper or copper or silver salts, into allene acetates (XII), which then add on acetic acid to form diacetates (XIII). Alkaline hydrolysis of (XII) and (XIII), and also acid hydrolysis of (XIII) yield $\alpha\beta$-unsaturated aldehydes (IX). The simultaneous action of alkali and acetone, however, converts (XII) and (XIII) into $\alpha\beta\gamma\delta$-unsaturated ketones (X).



By this method Isler obtained citral:



in more than 80% yield from dehydrolinalool (III) *via* its acetate:



and also methylcitral, farnesal, and several other aldehydes from the corresponding ethynyl alcohols. From dehydrolinalool and methyldehydrolinalool (IIIa), pseudoionone and pseudoirone can be prepared, also in yields exceeding 80%, by esterification and rearrangement into allene acetates and diacetates followed by treatment with alkali in acetone.

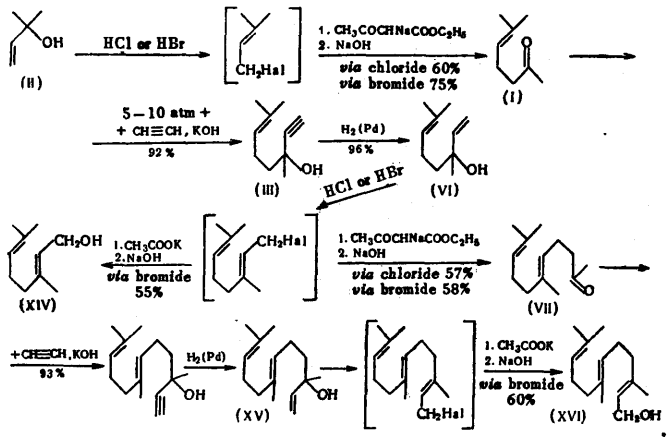
The simplicity and elegance of this route for converting tertiary ethynyl alcohols into unsaturated aldehydes or the corresponding dienones have attracted the interest of other chemists as well[51,57].

In order to obtain the unsaturated ketones which are intermediates in the synthesis of perfumes of the terpene and sesquiterpene series, much of the work published during recent years has also used the old, classical method of condensing halogeno-derivatives with the sodium derivative of acetoacetic ester followed by ketonic hydrolysis of the resulting substituted acetoacetic esters. In this way

methylheptenone (I) [9,14,64-66] and dimethylheptenone (Ia) [67] have been obtained from 3-methylbut-2-enyl halides $CH_3.C(CH_3):CR.CH_2Hal$, and geranylacetone (VII) [14,43,64,68-70] from geranyl halides $CH_3.C(CH_3):CH.CH_2.CH_2.C(CH_3):CH.CH_2Hal$.

By successive repetition of acetonylation, condensation of the ketones with acetylene, selective hydrogenation of the ethynyl alcohols to vinyl alcohol, and conversion of the tertiary alcohols *via* the halogen derivatives into primary alcohols, Nazarov *et al.* [14,64] synthesised a series of isoprenoid alcohols according to Scheme 2.

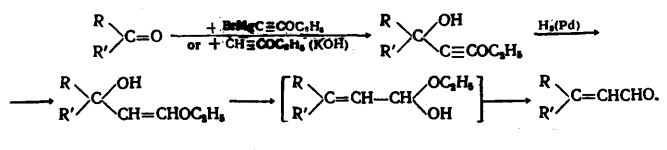
Scheme 2



The change from (II) to (I), from linalool (VI) to geraniol (XIV) or geranylacetone (VII), and also from nerolidol (XV) to farnesol (XVI), can be accomplished in one step, without isolation of the intermediate products.

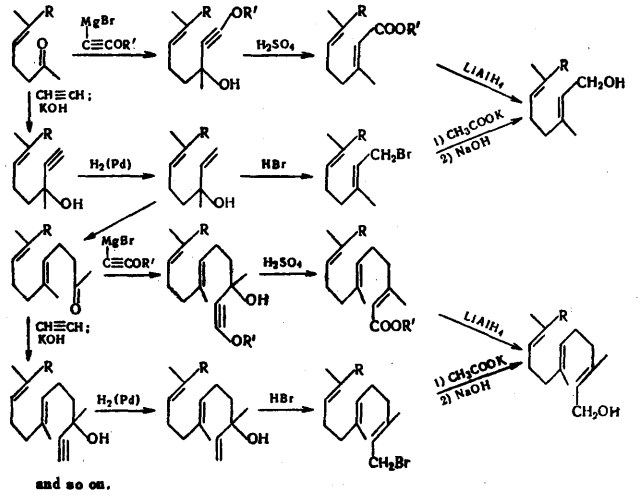
Starting from 4-bromobut-2-ene, Nazarov *et al.* [71] synthesised analogues of linalool and nerolidol containing one methyl group instead of the *gem*-dimethyl grouping.

Nazarov and his collaborators, in another synthetic route to isoprenoid compounds, have condensed the ketone with ethoxyacetylene instead of acetylene. This method of passing from a ketone to an unsaturated aldehyde containing two extra carbon atoms in the chain, which had been employed earlier in syntheses of terpenoid compounds [36,72-76], was used by Nazarov and his coworkers in two ways. In one of them the ethoxyacetylene was used in the form of its bromomagnesium derivative, and in the other the condensation with ethoxyacetylene was effected in the presence of caustic potash. The resulting ethoxyethynyl alcohols were hydrogenated to ethoxyvinyl alcohols, which were then converted into $\alpha\beta$-unsaturated aldehydes, probably *via* the intermediate formation of hemiacetals as a result of an allylic rearrangement [77]:

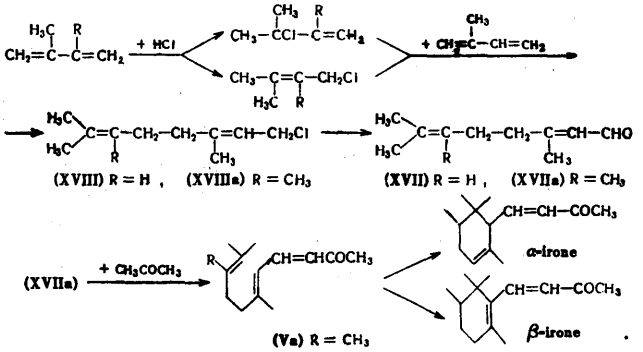


Use of methylheptenone (I) as starting compound gave a high yield of citral, and several of its homologues and analogues have been synthesised in the same way. This reaction has been employed also for the synthesis of analogues of geraniol, farnesol, and some other alcohols of isoprenoid structure [50,78] (see Scheme 3).

Scheme 3



A fundamentally new route for the synthesis of citral (XVII) [79-82] and 3,6,7-trimethylocta-2,6-dien-1-al (methylcitral) (XVIIa) [83,84] is based on the construction of a terpene skeleton by the treatment of the hydrochlorides of isoprene and dimethylbutadiene respectively with isoprene in the presence of a catalyst; the geranyl chloride (XVIII) and 1-chloro-3,6,7-trimethylocta-2,6-diene (XVIIIa), which were respectively obtained, were further converted into aldehydes by the Sommelet reaction¶. In the case of 3,6,7-trimethylocta-2,6-dien-1-al (methylcitral) (XVIIa) condensation with acetone was then carried out, followed by cyclisation of the pseudoirone (Va) into a mixture of α- and β-irones with a considerable preponderance of the former [83,84]:



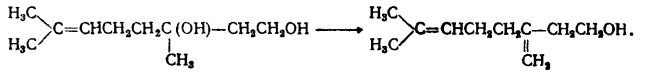
The dependence of the yield of geranyl chloride, and also of other terpene chlorides formed at the same time, on the

¶ Recently Swiss chemists [85] suggested a noteworthy new possibility for converting halogenated allyl derivatives into the corresponding unsaturated aldehydes by the action of nitroalkanes; among other examples, they give the preparation of citral from geranyl bromide; when the potassium salt of 2-nitropropane is used, the yield of citral reaches 75%. Nazarov *et al.* [86] employed the potassium salt of nitrocyclohexane for this purpose.

nature of the catalyst and the solvent, the temperature, and other conditions has been studied in a series of special investigations [87-90].

From a study of the infrared spectra of specimens of citral obtained by the Sommelet reaction from mixtures of terpene chlorides formed by the reaction of isoprene with its 1,2- and 1,4-hydrochlorides, Petrov *et al.* [91,92] established that such specimens consist of a mixture of geranial and neral, the content of the latter being higher than in natural citral [92]. This synthetic scheme for citral and methylcitral is attractive since it allows the carbon skeleton of the terpene compound to be constructed in a single step, by the direct combination of isoprene with its hydrochloride (or, in the case of methylcitral, with the hydrochloride of dimethylbutadiene), which are now readily available. Another extremely valuable feature is that the compound obtained in this way contains an active chlorine atom, which readily undergoes reactions leading to the formation of the corresponding oxygen derivatives (the alcohol by hydrolysis and the aldehyde by an oxidative change). All this distinguishes the method favourably from others. The processes which are assumed to form the basis of this scheme for constructing an isoprenoid chain have been worked out in detail in a series of investigations by Petrov and Leets and their collaborators [93-95].

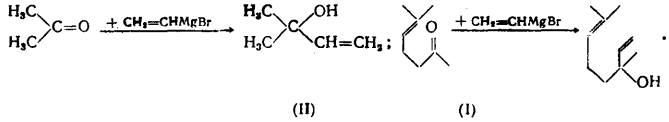
The formation of aliphatic terpene alcohols by the action of acidic reagents on 2-methylbut-3-en-2-ol (II) was studied by Lebedeva and Almashi [96]. They investigated the effect of pH on the composition of the mixture of products formed; the total yield of linalool and geraniol did not exceed 13–14% with a low recovery of the original methylbutenol. Subsequent work [97] established that, when aqueous $KHSO_4$ solution acts on (II), several reactions occur, including hydration of the geraniol formed during the reaction to geranyl hydrate (XIX), elimination of water from which in the presence of $KHSO_4$ yields an alcohol (XX) isomeric with geraniol:



(XIX) (XX)

Noteworthy work has also been done on the synthesis of terpenoid compounds using the method developed recently by Normant [98,99] for preparing organomagnesium compounds of vinyl type and using them in condensations with carbonyl compounds. The simplicity of the method (reaction is effected in tetrahydrofuran or tetrahydropyran solution) and the good yields of the reaction products make this an extremely attractive process, and have been responsible for its rapid introduction into laboratory practice†.

The change from acetone to methylbutenol (vinyldimethylmethanol) and from methylheptenone to linalool (yield 83%) was accomplished by Normant by treating these ketones with vinylmagnesium bromide [101-103]:

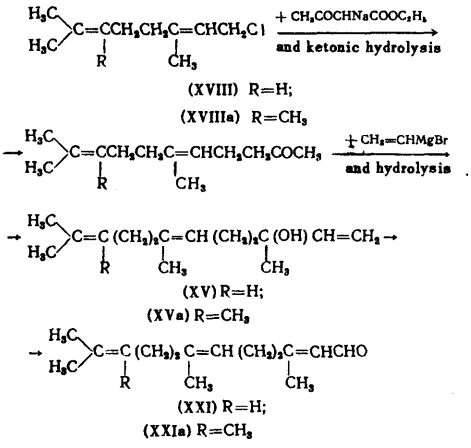


(II) (I)

Somewhat later other chemists reported the preparation of linalool in approximately the same yield by the reaction of methylheptenone with vinylmagnesium chloride [104].

† The vast literature on this reaction is quoted in a review by Ioffe [100].

Skvortsova *et al.* [84,105] utilised the Grignard reaction with vinylmagnesium chloride for the synthesis of nerolidol (XV), methylnerolidol (XVa), farnesal (XXI), and methylfarnesal (XXIa). The geranylacetone and methylgeranylacetone required for this were obtained by reaction of the corresponding chlorides, geranyl chloride (XVIII) and methylgeranyl chloride (XVIIIa), with the sodium derivative of acetoacetic ester. These syntheses made use of the chlorides obtained as intermediates in the synthesis of citral and irone by schemes discussed previously (see above):



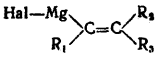
(XVIII) R=H;
(XVIIIa) R=CH_3
(XV) R=H;
(XVa) R=CH_3
(XXI) R=H;
(XXIa) R=CH_3

The transition from tertiary alcohols (XV) and (XVa) to aldehydes (XXI) and (XXIa) was accomplished by an allylic rearrangement and oxidation with chromic acid, the method which is customary for oxidations of this type.

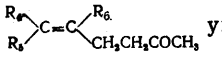
Subsequently, in the development of work on the use of terpene chlorides to obtain valuable perfumes of the sesquiterpene series, nerolidol and methylnerolidol were converted by a previously known method [84] into the corresponding primary alcohols, farnesol and methylfarnesol, by treatment with phosphorus tribromide, conversion of the resulting primary bromides into acetates, and saponification of these acetates [106]. The preparation of nerolidol by the reaction of geranylacetone with a vinylmagnesium halide has also been described by other chemists [107].

Normant's method has been successfully used also in syntheses of many other compounds, several of which, judging from their structure, may be of interest as perfumes. Unfortunately, in by no means all cases are the odours of the compounds obtained indicated in the papers.

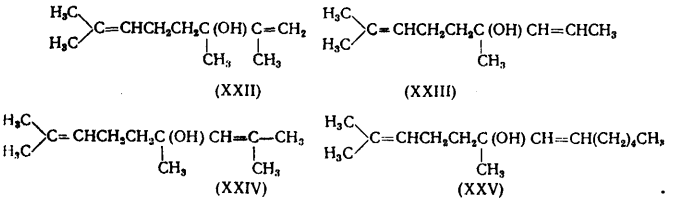
The reaction of magnesium halide derivatives of the type



with unsaturated ketones of general formula

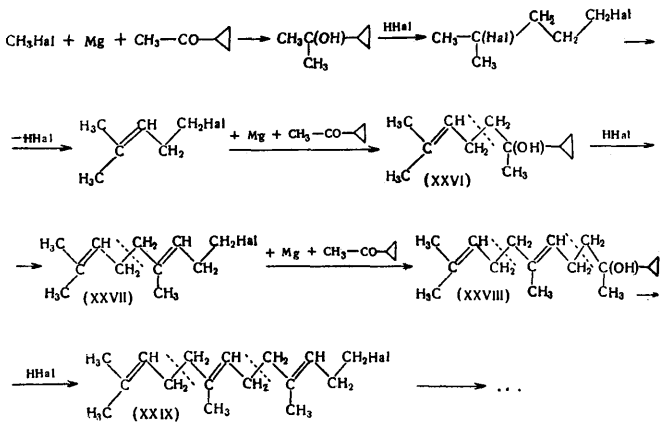


yields the diene tertiary alcohols (XXII)–(XXV) [103] possessing the odours of bergamot and lavender.



(XXII) (XXIII) (XXIV) (XXV)

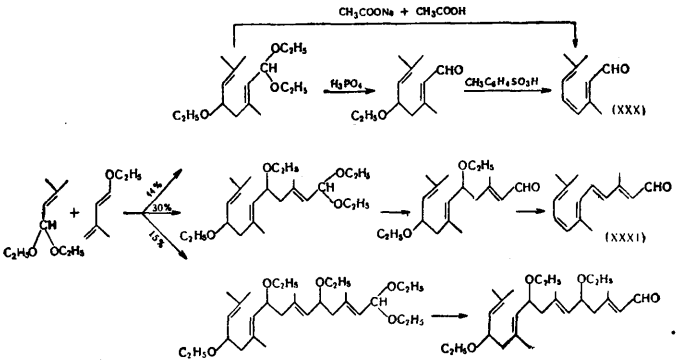
An extremely original new method for the successive building up of isoprenoid chains was suggested recently by French investigators [108], who utilised the Grignard reaction with cyclopropyl ketones for this purpose. The resulting cyclopropyl alcohols are converted by halogen hydracids into dihalogenated derivatives with opening of the ring, and these are then converted by partial dehydrochlorination and reaction with magnesium into organomagnesium compounds, which with the original cyclopropyl ketones give cyclopropyl alcohols containing five additional carbon atoms. Four of these form a straight chain, while the fifth is attached to the penultimate carbon atom. Repetition of these processes results in the formation of a chain of isoprene groups containing one double bond in each "isoprene" link:



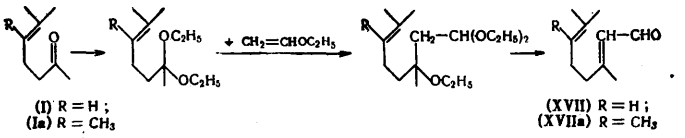
This method has yielded the tertiary cyclopropyl alcohols (XXVI) and (XXVIII), which differ from linalool and nerolidol in containing a three-membered ring instead of the vinyl group; reaction of (XXVII) and (XXIX) with sodium acetate followed by saponification gives primary alcohols which are the immediate homologues of geraniol and farnesol respectively. The alcohols (XXVI) and (XXVIII) have a very pleasant odour.

A recently developed method for passing from a carbonyl compound *via* an acetal to an $\alpha\beta$-unsaturated aldehyde containing two extra carbon atoms in the chain [109-113] has also been successfully employed for the synthesis of perfumes of terpenoid structure. This method, based on the reaction between acetals and vinyl ethers discovered by Müller-Cunradi [114] as early as 1939 (see also Ref. 115), has been developed during recent years by Soviet chemists [116-129]. We shall note only those papers which are most closely related to the synthesis of perfumes‡.

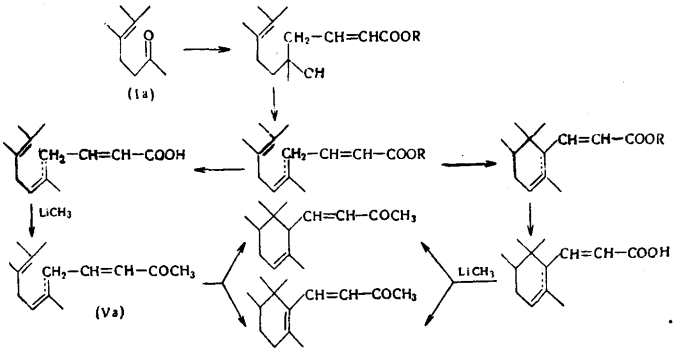
Nazarov and Krasnaya [123,125] studied the reaction of acetals with ethoxyisoprene (for the preparation of the latter, see Ref. 131). In the presence of zinc chloride or boron trifluoride, an acetal reacts with one, two, or more molecules of the ethoxyisoprene to form $\alpha\beta$-unsaturated alkoxy--acetals, which can then be readily converted into alkoxy--aldehydes and polyenals. The main synthetic products obtained when the acetal of dimethylacrylaldehyde is used are 3,7-dimethylocta-2,4,6-trien-1-al (XXX) and 3,7,11-trimethyldodeca-2,4,6,8,10-pentaen-1-al (XXXI).



Preobrazhenskii *et al.* [126,127] employed this reaction to convert methylheptenone (I) into citral (XVII), and Nazarova and Torgov to convert dimethylheptenone (Ia) into methylcitral (XVIIa): [124]



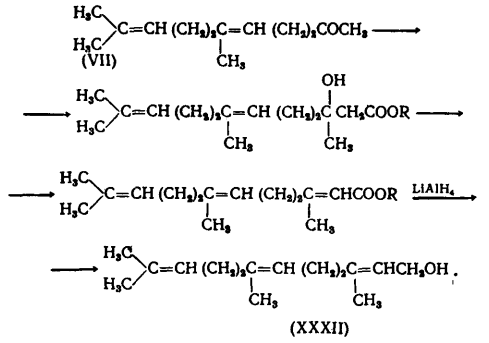
In a series of papers Preobrazhenskii and his collaborators used the well-known Reformatsky reaction to build up the carbon skeleton of perfumes of terpenoid structure. In a previous review we noted [132] their syntheses of pseudoionone (V) from methylheptenone (I) *via* its condensation products with esters of halogenated acids [133,134]. During recent years Preobrazhenskii, Samokhvalov, and their coworkers have studied the individual stages in these syntheses [135,136], and also the analogous conversion of dimethylheptenone (Ia) into pseudoirone (Va), which on cyclisation forms a mixture of isomeric irones. In another variant the ester of methylgeranic acid was cyclised, and then the product saponified and the acid converted into irone by the action of methyllithium in dry ether [137,138]:



The sesquiterpene alcohol farnesol (XXXII) was synthesised in Preobrazhenskii's laboratory by the reaction of geranylacetone (VII) with chloroacetic ester, followed by

‡ A detailed review of work on this reaction has recently been published by Yanovskaya [130].

dehydration of the resulting hydroxy-ester and reduction with lithium aluminium hydride[69]:



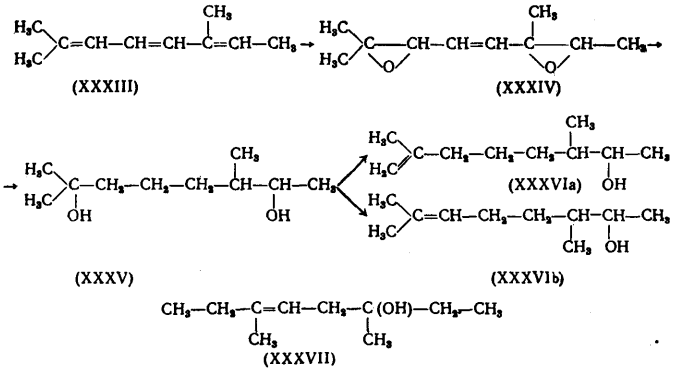
(XXXII)

A disadvantage of this synthesis is its clumsiness and the low yields at several stages. On passing from geranylacetone through the hydroxy-ester to the unsaturated ester, for example, the yield is only 8.5%.

The method of obtaining polyenecarboxylic esters by condensing $\alpha\beta$-unsaturated ketones with 4-halogenocrotonic esters was improved by Dorp *et al.*[139], who suggested treating the unpurified mixture of esters, before saponification, with dehydrating agents (PBr_3, P_2O_5, and several others).

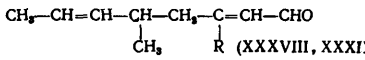
Apart from the new compounds considered above, several others have also been obtained during recent years, these being homologues or analogues of the terpene and sesquiterpene compounds. Some of them possess a pleasant odour and may find application as perfumes, while the preparation of others is of interest in elucidating the relation between odour and structure.

Several new compounds of this group having an interesting smell have been synthesised by Naves and his collaborators[140] using alloocimene (XXXIII) as starting material. Oxidation of (XXXIII) yielded the dioxide (XXXIV), hydrogenation of which gave the saturated diol (XXXV); dehydration of the latter resulted in unsaturated alcohols isomeric with citronellol, which were termed α-elgenol (XXXVIa) and β-elgenol (XXXVIb):



There are indications of the possibility of the use in perfumery also of another isomer of citronellol, 3,6-dimethyloct-5-en-3-ol (XXXVII).[141]

An aldehyde (XXXVIII) isomeric with citral was obtained by Petrov *et al.*[142] and reported as having an odour resembling that of citral. The citral analogue (XXXIX), which contains chlorine and was synthesised by the same chemists, possesses the same type of odour[143].



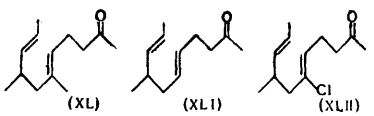
where in (XXXVIII) R = CH_3, and in (XXXIX) R = Cl.

A series of homologues and analogues of citral were obtained from the corresponding bromides or chlorides by Nazarov *et al.*[50,86] These compounds possess the odours indicated below:



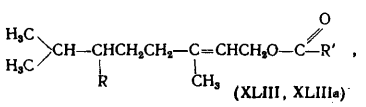
R = R′ = CH_3 (citral) smells like lemons; R = CH_3 and R′ = H unpleasant smell not resembling that of citral; R = CH_3 and R′ = Cl odour similar to that of citral; R = CH_3 and R′ = C_2H_5 odour not reported; R = CH_3 and R′ = iso-C_3H_7, R = CH_3 and R′ = C_4H_9, and R = R′ = iso-C_3H_7 the smell has an unpleasant fatty aroma.

The geranylacetone isomer (XL) (6,8-dimethylundec-5,9-dien-2-one), and also its lower homologue (XLI) (8-methylundec-5,9-dien-2-one) and its analogue (XLII), have been reported as possessing a peculiar, pleasant odour[144]:



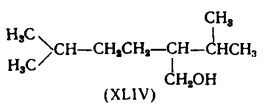
(XL) (XLI) (XLII)

Patents issued in 1958 describe the preparation of esters of dihydrogeraniol (XLIII)[145] and of dihydromethylgeraniol (XLIIIa),[146] several of which, for example those in which R′ is not higher than C_8, possess a scent of flowers and are of interest for perfumery:



(XLIII, XLIIIa)

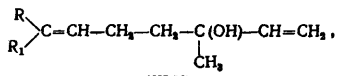
where in (XLIII) R = H and in (XLIIIa) R = CH_3.



(XLIV)

The German perfumery journal notes the valuable odour of several esters of tetrahydrolavandulol (XLIV), and the opinion is expressed that they could be usefully employed in perfumery[147,148].

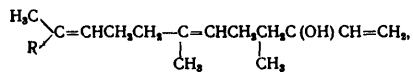
We may note also the homologues and analogues of linalool (XLV) [30] and nerolidol (XLVI) [33] synthesised by Nazarov and his collaborators:



(XLV)

where

R	H	CH_3	CH_3	CH_3	CH_3	CH_3	iso-C_3H_7
R_1	H	H	Cl	C_2H_5	iso-C_3H_7	t-C_4H_9	iso-C_3H_7

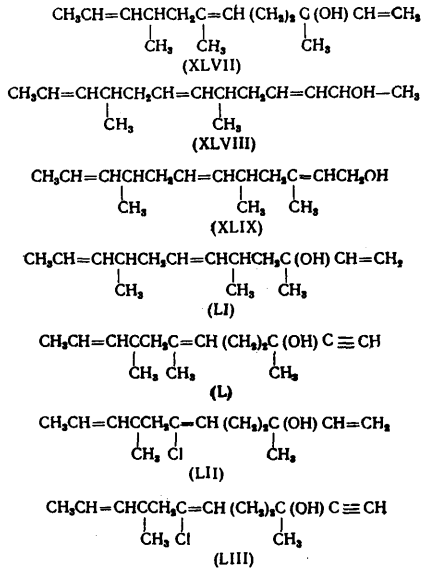


(XLVI)

where R = H, Cl, C_2H_5, iso-C_3H_7, t-C_4H_9.

Unfortunately, the odours of these compounds are not reported.

The alcohols (XLVII)–(L), which are isomers of nerolidol and farnesol and were prepared by Shvarts and Petrov [70,93] by the telomerisation of unsaturated chlorides and diene hydrocarbons (for this reaction see above, p.124), as well as the dehydronerolidol isomer (LI), the nerolidol analogue (LII), and the dehydronerolidol analogue (LIII), are described as liquids having a pleasant smell, which when dilute resembles that of nerolidol and farnesol:



(XLVII)

(XLVIII)

(XLIX)

(LI)

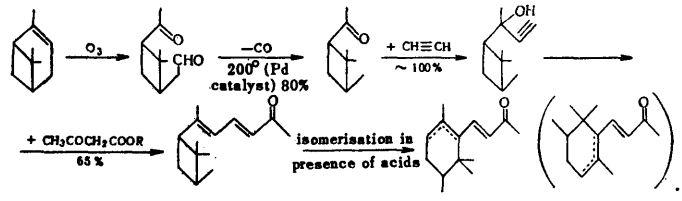
(L)

(LII)

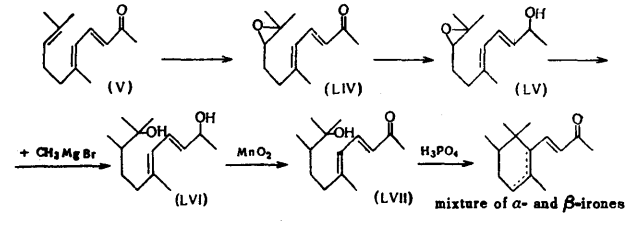
(LIII)

Great progress has been made during recent years in the chemistry of ionone preparations, one of the most interesting groups of odoriferous substances of terpenoid structure. Several new homologues of ionone have been obtained, the most important stage in their synthesis — cyclisation (the transition from pseudoionones to the ionones themselves) — has been studied in detail, new relations have been elucidated between the formation of individual isomers and the reaction conditions, the structure of several isomers has been more accurately determined, etc.

Some of these investigations relate to problems of the synthesis of irone (6-methylionone), the aromatic principle of orris oil. Several routes for obtaining irone which have been proposed recently have been given above in the discussion of general schemes for synthesising isoprenoid compounds. Several other syntheses of this valuable perfume have also been described. The starting material in one of them was α-pinene, which was converted into irone by the following reactions [149]:



According to another scheme, suggested recently by Barton and Mousseron-Canet [150], irone was synthesised from pseudoionone (V), which was converted by perphthalic acid into an epoxide (LIV), the latter yielding on reduction with sodium borohydride in methanol the epoxide of pseudoionol (LV); the Grignard reaction (with methylmagnesium bromide) was then used to introduce a methyl group into position 9 with formation of a diol (LVI), transformed by oxidation into a hydroxy-keton (LVII), from which it was then easy to pass to irone:



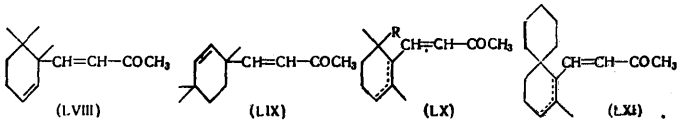
The significance of these two methods of synthesising irone is probably confined to laboratory research. A very tempting possibility mentioned in one of Verley's patents [151] is the *C*-methylation of citral or geraniol with dimethyl sulphate to form a 6-alkyl derivative. If the data in this patent are confirmed, there are good prospects for obtaining irone from citral or geraniol, since the further conversion of the resulting 6-methylcitral or 6-methylgeraniol respectively into irone presents no difficulty.

The possibility of the *C*-alkylation of terpenoid compounds was noted also by the Hungarian chemist Szabó [152] in his work on the mechanism of the cyclisation of pseudoionone in the presence of acid catalysts. According to his results, pseudoionone is converted on treatment with $AlCl_3$ and CH_3Cl into γ-irone; hence in this case cyclisation is accompanied by methylation. He observed the formation of irone also on treating pseudoionone with a solution of HCl in methyl alcohol. In a similar way, the action of isopropyl chloride and $AlCl_3$ on pseudoionone yields 6-isopropylionone, and interaction of pseudoionone with dichloroethylene and $AlCl_3$ results in a 6-hydroxyethyl derivative, which on dehydration gives 6-vinylionone. However, the yields of the alkylation products are not high.

A considerable number of investigations have been devoted also to preparing other homologues and analogues of ionine. An isomer (LVIII) of α-ionone has been described in which the methyl group is in position 2 instead of position 3 in the ring[153]. This ketone possesses an odour of violets differing somewhat from those of α-ionone and α-irone. Another ketone (LIX), isomeric with ionone and having a different arrangement both of methyl groups and of the double bond in the cyclohexene ring, has been described as having a faint smell slightly resembling that of violets[154]. Both the α- and β-forms have been obtained of a homologue of ionone containing both methyl and ethyl groups attached to the second carbon atom in the ring [(LX): R = C_2H_5]. The odour of the α-isomer is stated to resemble that of α-ionone[155], and the β-isomer is described as possessing the aroma of violets with a trace of cedar[156]. Higher homologues of ionone, containing R = iso-C_4H_9 in formula (LX), have a woody smell, which is most distinct with the α-isomer[157].

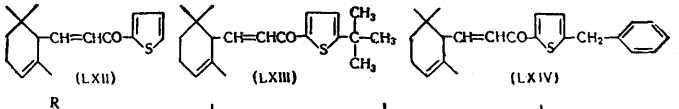
A series of such homologues and analogues of ionone [(LX) with R = H, Cl, C_2H_5, iso-C_3H_7, t-C_4H_9] have been synthesised by Makin *et al.*[158], but their odours are not described.

Naves and Ardizio[159] prepared structural analogues (LXI) of α- and β-ionones in which the *gem*-dimethyl grouping had been replaced by $[CH_2]_5$; these spiro-compounds were noted to have a faint but persistent odour of cedarwood with a hint of iris:

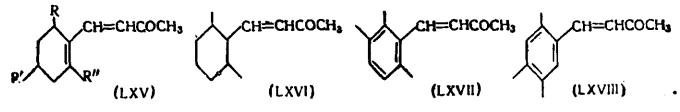


(LVIII) (LIX) (LX) (LXI)

Interesting work has been carried out on the synthesis of ionone analogues which are derivatives of thiophen[160,161]. It has been found that introduction of a thiophen ring into the molecule of an ionone preparation does not substantially affect its odour: the ketones (LXII), (LXIII), and even (LXIV), which has a considerably higher molecular weight than ionone (molecular weights 350 and 192 respectively), possess a well defined odour of violets, without the smell of sulphur compounds. It is noteworthy that, up to the present time, only comparatively few sulphur-containing organic compounds are known which have a pleasant smell:



(LXII) (LXIII) (LXIV)



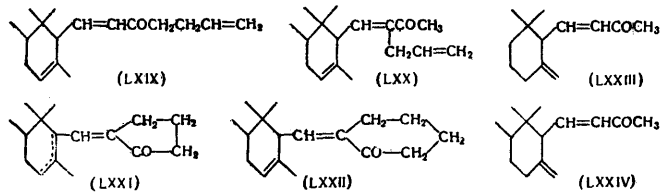
(LXV) (LXVI) (LXVII) (LXVIII)

Several analogues of β-ionone of general formula (LXV) were prepared recently by Nazarov, Kugatova, and their collaborators[162,163]; unfortunately, the odour is described only for the cyclohexane ketone (LXVI), which has an agreeable, flowerlike scent[162].

Information on odoriferous properties is also lacking for the aromatic ionone analogues (LXVII) and (LXVIII) obtained fairly recently[164].

Naves has prepared several new analogues of irone. Thus 2_4-allyl-α-irone (LXIX) and 2_2-allyl-α-irone (LXX) have been synthesised[165], the latter being stated to have a persistent smell resembling that of isovetivone§. In another paper Naves[166] has described α- and β-isomers of 6-methylcyclocitrylidenecyclopentanone (LXXI) and 6-methyl-α--cyclocitrylidenecyclohexanone (LXXII); it is interesting that, in contrast to the corresponding analogues of ionone, which have the odour of violets[167,168], these ketones possess a faint but persistent odour resembling that of oakwood from which the bark has been freshly peeled.

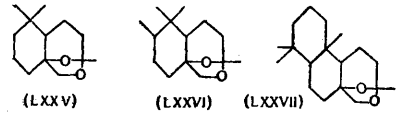
Noteworthy attempts have been made by Schinz and his coworkers to synthesise γ-ionone (LXXIII)[169] and γ-irone (LXXIV)[170] from compounds already containing an *exo*-cyclic methylene group (the conditions necessary for the formation of γ-isomers on cyclisation of the corresponding pseudo--products are not yet known).



(LXIX) (LXX) (LXXIII) (LXXI) (LXXII) (LXXIV)

The synthesis of γ-irone would be of the greater interest, since it is this structural isomer which constitutes the main component of the mixture of irones present in the oil from iris rhizomes. However, it did not prove possible in the above work to obtain the pure preparations desired: only crystalline derivatives enriched with those of the corresponding γ-isomers were isolated.

Several interesting new products have been obtained from ionones and irones which have been hydrogenated at the double bond in the side-chain. Thus of the bridged polycyclic ketals (LXXV)–(LXXVII), patented by Ruzicka and Jeger[171] and recommended for use in perfumery compositions, the first two can be obtained from dihydro-γ--ionone and dihydro-γ-irone respectively by oxidation to glycols with subsequent dehydration¶:



(LXXV) (LXXVI) (LXXVII)

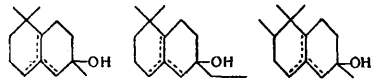
Stoll *et al.*[172,173] have studied the cyclisation of dihydro--γ-ionone in the presence of acid reagents. It has been suggested that three isomeric octahydro-2,5,5-trimethylnaphth-2-ols (LXXVIII), differing in the position of the double bond and termed the α-, β-, and γ-ambrinols, are formed in this process; the α- and γ-isomers were isolated from the reaction mixture and characterised, the structure of γ-ambrinol being confirmed by synthesis.

§ The name "isovetivone" is arbitrarily applied to the mixture of ketones isolated from oil of vetiver and possessing the specific odour of the latter.

¶ The ketal (LXXVII) is obtained in a similar manner from 4-(5,5,9-trimethyl-2-methylenedecalin-1-yl)but-3-en-2-one.

According to the suggested mechanism[172,173], the cyclisation of dihydro-γ-ionone involves the intermediate formation of a carbonium ion. The mixture of ambrinols possesses an odour which is valuable in perfumery, having a similarity to that of ambergris and civet[172,173]; the ethyl ether of ambrinol has a faint smell which is of little interest[173].

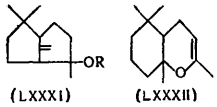
In another paper Stoll[174] has described the octalinols (LXXIX) and (LXXX), obtained by cyclisation of dihydro--2_4-methyl-γ-ionone (dihydro-γ-normethylionone) and *trans*-2,6-dihydro-γ-irone respectively; these homologues of ambrinol proved to have uninteresting odours.



(LXXVIII) (LXXIX) (LXXX)

However, the dihydro-γ-ionones themselves are difficult to obtain. It has already been mentioned above that conditions for the formation of γ-isomers of ionone derivatives on cyclisation of the pseudo-compounds are not yet known. Methods have not yet been described for converting pseudoirone into γ-irone, the latter being found in only very minute quantities in the mixtures remaining after cyclisation; therefore the sole source of γ-irone and dihydro-γ-irone so far is natural orris oil. Only complicated and multistage syntheses have been suggested for the preparation of dihydro-γ-iononeT: for example, Stoll's scheme[177] using dihydro-α-ionone as starting material. According to a 1959 Swiss patent[178], dihydro-γ-ionone is formed from dihydro-α-ionone by the action of phosphoric acid in the presence of pyridine.

Stoll and his collaborators[179-182] have studied also the acid cyclisation of dihydro-α-ionone. They have found that the nature of the reaction products depends to some extent on the solvent which is used. Thus the cyclisation of dihydro-α-ionone under the influence of HCl or BF_3 in solution in a primary alcohol, results in the formation of a bicyclic ether [(LXXXI): R = Alk, corresponding to the radical of the primary alcohol], whereas in solution in a secondary alcohol a bicyclic alcohol is formed [(LXXXI): :R=H]. The action of BF_3 in benzene solution yields an unsaturated oxide (LXXXII). The alcohol and its ethers (for example with R = C_2H_5) possess an odour of ambergris and wood with a suggestion of camphor; this last is attributed to impurities, which may be formed as side-products in the cyclisation of dihydro-α-ionone.



(LXXXI) (LXXXII)

The exceptional significance, for the chemistry and technology of perfumes, of processes involving the cyclisation of terpenoid compounds has been responsible for the great interest of chemists in a comprehensive investigation of these reactions. The detailed reviews published during recent years on the mechanism of the cyclisation of terpene compounds[183,184] make it unnecessary to dwell on this question here, so that we can confine ourselves to those investigations which are directly related to the preparation or study of the individual isomers formed in the course of cyclisation. Several such papers have already been cited above in discussing the synthesis of individual perfumes of terpenoid structure.

Several other workers have studied the effect of various cyclising agents, and of the conditions under which pseudoionone is cyclised, on the composition of the resulting ionone isomers. This question, of very great importance for the perfume industry, is as yet far from being completely elucidated, although its study started at the end of the past century. Krishna and Joshi[185] have specified the conditions necessary for the preferential formation of β-ionone; they emphasise the great value of spectroscopic methods of analysis for determining the content of isomers in the mixture of ionones.

A detailed study of the way in which the composition of the isomeric ionones depends on temperature, duration, and amount of sulphuric acid used as a cyclising agent was made by Kucherov *et al.*[186,187] They established that formation of α-ionone is favoured by the use of low temperatures (of the order of -60° to -40°), small quantities of sulphuric acid, and short times of cyclisation.

The problem of the cyclisation of pseudoionone with the aim of obtaining α-ionone as the main reaction product is dealt with also in a paper by Hung Lu-ming[188]. Kucherov *et al.*[189] had confirmed Schinz's results[190], according to which mixtures containing the same amounts of α- and β-ionones are formed in the cyclisation of the *cis*- and *trans*-isomers of pseudoionone (geometrical isomerism due to the presence of a double bond between carbon atoms 5 and 6). They have suggested a mechanism for this process.

Makin *et al.*[50,158] have studied the cyclisation of a series of homologues and analogues of pseudoionone containing various *gem*-substituents in position 10.

Dulou and Clément[20] compare their results on the cyclisation of pseudoirone by the action of sulphuric acid, phosphoric acid, and boron trifluoride with those published somewhat earlier by Naves‡ (pseudoirone was prepared by the reaction of dehydro-6-methyllinalool with acetoacetic ester; the stereoisomers were determined from the characteristics of crystalline derivatives of the dihydroirones§ and from the ultraviolet and infrared spectra of the latter). The agreement between the results is very good; Naves's statement that the action of boron trifluoride is stereospecific in this reaction is confirmed. The advantage of this cyclising agent in forming the most valuable stereoisomers from the point of view of odour has been reflected in a series of patent claims during recent years[191-194]. However, there are indications that the mixtures of isomers obtained by the cyclisation of pseudoirone in the presence of sulphuric acid[195] or of a sulphuric acid–acetic acid mixture[196] can also be used in perfumery (*cf.* the paper[186] cited above on the cyclisation of pseudoionone).

Fresh data have also been published on the properties and structures of the individual isomers of ionone and its homologues. Lecomte and Naves[197] give the detailed spectroscopic characteristics of several isomers of ionone, methylionone, and irone; new crystalline derivatives of methyliso-α-ionone and of isomeric irones have been described[198].

† Dihydro-γ-ionone is found in minute amounts among the oxidation products of ambrein[175,176].

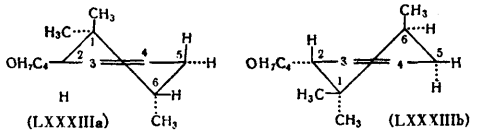
‡ This work of Naves is discussed in our previous review[132].

§ In order to eliminate the stereoisomerism due to the double bond in the side-chain (at the 2_1–2_2 C-atoms).

Beets and van Essen[199] made a thorough investigation of the effect of the conditions under which citral is condensed with ethyl methyl ketone with the aim of elucidating the factors favouring the predominant formation of methylpseudoisoionone (which gives methylisoionone¶ on cyclisation). These workers assume that the condensation of citral with ethyl methyl ketone takes place by two competing reactions, the first being the classical condensation catalysed by anions, and the second a condensation catalysed by anions and cations together, depending more on a hyperconjugation than on a steric effect, and increasing the probability of condensation at the methylene group. They recommend that this condensation should be carried out in the presence of quaternary ammonium bases in lower aliphatic alcohols.

New data obtained by Naves forced him to change his previous view of the structure of the irone isomer whose 4-phenylsemicarbazone melts at 174.5°–175.5°. Previously this isomer had been assigned the structure of iso-α--ironeț (*trans*-2,6, *cis*-2_1, 2_2-α-irone).[200] Study of the spectra showed that this isomer has a *trans*-arrangement of the substituents attached to the carbon atoms 2_1 and 2_2, and is thus neoiso-α-irone (*trans*-2,6, *trans*-2_1, 2_2-α--irone).[201-203] By fractional recrystallisation of the mixed semicarbazones of the isomeric irones followed by hydrolysis and fractional distillation in a highly efficient column, however, he was able to isolate an isomer which was iso--α-irone.[201-203] Reduction of iso-α-irone and neoiso-α--irone with lithium aluminium hydride yielded the corresponding alcohols, iso-α-irol and neoiso-α-irol[203].

Somewhat earlier Naves[204] had established an interesting case of stereoisomerism of the incompletely hydrogenated 2_2-methylirones, and had shown that hydrogenation of 2_2-methyl-*trans*-2,6-α-irone yields two dihydro-ketones (LXXXIIIa) and (LXXXIIIb), further hydrogenation of which results in two tetrahydro-2_2-methyl-*trans*-2,6-irones, which are stereoisomeric at the carbon atoms 2 and 3. Naves adopts "half-chair" forms for (LXXXIIIa) and (LXXXIIIb), with carbon atoms 2–5 lying approximately in the same plane, while the positions of carbon atoms 1 and 6 relative to this plane differ. The substituent containing the oxo-group is equatorial in both configurations. Naves remarks that one configuration can be readily converted into the other in the case of 2_2-methyl-*trans*-2,6-α-irone, but the transition is difficult with the dihydro-derivatives.



Some new work has been done on the stereoisomerism of the ionones. Tribolet and Schinz[205,206] established that α-ionone obtained by the cyclisation of pseudoionone possesses a *trans*-configuration at the double bond in the side--chain; they also suggested a *trans*-configuration for α-ionone and its derivatives. Büchi and Yang[207-209] achieved stereoisomeric transformations of the ionones by exposing them to ultraviolet radiation. From *trans*-α-ionone these workers obtained *cis*-α-ionone by this method; the odour of the latter was found to differ from the smell of violets possessed by the *trans*-isomers of ionone, and to resemble that of cedarwood. Irradiation of β-ionone did not yield the *cis*-isomer, since cyclisation took place with the formation of a pyran derivative. From the latter the semicarbazone of *cis*-β-ionone could be obtained, attempts at the hydrolysis of which yielded the pyran compound again.

Great new opportunities for the complete analysis of the complicated mixtures formed in syntheses of ionone preparations are provided by the use of gas–liquid partition chromatography. This research method, which has already been widely used in studying the most diverse organic compounds, has been successfully employed during recent years to separate and determine individual ionone and irone isomers. Naves reports the results of an extensive investigation of the application of gas–liquid chromatography to the analysis of mixtures of citral and some related compounds[210]. He determined the geometrical isomers of citral (geranial, neral) 6-methylcitral, and geraniol (nerol) in various samples of these products, and noted the advantages of gas–liquid chromatography compared with infrared spectroscopy. He confirmed that, of the four possible stereoisomers of pseudoionone (and also of pseudoirone), only two exist, corresponding to the geraniol–nerol isomerism. The content of isomeric pseudoionones was determined in mixtures obtained by the pyrolysis of dehydrolinalool acetoacetate, and the content of isomeric pseudoirones in the mixtures obtained by the pyrolysis of dehydro-6-methyllinalool acetoacetate. It was shown that mixtures of isomeric irones could be reliably analysed by this chromatographic method. Iso-α-irone, neoiso-α-irone, the total content of α-irone and neo-α-irone, and neo-β-irone can be determined in mixtures of α-irones. Furthermore, such a method of analysis can reveal the possible presence of impurities, particularly of oxides, isomeric with the irones, which are formed as side-products during cyclisation, as well as of pseudoirones which have not undergone cyclisation.

In the same work Naves used gas–liquid chromatography to analyse the isomeric constitution of the nerolidols obtained by the action of acetylene on geranylacetone (VII) followed by partial reduction (see Scheme 2, above), compared with samples of nerolidol isolated from natural essential oils. The relative proportions of the isomeric farnesols obtained from specimens of synthetic and of natural nerolidol were determined.

Crisler and Benford[211] used this method of analysis to determine the content of individual isomers of ionone and also of methylionone in mixtures.

There are also interesting new publications on the structure and stereochemistry of other terpenoid perfumes. New experimental results have been obtained on the content in natural products of the isopropylidene (β) and isopropenyl (α) forms of citronellol, geraniol, nerol, linalool, nerolidol, farnesol, citral, citronellal, and other related compounds[212-214].

The absolute configuration has been established of (+)-citronellic acid and of (+)-citronellol[215]. From an examination of the absolute configuration of the optically active linalools, Prelog and Watanabe[216] have explained the long known fact[217] of the formation, by the cyclisation of linalool, of a terpineol whose rotation is opposite in sign to that of the original linalool.

¶ Methylisoionones possess a more pleasant odour than their isomers having a side-chain of normal structure. Methyliso-α--ionone (more precisely a mixture enriched with this isomer) is widely used in perfumery under the trade name "iralia".

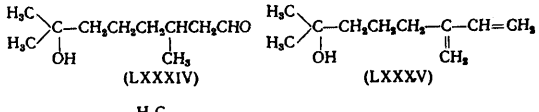
ț For the nomenclature adopted for the stereoisomeric irones, see our previous review[132].

We have discussed above new work on the general problems of the synthesis of terpenoid perfumes and also of the separate stages in the synthesis of the most important compounds of this group, ionone preparations, the improvement of methods for their analysis, and several closely connected investigations. In concluding this section we have to consider briefly a small number of papers published during recent years concerned with the preparation and investigation of several other odoriferous compounds of terpenoid structure which are of a somewhat more specialised character.

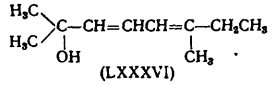
Joffre[218] has patented a method for isomerising citronellol into rhodinol by the action of ultraviolet radiation at ~20°. A new method has been proposed for obtaining citronellol based on the ozonisation of *p*-menth-3-ene, reduction of the ozonide with lithium aluminium hydride, and dehydration of the resulting 3,7-dimethyloctane-1,6-diol by heating it with sulphuric acid[219]. Bag *et al.*[220,221] have worked out a process for converting geraniol into citronellal (dehydrogenation with simultaneous selective addition of hydrogen at one of the double bonds) in the presence of a copper–chromium catalyst containing barium oxide at 220°–230° and a residual pressure of 100 mm. The yield of the aldehyde is 65% (based on the geraniol). Bag *et at.*[222] have discovered the conditions for the selective catalytic hydrogenation of citral which make it possible to obtain mixtures considerably richer in nerol.

Polyakov[223] noted a favourable effect of adding the pinene fraction of turpentine on the yield of citral in the oxidation of pure linalool or of coriander oil containing linalool.

The conversion of hydroxycitronellal (LXXXIV) into 2,6-dimethyloctan-2-ol and the study of the infrared spectrum have confirmed[224] the structure 7-hydroxy-3,7-dimethyloctanal which has long been accepted for this valuable perfume. Myrcene can be hydrated at the isolated double bond, by the action of acetic acid in the presence of a small amount of sulphuric acid followed by saponification of the resulting acetate, with the formation of a tertiary alcohol (LXXXV).[225,226] The alcohol itself, "myrcenol" possesses an agreeable odour resembling that of linalool and α-terpineol, its acetate being reported as having a strong smell with a fruity and bergamot tinge[226]. According to an American patent[227], the isomeric tertiary alcohol (LXXXVI), with an arrangement of double bonds different from that in myrcenol (it is prepared from alloocimene by hydrochlorination followed by hydrolysis), can be employed in perfumery compositions to give the scent of lilies of the valley and of roses. Another patent[228] describes a process for obtaining linalyl acetate by the addition of hydrogen chloride to myrcene with subsequent acetylation: the resulting mixture comprises 80% of linalyl acetate and 20% of geranyl acetate.

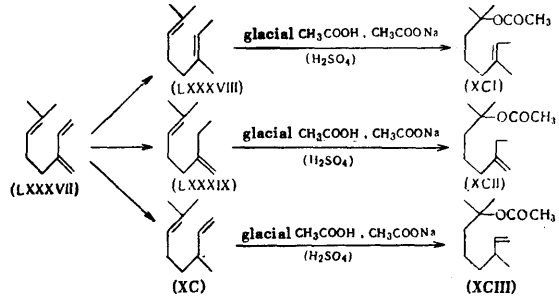


(LXXXIV) (LXXXV)



(LXXXVI)

The patent literature also indicates that several new acetates, prepared from myrcene possess an interesting odour[229]. Depending on the conditions, the incomplete hydrogenation of myrcene (LXXXVII) can yield the diene hydrocarbons (LXXXVIII)–(XC), converted by the addition of acetic acid into (XCI)–(XCIII), the first two of the latter group having a very pleasant odour.



Italian chemists have investigated the isomerisation of linalool to geraniol in the presence of acetic anhydride. Boiling a mixture of linalool with 1.5 moles of acetic anhydride for 10 h leads to the formation of geranyl acetate (34%) and a mixture (40%) of limonene, myrcene, and ocimene. These hydrocarbons were separated by gas chromatography and identified by their ultraviolet and infrared spectra. The kinetics of the isomerisation of linalool have been studied[230].

Several improvements have been suggested for the conversion of α-pinene into terpineol and into terpin hydrate. Thus it has been recommended[231] that the well-known hydration of α-pinene with sulphuric acid should be carried out at a temperature not exceeding 3°; good results are obtained by the addition of small quantities of cetylpyridinium chloride[231], polyethyleneglycol monolauryl ether[231], or gelatin[232] as emulsifiers, which considerably increases the reaction velocity; access of air also has a favourable effect[232].

A study of the influence of the polarity of the medium on the mode and rate of reaction of pinene with acids[233] has established that, in a strongly polar medium (CH_3COOH with water, CH_3COOH with formamide or *N*-methylformamide), α-terpineol containing the acetate as impurity, and limonene with α-terpinene as impurity, are formed respectively; the yield of the terpineol increases with increasing duration of the reaction and decreasing concentration of acid.

In the absence of a catalyst, α-terpineol can be obtained mixed with its acetate by boiling α-pinene with dilute acetic acid[234].

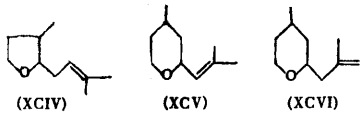
It is recommended[232] that terpin hydrate should be converted into α-terpineol in the presence of 5% sulphuric acid in an organic solvent; when 0.5% of oxalic acid is employed as dehydrating agent, the terpineol obtained is of high quality[232].

The work of Japanese chemists[235] has shown that treatment of terpin hydrate with lead tetraacetate in acetic anhydride at 65° for 8 h yields *d,l*-terpineol together with terpin monoacetate, whereas treatment of terpin hydrate with a mixture of acetic anhydride and acetic acid in the absence of lead tetraacetate gives *d,l*-terpineol, its acetate, and terpin monoacetate, the yield of these products being higher than in the first case. It was concluded from these observations that the transformations of terpin hydrate in the presence of a mixture of lead tetraacetate and acetic anhydride are a result of dehydration and acetylation under the influence of the acetic anhydride.

One patent[236] notes the high yields of terpineol, containing no hydrocarbons, produced by the dehydration of terpin or terpin hydrate in the presence of feebly acid solid catalysts such as silica gel activated with phosphoric acid, titanium hydroxide activated with acetic acid, acid cation-exchange resins, etc.

The conditions for the conversion of α-terpineol, limonene, and some other related compounds into *cis*- and *trans*-terpin under the influence of sulphuric acid have been studied by Lombard and Geiger[237].

Interesting results have been obtained from a careful study of the substance having the composition $C_{10}H_{18}O$, first isolated by Seidel and Stoll[238] from high-boiling fractions of Bulgarian rose oil, and given the name "rose oxide". It has been established that this compound is not a tetrahydrofuran derivative of formula (XCIV), as had at first been supposed, and in conformity with which the first attempts at synthesis had been made[239]; it was in fact a tetrahydropyran derivative having the structure (XCV).[240-243] Stereoisomers of the "rose oxide" were then synthesised in a series of investigations[240,244-246], as well as its structural isomer (XCVI).[246]

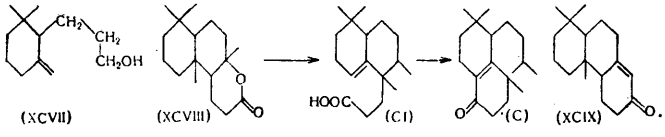


(XCIV) (XCV) (XCVI)

3. PERFUMES OBTAINABLE FROM AMBERGRIS AND FROM SCLAREOL

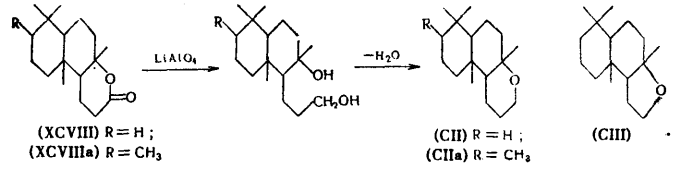
In our review[132] we reported the results obtained mainly by Swiss chemists, which established the nature of the odoriferous substances in ambergris. Since then, some new work has been published which has refined the earlier results and also indicated new routes for the synthesis of compounds having an ambergris odour.

From the non-ketonic portion of ambergris, Seidel and Stoll isolated an alcohol which is a homologue of γ-cyclogeraniol and is a liquid with an ambergris type of smell. The structure of γ-cyclohomogeraniol (XCVII) has been confirmed by synthesis[247]. This alcohol has been synthesised also by other investigators[248], but they do not describe its odour.



(XCVII) (XCVIII) (CI) (C) (XCIX)

Various products have previously been described, obtained by chemical transformations of ambreinolide (XCVIII), a lactone formed together with other products by the oxidation of ambrein, which is contained to the extent of ~25–45% in ambergris. A product of the action of acidic reagents on ambreinolide is an unsaturated tricyclic ketone $C_{17}H_{26}O$, which possesses a strong ambergris–musk smell; this ketone had previously been assigned the structure (XCIX).[249] Recently, a somewhat different structure (C) has been established for this compound; its formation from the lactone (XCVIII) is explained by a Wagner–Meerwein rearrangement yielding an unsaturated bicyclic acid (CI), dehydration of which gives the compound (C).[250] In 1950 the preparation from ambreinolide (XCVIII) of an oxide (CII), having a smell of ambergris, was described[251]. Somewhat later a similar scheme was used to convert 2-methylambreinolide (XCVIIIa) into the corresponding oxide (CIIa), which was described as a compound having a fruity odour[252,253].



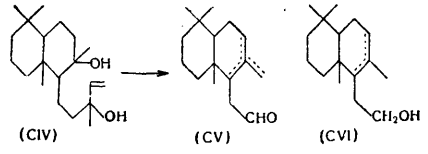
(XCVIII) R = H; (XCVIIIa) R = CH_3 (CII) R = H; (CIIa) R = CH_3 (CIII)

In the development of this work a lactone containing a smaller lactone ring than (XCVIII) and (XCVIIIa), and thus constituting their lower homologue, was converted by reduction followed by dehydration into an oxide (CIII) smelling, like (CII), of ambergris[254].

From the same series of investigations, we may mention papers on the synthesis of (XCVIII) and (XCVIIIa) from dihydro-α-ionone[255] and dihydroiso-α-irone[252,253] respectively. This work again emphasises the close genetic relation between the aromatic principles of ambergris and derivatives of the ionone group; its practical interest consists in the indication of new routes for the synthesis of compounds containing an ambreinolide skeleton and related products.

Another line of work in this field, which in our view is promising, is the preparation of valuable products from sclareol (CIV), a bicyclic triterpene glycol present in the waste remaining from the plant *Salvia sclarea* L. (muscatel sage) after the essential oil has been distilled off. Some years earlier the multistage preparation had been described of bicyclohomofarnesal (CV) and bicyclohomofarnesol (CVI), which have an odour of ambergris, from the products of the oxidative degradation of sclareol (for a description of this work see, for example, our previous review[132]).

A method has now become available for the direct conversion of (CIV) into (CV) by the action of a chromic acid mixture or of chromium trioxide in glacial acetic acid[256-259]:



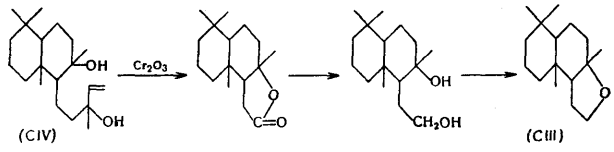
(CIV) (CV) (CVI)

The composition of the products obtained has been studied as a function of the reaction conditions, and a mechanism suggested for their formation[259]; the method for obtaining bicyclohomofarnesal, which is known also as ambrial, has been tested on a large scale in our institute.[258]

The use of bicyclohomofarnesal and bicyclohomofarnesol in perfumery compositions has been described in a recent patent from the Federal Republic of Germany[260].

The work of Soviet chemists[259,261] has repeated and somewhat improved the conversion of sclareol (CIV) through a series of intermediate products into the oxide (CIII) (termed "ambroxide"), which had been accomplished earlier by Ruzicka and his collaborators[262] and later by Stoll and Hinder[263,264]. The lithium aluminium hydride

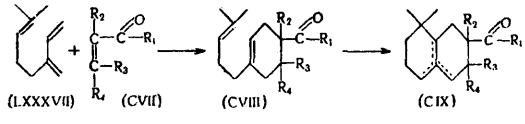
used earlier to reduce the lactone to a glycol was successfully replaced in this work by sodium borohydride[259,265]; however, an attempt to effect the process catalytically was unsucessful[266].



Thus new investigations in this branch of the chemistry of perfumes have led to the discovery of comparatively simple methods for obtaining compounds possessing the odour of ambergris.

4. ALKYLOCTALIN DERIVATIVES

An extremely interesting new class of odoriferous compounds has been described recently in a series of papers by Ohloff[267-272]. He has made a detailed study of the diene synthesis reaction using as the initial compounds myrcene (LXXXVII)‡ and various dienophils (CVII). The cyclisation of the resulting adducts (CVIII) yielded a series of different derivatives of 1,1-dimethyloctalin. The readiness of (CVII) to undergo diene synthesis was found to depend to a considerable extent on the degree of substitution and the positions of the substituents: thus α-substituted (CVII) derivatives are more reactive than the β-substituted compounds.

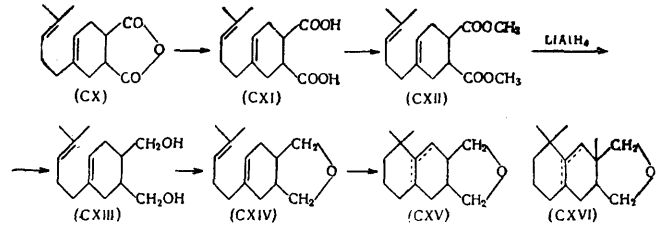


Cyclisation of (CVIII) in the presence of sulphuric or phosphoric acid, or a mixture of formic and sulphuric acids, is made more difficult by increasing the number of substituents in the cyclohexene ring; however, when boron trifluoride is employed as cyclising agent§, the rate of cyclisation is the same independently of the degree of substitution of (CVIII).[270]

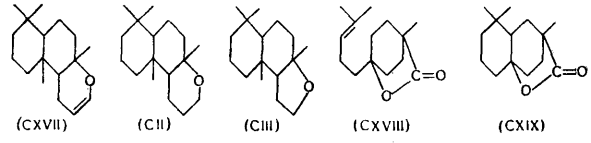
In Ohloff's view[268,271] the formation of isomers [α, β, and γ, differing in the position of the double bond, indicated by dotted lines in formula (CIX)] can be explained by the intermediate formation of a carbonium ion¶, just as in the cyclisation of pseudoionone.

The preparation by the above scheme of a wide variety of derivatives of 1,1-dimethyloctalin has enabled some generalisations to be made concerning the dependence of the odour of these compounds on their structure[268,269,271,272]. Thus (CIX) with $R_1 = CH_3$ or C_2H_5 and $R_2 = R_3 = R_4 = H$ possess an ionone smell, which becomes weaker with increase in the size of R_1 and completely disappears when $R_1 = n\text{-}C_4H_9$ or $C(CH_3)_3$. Special interest attaches to derivatives of unsaturated 1,1,7-trimethyloctalins containing a functional group and a methyl group on the same carbon atom. Thus esters of this group ($R_1 = OR$; $R_2 = CH_3$; $R_3 = R_4 = H$) possess a very persistent odour of animal musk, which becomes especially intense if the COOR group is transesterified with higher iso-alcohols. When $R_1 = H$ or Alk, the 1,1,7-trimethyloctalin derivatives have a woody or ambergris type of smell. For example, (CIX) in which $R_1 = R_3 = R_4 = CH_3$ and $R_2 = H$ is described as a compound having such an odour[275].

A group of French chemists[276] have recently utilised the long known reaction of myrcene with maleic anhydride for the synthesis of new perfumes. The dibasic acid (CXI), which is readily obtainable from the adduct (CX), was converted into the ester (CXII), which on reduction with lithium aluminium hydride gave the corresponding diol (CXIII), dehydration of which yielded the bicyclic oxide (CXIV), which was then isomerised to the unsaturated tricyclic oxide (CXV). The adduct of myrcene with citraconic anhydride was used to synthesise, by an analogous series of reactions, the unsaturated tricyclic oxide (CXVI). These tricyclic oxides possess a very interesting ambergris odour.



It is interesting to note here some analogy in structure between these oxides and those obtained earlier[277] and also possessing an ambergris smell, such as the unsaturated oxide (CXVII), formed by the oxidation of ambrein (a tricyclic triterpene alcohol present in ambergris) and also the saturated oxides (CII) and (CIII) (the so-called ambroxide, obtained from sclareol) mentioned in the present review (see Section 3).



Among other interesting compounds synthesised from myrcene as diene component we may mention the lactones (CXVIII) and (CXIX), the latter possessing a strong odour of animal-faecal type. Experimental details of its preparation have been reported recently by Ohloff in a West German patent[278]. The value of this lactone for perfumery has been confirmed by the work of Soviet chemists[279].

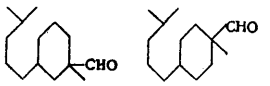
Several adducts of myrcene with unsaturated aldehydes, as well as compounds obtained after their hydrogenation,

‡ In the reactions with some of the dienophils, 3-methylmyrcene[273], its isomer 2-isopropyl-5-methylenehepta-1,6-diene[273], and a homologue of myrcene 2-methyl-6-methylenenona-2,7--diene[274] were also studied as diene components.

§ As in several other cases known previously, this shows the specific character of the catalytic action of boron trifluoride. Another example of this is the stereospecific cyclisation of pseudoirone under the influence of boron trifluoride, which we have examined in detail[132] and which has been mentioned in the present review (Section 2).

¶ The cyclisation of (CVIII) is discussed in greater detail in the review by Smit and Kucherov[183].

also merit attention as perfumes. Thus, for example, the adduct of myrcene with crotonaldehyde [(CVIII): $R_1 = R_2 = R_3 = R_4 = H$] possesses the odour of aubépine (*p*-methoxybenzaldehyde), while the corresponding alcohol is said to have a pleasant delicate scent[280]; the mixture of the isomeric aldehydes (CXX) and (CXXI), obtained by the condensation of myrcene with methacrylaldehyde followed by hydrogenation, has a strong scent of flowers[281].



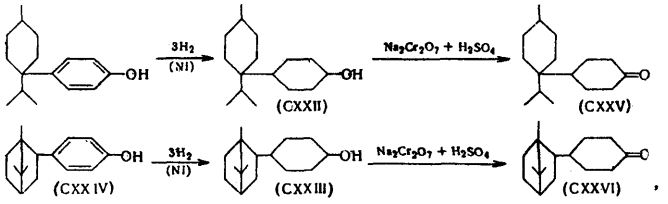
(CXX) (CXXI)

The group of octalin derivatives includes also the ambrinols discussed above [(LXXVIII) in Section 2], as well as bicyclohomofarnesal or ambrial (CV) and bicyclohomofarnesol [(CVI) in Section 3], compounds possessing an extremely valuable scent.

5. PERFUMES BASED ON TERPENYLPHENOLS

On the basis of the little information available, mainly in the patent literature[281-286], Soviet chemists have synthesised a series of new compounds which are oxygen-containing derivatives of cyclohexane with a terpene radical. In view of the great value of some of the products obtained, the synthesis was extended to a wide variety of derivatives, differing from one another in the functional group and the structure of the terpene radical.

Belov and Kheifits[287] have described compounds based on the condensation products of menthyl chloride with phenol, and also of a mixture of bornyl and isobornyl chlorides with phenol†, *m*-cresol, and *o*-cresol respectively. The resulting condensation products were subjected to hydrogenation. It was found that menthylcyclohexanol (CXXII) possesses a weak odour of cedar, whereas alcohols containing a bornyl radical have a stronger smell. Bornylcyclohexanol itself (CXXIII) has a very persistent, but not strong, cedar type of odour.



(CXXII) (CXXV)
(CXXIV) (CXXIII) (CXXVI)

The smell becomes weaker on passing to bornyl-3--methylcyclohexanol, but is intensified with bornyl-2--methylcyclohexanol, which, in the opinion of the authors of the paper, is due to the presence of the tertiary carbon atom, linked to the methyl group, adjacent to the alcoholic hydroxyl. Furthermore, with the 2-methyl isomer the odour acquires a sandalwood nuance. The acetates were almost devoid of smell. Oxidation of the alcohols with a chromic acid mixture yielded previously undescribed ketones. The transition to the ketones results in a considerable intensification of the odour; further, terpenylcyclohexanones containing a bornyl radical possess a pleasant odour, while menthylcyclohexanone (CXXV) has a disagreeable, obtrusive smell.

On passing from bornylcyclohexanone (CXXVI) to its homologues, a similar variation in odour is observed as in the case of the corresponding alcohols: with bornyl-3--methylcyclohexanone the odour does not change in character but becomes weaker, whereas with isobornyl-2-methylcyclohexanone the smell is markedly stronger and has acquired a different character, of musk and balsam.

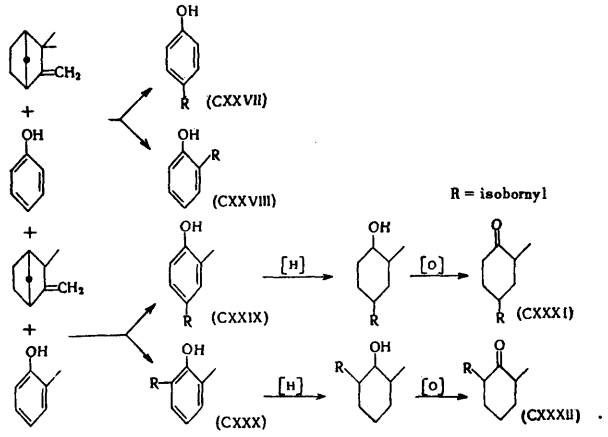
In order to simplify the synthesis of isobornyl-2-methylcyclohexanol and isobornyl-2-methylcyclohexanone, which are valuable compounds for perfumery, the alkylating agent used for the preparation of isobornyl-2-methylphenol, an intermediate in this synthesis, was camphene, a cheap and readily available product which can be made to react with *o*-cresol without preliminary conversion into the chloride[289]. The product formed as a result of the condensation of camphene with *o*-cresol followed by hydrogenation, which is obviously isobornyl-2-methylcyclohexanone, has found application in the perfumery industry under the name "musterone"; some details of its industrial synthesis were published recently[290].

The condensation of camphene with phenols has been studied in detail by Kheifits in the case of the preparation of isobornylphenol: it was found that, on alkylation in the presence of boron trifluoride, the proportions of *ortho*- and *para*-isomers were 3.5 : 1, a simple and convenient method was worked out for separating the isomeric isobornylphenols from their mixtures[291].

Recently Kheifits, Belov, and their collaborators have published a series of papers on the structure and the composition of the condensation products formed by camphene with *o*- and *p*-cresols. It is assumed that, under the conditions of acid catalysis, the camphene undergoes a Wagner–Meerwein rearrangement and enters the aromatic ring as an isobornyl radical. On the basis of the different acidities of the individual isomers, due to the strong screening of the OH group in compounds containing an *o*-isobornyl radical, an elegant method has been worked out for separating the *ortho*- and *para*-isomers, which are thus obtained in a quite pure form, by treatment with an insufficient quantity of aqueous-alcoholic alkali[291,292]. The dissociation constants of the compounds (CXXVII)–(CXXX) in various aqueous organic solvents have been determined[293]; the acidity of the *para*-isomers is considerably the higher. The structure of (CXXVII)–(CXXX) has been rigorously established from the infrared spectra[291,292] and measurements of the dipole moments of their bromo-derivatives[294]. Quantitative analysis by means of the infrared spectra has shown that the ratio of the *ortho*- and *para*-isomers on alkylation with camphene is 3.5 : 1 in the case of phenol[291], whereas with *o*-cresol it is 1.9 : 1 [292] (probably owing to one *ortho*-position being occupied). A method has been developed for identifying the individual isobornylphenols and isobornylcyclohexanones by thin-layer chromatography[295,296]. The compounds (CXXIX) and (CXXX) are converted by hydrogenation and oxidation into the corresponding cyclohexanones (CXXXI) and (CXXXII), when it is found that the former has a strong smell of musk, whereas the latter has a very faint but more pleasant odour of the same type[295]. Musterone contains ~30% of (CXXXI) and ~70% of (CXXXII).[295]

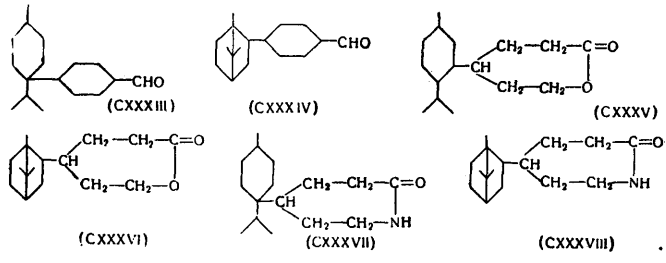
† Later the reaction of bornyl chloride with phenol formed the subject of a special study by Bulgarian chemists[288], who carried it out in the presence of aluminium chloride. They consider that the most probable formula for the resulting bornylphenol is (CXXIV).

2-Isobornyl-4-methylcyclohexanone[296], prepared in a similar manner, has a peculiar faint odour.



Belov and Kheifits[297] have studied the effect on the odour of converting terpenylcyclohexanones into previously undescribed related compounds containing different functional groups. The aldehydes (CXXXIII) and (CXXXIV) obtained from (CXXV) and (CXXVI) respectively were found to have a rancid tinge to their odour and to be of no interest for perfumery. Of the hexan-1,6-olides which have been synthesised, (CXXXV) is completely devoid of smell, and (CXXXVI) possesses an odour similar to but fainter than that of the original (CXXVI). These observations agree with earlier information[298] on the odour of other hexan-1,6-olides; the conversion of substituted cyclohexanones into such lactones is obviously accompanied by the disappearance or weakening of the odour.

The ketones (CXXV) and (CXXVI) have also been converted into the corresponding hexane-1,6-lactams (ε-caprolactams), of which (CXXXVII) is reported to be odourless, while (CXXXVIII) possesses a peculiar smell, somewhat resembling that of the lactone (CXXXVI) but still weaker than that of the ketone.



An extremely interesting product, possessing a sandalwood odour and excellent fixation properties, is formed by the hydrogenation of isobornylguaiacol (isobornyl-2-methoxyphenol). A team of workers at the VNIISNDV (All-Union Synthetic and Natural Perfumes Research Institute) and industrial scientists have worked out and published an industrial method for the synthesis of this most valuable product, which has been provisionally named "santalidol".[299] The preparation of isobornyl-2-methoxyphenol was accomplished by condensing camphene with guaiacol in the presence of boron trifluoride, the benzene ring being subsequently hydrogenated to a cyclohexane ring in the presence of a Raney nickel catalyst. The chemical structure of the product has not been finally elucidated, the authors of the paper regarding it as a mixture of various alcohols of closely similar structure.

A hydrogenation product of isobornyl-2-ethoxyphenol, synthesised from camphene and guaethol, was likewise obtained as a mixture of alcohols, having a very similar odour to that of santalidol[289]. Oxidation on the alcohols with a chromic acid mixture yielded a mixture of ketones having a stronger scent of sandalwood than the original alcohols.

Thus the research done during recent years on terpenylphenols has yielded several products of great value in perfumery, and has provided new data on the effect of the structure of organic compounds on their odour. Even the fact itself of a strong and persistent odour in terpenylcyclohexanols and terpenylcyclohexanones, which have quite large molecules with radicals of high molecular weight, is undoubtedly of interest.

1. M. Carroll, J. Chem. Soc., 704 (1940).
2. M. Carroll, J. Chem. Soc., 1266 (1940).
3. W. Kimel and A. Cope, J. Amer. Chem. Soc., 65, 1992 (1943).
4. Y. Naves, Compt. rend., 240, 1437 (1955).
5. W. Kimel, U.S.P. 2 658 911, 2 662 920 (1953); Chem. Abs., 49, 1099 (1955).
6. W. Kimel, J. Surmatis, J. Weber, G. Chase, N. Sax, and A. Ofner, J. Org. Chem., 22, 1611 (1957).
7. J. Dreux and J. Colonge, Bull. Soc. chim. France, 1312 (1955).
8. I. K. Sarycheva, G. A. Vorob'eva, and N. A. Preobrazhenskii, Zhur. Obshch. Khim., 27, 2662 (1957).
9. I. N. Nazarov, L. A. Yanovskaya, B. P. Gusev, S. S. Yufit, V. I. Gunar, and V. A. Smit, Dokl. Akad. Nauk SSSR, 114, 331 (1957).
10. I. N. Nazarov, S. M. Makin, V. B. Mochalin, D. V. Nazarova, V. P. Vinogradov, B. K. Kruptsov, I. I. Nazarova, and O. A. Shavrygina, Dokl. Akad. Nauk SSSR, 114, 1242 (1957).
11. I. N. Nazarov, L. A. Yanovskaya, B. P. Gusev, S. M. Makin, and I. I. Nazarova, Dokl. Akad. Nauk SSSR, 114, 1029 (1957).
12. P. Teisseire, P. Bernard, and B. Corbier, Recherches, 30 (1956); Chem. Abs., 51, 2565 (1957).
13. P. Teisseire, French P. 1 132 659 (1957).
14. I. N. Nazarov, B. P. Gusev, and V. I. Gunar, Izv. Akad. Nauk SSSR, Otd. Khim. Nauk, 1267 (1957).
15. W. Kimel and N. Sax, U.S.P. 2 661 368 (1953).
16. R. Lacey, J. Chem. Soc., 827 (1954).
17. R. Lacey, B. P. 741 047 (1955); Chem. Abs., 50, 16 839 (1956).
18. P. Teisseire, Recherches, 3 (1955); Chem. Abs., 49, 14 645 (1955).
19. P. Teisseire, French P. 1 132 659 (1957).
20. R. Dulou and G. Clément, Fette u. Seifen, 595 (1955).
21. Y. Naves and P. Ardizio, Bull. Soc. chim. France, 1497 (1955).
22. Y. Naves and P. Ardizio, Bull. Soc. chim. France, 672 (1956).
23. M. Carroll, B. P. 762 656 (1956).
24. L. Givaudan, B. P. 802 534 (1958); Chem. Abs., 53, 11 434 (1959).
25. G. I. Samokhavlov, M. A. Miropol'skaya, and N. A. Preobrazhenskii, Russ. P. 103 777 (1955).
26. G. I. Samokhavalov, M. A. Miropol'skaya, and N. A. Preobrazhenskii, Dokl. Akad. Nauk SSSR, 107, 103 (1956).

27. G. I. Samokhvalov, M. A. Miropol'skaya, L. V. Luk'yanova, and N. A. Preobrazhenskii, Zhur. Obshch. Khim., 27, 2501 (1957).
28. A. E. Favorskii and Skosarevskii, Zhur. Russ. Fiz.-Khim. Obshch., 32, 652 (1900).
29. A. E. Favorskii and Skosarevskii, Zhur. Russ. Fiz.-Khim. Obshch., 26, 284 (1901).
30. I. N. Nazarov, V. P. Gusev, S. M. Makin, V. P. Mochalin, I. I. Nazarova, V. P. Vinogradov, B. K. Kruptsov, O. A. Shavrygina, and D. V. Nazarova, Dokl. Akad. Nauk SSSR, 114, 796 (1957).
31. I. N. Nazarov, I. L. Kotlyarevskii, and V. F. Ryabchenko, Izv. Akad. Nauk SSSR, Otd. Khim. Nauk, 960 (1956).
32. I. N. Nazarov, I. L. Kotlyarevskii, and V. F. Ryabchenko, Zhur. Obshch. Khim., 23, 1900 (1953).
33. I. N. Nazarov, S. M. Makin, V. B. Mochalin, O. A. Shavrygina, and D. V. Nazarova, Zhur. Obshch. Khim., 29, 1176 (1959).
34. S. Kambara, S. Tajima, and N. Sato, J. Chem. Soc. Japan, Ind. Chem. Sect., 62, 295, 17A (1959); Ref. Zhur. Khim., 31 742 (1960).
35. R. Lacey, and H. Jowitt, B. P. 813490 (1959).
36. O. Isler, M. Montavon, R. Rüegg, and P. Zeller, Helv. Chim. Acta, 39, 259 (1956).
37. H. Lindlar, Helv. Chim. Acta, 35, 446 (1952).
38. C. Garbers, C. Engster, and P. Karrer, Helv. Chim. Acta, 35, 1850 (1952).
39. B. Elsner and P. Paul, J. Chem. Soc., 3156 (1953).
40. K. Hofmann and S. Sax, J. Biol. Chem., 205, 55 (1953).
41. B. Baker, R. P. Linstead, and B. Weedon, J. Chem. Soc., 2218 (1955).
42. L. Crombie, J. Chem. Soc., 3510 (1955).
43. O. Isler, R. Rüegg, L. Chopard-dit-Jean, H. Wagner, and K. Bernhard, Helv. Chim. Acta, 39, 897 (1956).
44. J. Kalish, Drug and Cosm. Ind., 80, 739 (1957).
45. Chem. Eng., 148 (1957).
46. Ph. Chaleyer, Perfumery Essent. Oil Record, 49, No. 1, 17 (1958).
47. O. V. Leontovich, Novosti Pishchevoi Prom., No. 7, 37 (1959).
48. L. A. Yanovskaya and V. F. Kucherov, Symposium, "Voprosy Teorii Stroeniya Organicheskikh Soedinenii" (Theoretical Problems of the Structure of Organic Compounds), Leningrad University, Leningrad, 1960, p. 135.
49. I. N. Nazarov, S. M. Makin, V. B. Mochalin, O. A. Shavrygina, D. V. Nazarova, and B. K. Kruptsov, Zhur. Obshch. Khim., 29, 744 (1959).
50. V. B. Mochalin, O. A. Shavrygina, D. V. Nazarova, and S. M. Makin, "Voprosy Khimii Terpenov i Terpenoidov (Trudy Vsesoyuznogo Soveshchaniya po Voprosam Khimii Terpenov i Terpenoidov, Sostoyavshegosya v Vil'nyuse 4–6/VI–1959)" [Problems of the Chemistry of Terpenes and Terpenoids (Transactions of the All-Union Conference on Problems of the Chemistry of Terpenes and Terpenoids held in Vilna during 4–6th June 1959)], Gos. Izd. Polit. i Nauch. Liter. Lit. SSR, Vilna, 1960, p. 225.
51. G. I. Samokhvalov, M. A. Miropol'skaya, and S. Ya. Mel'nik, "Voprosy Khimii Terpenov i Terpenoidov (Trudy Vsesoyuznogo Soveshchaniya po Voprosam Khimii Terpenov i Terpenoidov, Sostoyavshegosya v Vil'nyuse 4–6/VI–1959)" [Problems of the Chemistry of Terpenes and Terpenoids (Transactions of the All-Union Conference on Problems of the Chemistry of Terpenes and Terpenoids held in Vilna during 4–6th June 1959)], Gos. Izd. Polit. i Nauch. Liter. Lit. SSR, Vilna, 1960, p. 179.
52. Y. Naves, P. Ardizio, and B. Wolf, Bull. Soc. chim. France, 1213 (1957).
53. Y. Naves, P. Ardizio, and B. Wolf, Compt. rend., 244, 2393 (1957).
54. O. Isler, L. Chopard-dit-Jean, W. Guex, G. Ryser, and G. Saucy, Chimia (Switz.), 11, 103 (1957).
55. G. Saucy, L. Chopard-dit-Jean, W. Guex, G. Ryser, and O. Isler, Helv. Chim. Acta, 41, 160 (1958).
56. W. Kimel, N. Sax, S. Keiser, G. Eichmann, G. Chase, and A. Ofner, J. Org. Chem., 23, 153 (1958).
57. G. I. Samokhvalov, Symposium, "Obmen Opytom Raboty Parfyumernokosmeticheskikh Fabrik, Predpriyatii Sinteticheskikh Dushistykh Veshchestv i Efiro-Maslichnoi Promyshlennosti" (Interchange of Experience of Work in Perfume and Cosmetic Factories and Undertaking of the Synthetic Perfume and Essential Oil Industry), Gosinti, Moscow, 1960, p. 106.
58. I. N. Nazarov and Zh. A. Krasnaya, Izv. Akad. Nauk SSSR, Otd. Khim. Nauk, 870 (1958).
59. N. A. Daev and V. M. Dashunin, Khim. Nauka i Prom., 2, 667 (1957).
60. N. A. Daev and V. M. Dashunin, Khim. Nauka i Prom., 3, 127 (1958).
61. G. Saucy, R. Marbet, H. Lindlar, and O. Isler, Chimia (Switz.), 12, 326 (1958).
62. G. Saucy, R. Marbet, H. Lindlar, and O. Isler, Angew. Chem., 71, 81 (1959).
63. G. Saucy, R. Marbet, H. Lindlar, and O. Isler, Helv. Chim. Acta, 42, 1954 (1959).
64. I. N. Nazarov, B. P. Gusev, and V. I. Gunar, Zhur. Obshch. Khim., 28, 1444 (1958).
65. G. I. Samokhvalov, M. A. Miropol'skaya, L. A. Vakulova, and N. A. Preobrazhenskii, Zhur. Obshch. Khim., 25, 545 (1955).
66. B. P. Gusev and I. N. Nazarov, Russ. P. 112578 (1957).
67. Y. Naves, U. S. P. 2740817 (1956).
68. A. Mondon, Chem. Ber., 88, 724 (1955).
69. I. K. Sarycheva, N. G. Morozova, V. A. Abramovich, S. A. Breitburt, L. F. Sergienko, and N. A. Preobrazhenskii, Zhur. Obshch. Khim., 25, 2001 (1955).
70. O. Yu. Shvarts and A. A. Petrov, Zhur. Obshch. Khim., 30, 3598 (1960).
71. I. N. Nazarov, S. M. Makin, O. A. Shavrygina, and V. A. Smirnyagin, Zhur. Obshch. Khim., 30, 443 (1960).
72. J. Arens and D. Dorp, Rec. Trav. chim., 67, 973 (1948).
73. A. Rouve and M. Stoll, Helv. Chim. Acta, 33, 2019 (1950).
74. Y. Naves, Helv. Chim. Acta, 34, 411 (1951).
75. Y. Naves and P. Ardizio, Bull. Soc. chim. France, 374 (1951).
76. M. Stoll and B. Willhalm, Helv. Chim. Acta, 35, 775 (1952).
77. I. N. Nazarov, Zh. A. Krasnaya, and V. P. Vinogradov, Zhur. Obshch. Khim., 28, 460 (1958).
78. I. N. Nazarov, S. M. Makin, D. V. Nazarova, V. B. Mochalin, and O. A. Shavrygina, Zhur. Obshch. Khim., 30, 1168 (1960).
79. K. V. Leets, Russ. P. 105428 (1955).
80. K. V. Leets, A. K. Shumeiko, A. A. Rozenoer, N. V. Kudryasheva, and A. I. Pilyavskaya, Zhur. Obshch. Khim., 27, 1510 (1957).
81. K. V. Leets, Ya. E. Kachanov, and A. K. Shumeiko, Maslo-boinozhirov. Prom., No. 8, 33 (1957).
82. K. V. Leets, Ya. E. Kachanov, and A. K. Shumeiko, see Ref. 57, p. 97.
83. V. N. Belov, N. A. Daev, S. D. Kustova, K. V. Leets, S. S. Poddubnaya, N. I. Skvortsova, E. I. Shepelenkova, and A. K. Shumeiko, Zhur. Obshch. Khim., 27, 1384 (1957).
84. V. N. Belov, N. A. Daev, S. D. Kustova, K. V. Leets, G. V. Meleshkina, S. S. Poddubnaya, N. I. Skvortsova, V. Ya. Tokareva, E. I. Shepelenkova, and A. K. Shumeiko, see Ref. 50, p. 21.
85. M. Montavon, H. Lindlar, R. Marbet, R. Rüegg, G. Ryser, G. Saucy, P. Zeller, and O. Isler, Helv. Chim. Acta, 40, 1250 (1957).
86. I. N. Nazarov, S. M. Makin, V. B. Mochalin, and D. V. Nazarova, Zhur. Obshch. Khim., 29, 3965 (1959).
87. A. A. Petrov, Kh. V. Bal'yan, Yu. I. Kheruze, E. Yu. Shvarts,

and L. L. Cherenkova, Zhur. Obshch. Khim., 28, 1435 (1958).
88. K. V. Leets, Zhur. Obshch. Khim., 28, 1823 (1958).
89. K. V. Leets, Zhur. Obshch. Khim., 28, 3096 (1958).
90. A. A. Petrov, Kh. V. Bal'yan, Yu. I. Kheruze, E. Yu. Shvarts, and L. L. Cherenkova, Zhur. Obshch. Khim., 29, 1876 (1959).
91. A. A. Petrov, Kh. V. Bal'yan, Yu. I. Kheruze, E. Yu. Shvarts, and T. V. Yakovleva, Zhur. Obshch. Khim., 29, 445 (1959).
92. A. A. Petrov and T. V. Yakovleva, Izv. Akad. Nauk SSSR, Ser. Fiz., 23, 1217 (1959).
93. E. Yu. Shvarts and A. A. Petrov, Zhur. Obshch. Khim., 31, 433 (1961).
94. A. A. Petrov and Z. N. Kolyaskina, Zhur. Obshch. Khim., 30, 1450 (1960).
95. K. V. Leets, Candidate's Thesis (Ph. D. Equivalent) Lensovet Leningrad Institure of Technology, 1954.
96. A. I. Lebedeva and L. A. Almashi, Zhur. Obshch. Khim., 28, 904 (1958).
97. A. I. Lebedeva and L. V. Kukhareva, Zhur. Obshch. Khim., 28, 2728 (1958).
98. H. Normant, Compt. rend., 239, 1510 (1954).
99. H. Normant, Bull. Soc. chim. France, 728 (1957).
100. S. T. Ioffe, Uspekhi Khim., 27, 1010 (1958).
101. H. Normant, Ind. Parfumerie, 11, No. 5, 172 (1956).
102. H. Normant, Compt. rend., 240, 631 (1955).
103. H. Normant, French P., 1 136 255 (1957).
104. H. Ramsden, J. Leebrick, S. Rosenberg, E. Miller, J. Walburn, A. Balint, and R. Cserr, J. Org. Chem., 22, 1602 (1957).
105. N. I. Skvortsova, V. Ya. Tokareva, and V. N. Belov, Zhur. Obshch. Khim., 29, 3113 (1959).
106. N. I. Skvortsova, V. Ya. Tokareva, and V. N. Belov, Trudy Vses. Nauch.-Issled. Inst. Sintet. Natural. Dushistykk Veshchestv, Pishchepromizdat, No. 5, 37 (1961).
107. A. Ofner, W. Kimel, A. Holmgren, and F. Forrester, Helv. Chim. Acta, 42, 2577 (1959).
108. M. Julia, S. Julia, and R. Guégan, Compt. rend., 248, 820 (1959).
109. O. Isler, H. Lindlar, M. Montavon, R. Rüegg, G. Saucy, and P. Zeller, Angew. Chem., 67, 758 (1955).
110. O. Isler, H. Lindlar, M. Montavon, R. Rüegg, and P. Zeller, Helv. Chim. Acta, 39, 249 (1956).
111. O. Isler, M. Montavon, R. Rüegg, and P. Zeller, Helv. Chim. Acta, 39, 259 (1956).
112. O. Isler, H. Gutmann, H. Lindlar, M. Montavon, R. Rüegg, G. Ryser, and P. Zeller, Helv. Chim. Acta, 39, 463 (1956).
113. W. Surber, V. Theus, L. Colombi, and H. Schinz, Helv. Chim. Acta, 39, 1299 (1956).
114. M. Müller-Cunradi and K. Pieroh, U. S. P. 2 165 962; Chem. Abs., 33, 8210 (1939).
115. R. Hoaglin and D. Hirsh, J. Amer. Chem. Soc., 71, 3468 (1949).
116. B. M. Mikhailov and L. S. Povarov, Izv. Akad. Nauk SSSR, Otd. Khim. Nauk, 1239 (1957).
117. B. M. Mikhailov and G. S. Ter-Sarkisyan, Zhur. Obshch. Khim., 29, 1642 (1959).
118. B. M. Mikhailov and L. S. Povarov, Zhur. Obshch. Khim., 29, 2079 (1959).
119. B. M. Mikhailov and G. S. Ter-Sarkisyan, Zhur. Obshch, Khim., 29, 2560 (1959).
120. I. N. Nazarov and Zh. A. Krasnaya, Dokl. Akad. Nauk SSSR, 118, 716 (1958).
121. I. N. Nazarov and Zh. A. Krasnaya, Dokl. Akad. Nauk SSSR, 121, 1034 (1958).
122. I. N. Nazarov, I. I. Nazarova, and I. V. Torgov, Dokl. Akad. Nauk SSSR, 122, 82 (1958).
123. I. N. Nazarov and Zh. A. Krasnaya, Zhur. Obshch. Khim., 28, 2440 (1958).
124. I. I. Nazarova and I. V. Torgov, see Ref. 50, p. 93.
125. Zh. A. Krasnaya and I. N. Nazarov, see Ref. 50, p. 51.
126. G. I. Samokhalov, L. A. Vakulova, L. T. Zhikhareva, G. V. Serebryakova, and N. A. Preobrazhenskii, Russ. P. 118 496 (1958).
127. G. I. Samokhvalov, L. A. Vakulova, T. V. Men, L. T. Zhikhareva, V. I. Koltunova, and N. A. Preobrazhenskii, Zhur. Obshch. Khim., 29, 2575 (1959).
128. G. P. Kugatova and V. S. Vesa, see Ref. 50, p. 73.
129. G. P. Kugatova and V. S. Vesa, Zhur. Obshch. Khim., 30, 3731 (1960).
130. L. A. Yanovskaya, Symposium, "Reaktsii i Metody Issledovaniya Organicheskikh Soedinenii" (Reactions of Organic Compounds and Methods for Their Investigation), Vol. 11, Gos. Nauch.-tekh. Izd. Khim. Lit., Moscow, 1962, p. 231.
131. I. N. Nazarov, S. M. Makin, and B. K. Kruptsov, Dokl. Akad. Nauk SSSR, 117, 823 (1957).
132. V. B. Belov, N. A. Daev, N. I. Skvortsova, and E. K. Smol'yaninova, Uspekhi Khim., 26, 96 (1957).
133. G. I. Samokhvalov, M. A. Miropol'skaya, L. A. Vakulova, and N. A. Preobrazhenskii, Dokl. Akad. Nauk SSSR, 84, 1179 (1952).
134. G. I. Samokhvalov, M. A. Miropol'skaya, L. A. Vakulova, and N. A. Preobrazhenskii, Zhur. Obshch. Khim., 25, 545 (1955).
135. G. I. Samokhvalov, M. A. Miropol'skaya, and N. A. Preobrazhenskii, Zhur. Obshch. Khim., 26, 2793 (1956).
136. G. I. Samokhvalov, M. A. Miropol'skaya, and N. A. Preobrazhenskii, Zhur. Obshch. Khim., 26, 54 (1956).
137. I. K. Sarycheva, G. A. Vorob'eva, A. S. Vasilenko, G. G. Vinoklurova, S. A. Elkina, and N. A. Preobrazhenskii, Zhur. Obshch. Khim., 25, 1775 (1955).
138. I. K. Sarycheva, G. A. Vorob'eva, and N. A. Preobrazhenskii, Zhur. Obshch. Khim., 27, 2653 (1957).
139. D. Dorp, J. Arens, and H. Inhoffen, German P. 893 051 (1953).
140. Y. Naves, L. Désalbres, and P. Ardizio, Bull. Soc. chim. France, 1768 (1956).
141. H. Riegl and H. Kröper, German P. 927 946 (1955).
142. A. A. Petrov, N. A. Razumova, and M. L. Genusov, Zhur. Obshch. Khim., 28, 1128 (1958).
143. A. A. Petrov, N. A. Razumova, and M. L. Genusov, Nauch. Dokl. Vys. Shkoly, Khim. i Khim. Teknol., 530 (1958).
144. A. A. Petrov and L. I. Bunina-Krivorukova, Zhur. Obshch. Khim., 30, 1165 (1960).
145. J. Surmatis, U. S. P. 2 833 811 (1958).
146. J. Surmatis, U. S. P. 2 833 812 (1958).
147. R. Panradi, Riechstoffe u. Aromen, 304, 335 (1955).
148. R. Panradl, Riechstoffe u. Aromen, 129 (1956).
149. H. Eschinazi, J. Amer. Chem. Soc., 81, 2905 (1959).
150. D. Barton and M. Mousseron-Canet, J. Chem. Soc., 271 (1960).
151. A. Verley, U. S. P. 2 837 569 (1958); Chem. Abs., 52, 18 513 (1958).
152. D. Szabó, Magyar tud. akad. Kém. tud. oszt. közl., 12, 343 (1959).
153. C. Daessle and H. Schinz, Helv. Chim. Acta., 40, 2270 (1957).
154. L. Re and H. Schinz, Helv. Chim. Acta., 41, 1710 (1958).
155. M. Montavon, Swiss P. 3 337 522 (1959).
156. J. Surmatis, U. S. P. 2 815 379 (1957).
157. J. Surmatis, U. S. P. 2 815 386 (1957).
158. S. M. Makin, V. B. Mochalin, and D. V. Nazarova, Zhur. Obshch. Khim., 30, 1471 (1960).
159. Y. Naves and P. Ardizio, Bull. Soc. chim. France, 1409 (1956).
160. M. Sy, Compt. rend., 243, 1772 (1956).
161. M. Sy, Ind. Parfum. et Cosmét., 12, 351 (1957).
162. I. N. Nazarov, G. P. Kugatova, and G. A. Laumenskas, Zhur. Obshch. Khim., 27, 2450 (1957).
163. G. P. Kugatova, G. A. Laumenskas, V. V. Mozolis, and P. I.

Steponavichyus, see Ref. 50, p. 57.
164. G. Lowe, F. Torto, and B. Weedon, J. Chem. Soc., 1855 (1958).
165. Y. Naves and P. Ardizio, Bull. Soc. chim. France, 1713 (1956).
166. Y. Naves and P. Ardizio, Bull. Soc. chim. France, 672 (1956).
167. S. I. Lur'e and N. I. Skvortsova, Trudy Vses. Nauch.-Issled. Inst. Sintet. Natural. Dushintykh Veshchestv, Pishchepromizdat, No. 1, 82 (1952).
168. M. Bogert and V. Fourman, Amer. Perf. Essent. Oil Rev., 28, 345 (1933); Chem. Zentr., I, 472 (1934).
169. B. Willhalm, U. Steiner, and H. Schinz, Helv. Chim. Acta, 41, 1359 (1958).
170. H. Favre and H. Schinz, Helv. Chim. Acta, 41, 1368 (1958).
171. L. Ruzicka and O. Jeger, Swiss P. 338 469 (1959).
172. M. Stoll and M. Hinder, Helv. Chim. Acta, 38, 1593 (1955).
173. M. Stoll, C. Seidel, B. Willhalm, and M. Hinder, Helv. Chim. Acta, 39, 183 (1956).
174. M. Stoll, M. Hinder, and B. Willhalm, Helv. Chim. Acta, 39, 200 (1956).
175. L. Ruzicka and F. Lardon, Helv. Chim. Acta, 29, 912 (1946).
176. E. Lederer, F. Marx, D. Mercier, and G. Pérot, Helv. Chim. Acta, 29, 1354 (1946).
177. M. Stoll, Helv. Chim. Acta, 38, 1587 (1955).
178. B. Willhalm, Swiss P. 339 619 (1959).
179. M. Stoll, B. Willhalm, and G. Büchi, Helv. Chim. Acta, 38, 1573 (1955).
180. M. Stoll, B. Willhalm, and G. Büchi, Ind. Parfum. Cosmét., 11, 158 (1956).
181. G. Büchi, K. Biemann, B. Vittimberga, and M. Stoll, J. Amer. Chem. Soc., 78, 2622 (1956).
182. M. Stoll, U. S. P. 2 803 662 (1957); Chem. Abs., 52, 3858 (1958).
183. V. A. Smit and V. F. Kucherov, Uspekhi Khim., 28, 272 (1959).
184. L. Ruzicka, "Bedeutung der theoretischen organischen Chemie für die Chemie der Terpenverbindungen" in "Perspectives in Organic Chemistry" (Edited by Sir Alexander Todd) (Translated into Russian), Inostr. Lit., Moscow, 1959, p. 197.
185. H. Krishna and B. Joshi, J. Org. Chem., 22, 224 (1957).
186. V. A. Smit, A. V. Semenovskii, V. M. Medvedeva, and V. F. Kucherov, Dokl. Akad. Nauk SSSR, 124, 1080 (1959).
187. V. F. Kucherov, V. A. Smit, and A. V. Semenovskii, see Ref. 50, p. 31.
188. Hung Lu-ming, Huaxue shijie, 14, 439 (1959); Ref. Zhur. Khim., 58 623 (1960).
189. A. V. Semenovskii, V. A. Smit, and V. F. Kucherov, Dokl. Akad. Nauk SSSR, 132, 1107 (1960).
190. H. Kappeler, H. Grütter, and H. Schinz, Helv. Chim. Acta, 36, 1862 (1953).
191. French P. 1 026 061 (1953).
192. German P. 934 888 (1955).
193. German P. 933 149 (1955).
194. German P. 931 351 (1955).
195. U. S. P. 2 801 266 (1957); Chem. Abs., 52, 668 (1958).
196. U. S. P. 2 740 817 (1956); Chem. Abs., 50, 16 861 (1956).
197. J. Lecomte and Y. Naves, J. Chim. phys., 462 (1956).
198. Y. Naves and A. Grampoloff, Bull. Soc. chim. France, 1220 (1957).
199. M. Beets and H. van Essen, Rec. Trav. chim., 77, 1138 (1958).
200. Y. Naves, Helv. Chim. Acta, 32, 2552 (1949).
201. Y. Naves, Compt. rend., 241, 1209 (1955).
202. Y. Naves, Bull. Soc. chim. France, 253 (1956).
203. Y. Naves, Helv. Chim. Acta, 40, 1123 (1957).
204. Y. Naves, Compt. rend., 240, 1781 (1955).
205. P. Tribolet and H. Schinz, Helv. Chim. Acta, 37, 2184 (1954).
206. P. Tribolet, Diss., techn. Wiss., ETH, Zürich, 1955.
Schweiz, Buch, 55B, N5, 288 (1955); Ref. Zhur. Khim., 43 345 (1956).
207. G. Büchi and N. Yang, Helv. Chim. Acta, 38, 1338 (1955).
208. G. Büchi and N. Yang, Chem. and Ind., 357 (1955).
209. G. Büchi and N. Yang, J. Amer. Chem. Soc., 79, 2318 (1957).
210. Y. Naves and A. Odermatt, Bull. Soc. chim. France, 377 (1958).
211. R. Crisler and C. Benford, Analyt. Chem., 31, 1516 (1959).
212. M. Carroll and W. Fordham, Soap, Perf., Cosm., 28, 178 (1955).
213. J. Knights and E. Waight, J. Chem. Soc., 2830 (1955).
214. Y. Naves, Bull. Soc. chim. France, 297 (1956).
215. R. Lukeš, A. Zobáčová, and J. Plešek, Croat. Chem. Acta, 29, 201 (1957).
216. V. Prelog and E. Watanabe, Annalen 603, 1 (1957).
217. K. Stephan, J. prakt. Chem., 58, 116 (1898).
218. S. Joffre, U. S. P. 2 679 476 (1954).
219. I. Siemion, Roczniki Chem., 33, 1183 (1959).
220. V. N. Kraseva and A. A. Bag, Trudy Vses. Nauch.-Issled. Inst. Sintet. Natural. Dushistykh Veshchestv, Pishchepromizdat, No. 4, 55 (1958).
221. V. N. Kraseva, A. A. Bag, L. L. Malkina, O. M. Khol'mer, and I. M. Lebedev, Russ. P. 118 498 (1958).
222. A. A. Bag, V. G. Cherkaev, and S. A. Perepelkina, Trudy Vses. Nauch.-Issled. Inst. Sintet. Natural. Dushistykh Veshchestv, Pishchepromizdat, No. 4, 61 (1958).
223. A. F. Polyakov, Trudy Krasnodar. Inst. Pishch. Prom., No. II, 83 (1955).
224. W. Houlihan, J. Org. Chem., 23, 689 (1958).
225. W. Houlihan, J. Levy, and J. Mayer, J. Amer. Chem. Soc., 81, 4692 (1959).
226. H. Farnow and F. Porsch, Dragoco Berichte, No. 7, 149 (1960).
227. E. Theimer, U. S. P. 2 867 668 (1959).
228. A. Bell, C. Kibler, and T. Strickland, U. S. P. 2 794 826 (1957).
229. R. Webb, U. S. P. 2 902 510 (1959).
230. F. Ascoli and V. Crescenzi, Chimica e Industria, 40, 724 (1958).
231. J. Mikumo, M. Tsuboi, and T. Kusano, J. Chem. Soc. Japan, Ind. Chem. Sect., 60, 440 (1957); Ref. Zhur. Khim., 14 614 (1958).
232. S. Prosinski, Z. Adamski, and Sylwan, 99, 180 (1955) Ref. Zhur. Khim., 2388 (1958).
233. A. Kergomard, Bull. Soc. chim. France, 1356 (1956).
234. A. Kergomard, French P. 1 145 634 (1957).
235. T. Matsuura and T. Aratani, J. Sci. Hiroshima Univ., 18A, 439 (1955); Ref. Zhur. Khim., 75 032 (1956).
236. H. Hoyer, G. Keicher, and H. Schubert, German P. 955 499 (1957).
237. R. Lombard and E. Geiger, Bull. Soc. chim. France, 1564 (1956).
238. C. Seidel and M. Stoll, Helv. Chim. Acta, 42, 1830 (1959).
239. G. Cainelli, R. Mihailovoc, D. Arigoni, and O. Jeger, Helv. Chim. Acta, 42, 1124 (1959).
240. C. Seidel and M. Stoll, Chimia (Switz.), 15, 311 (1961).
241. C. Seidel, D. Felix, A. Eschenmoser, K. Biemann, E. Pallny, and M. Stoll, Helv. Chim. Acta, 44, 598 (1961).
242. A. Melera and Y. Naves, Compt. rend., 252, 1937 (1961).
243. Y. Naves, D. Lamparsky, and P. Ochsner, Bull. Soc. chim. France, 645 (1961).
244. G. Ohloff, E. Klein, and G. Schenk, Angew. Chem., 73, 578 (1961).
245. Y. Naves and P. Tullen, Helv. Chim. Acta, 44, 1867 (1961).
246. Y. Naves and P. Ochsner, Helv. Chim. Acta, 45, 397 (1962).
247. C. Seidel and M. Stoll, Helv. Chim. Acta, 40, 1990 (1957).
248. G. Ohloff and G. Schade, Angew. Chem., 70, 24 (1958).
249. C. Collin-Asselineau, E. Lederer, D. Mercier, and J. Polonsky, Bull. Soc. chim. France, 720 (1950).

250. G. Büchi, W. Saar, and A. Eschenomser, Experientia, 12, 136 (1956).
251. M. Hinder and M. Stoll, Helv. Chim. Acta, 33, 1308 (1950).
252. R. Wolff, Compt. rend., 711 (1954).
253. R. Wolff and E. Lederer, Bull. Soc. chim. France, 772 (1956).
254. G. Lucius, Angew. Chem., 68, 247 (1956).
255. R. Wolff and E. Lederer, Bull. Soc. chim. France, 1466 (1955).
256. G. Ohloff, German P. 1 019 031 (1958)
257. V. E. Sibirtseva, S. D. Kustova, S. I. Virezub, M. P. Gerasimova, A. S. Kaluzhskaya, and K. D. Oreshkina, Russ. P. 130 897 (1960).
258. V. E. Sibirtseva, S. I. Virezub, and S. D. Kustova, see Ref. 57, p. 116.
259. V. E. Sibirtseva, S. I. Virezub, and S. D. Kustova, Trudy Vses. Nauch.-Issled. Inst. Sintet. Natural. Dushistykh Veshchestv, Pishchepromizdat, No. 5, 9 (1961).
260. G. Ohloff, German P. 1 038 681 (1959).
261. K. A. Guseva, R. Ya. Rafanova, A. V. Bulanova, and S. I. Virezub, Masl.-zhir. Prom., No. 3, 29 (1959).
262. L. Ruzicka and M. Janot, Helv. Chim. Acta, 14, 645 (1931).
263. M. Stoll and M. Hinder, Helv. Chim. Acta, 33, 1308 (1950).
264. M. Stoll, Riechstoffe u. Aromen, 9, 394 (1959).
265. S. D. Kustova, S. I. Virezub, V. E. Sibirtseva, and S. A. Voitkevich, Russ. P. 134 681 (1961).
266. A. A. Bag, N. V. Bliznyak, A. V. Bulanova, S. D. Kustova, and V. G. Cherkaev, Trudy Vses. Nauch.-Issled. Inst. Sintet. Natural. Dushistykh Veshchestv, Pishchepromizdat, No. 5, 14 (1961).
267. G. Ohloff, Ind. Parfumerie, 11, 401 (1956).
268. G. Ohloff, Riechstoffe u. Aromen, 7, 38 (1957).
269. G. Ohloff, Drug and Cosm. Industry, 80, 606, 690 (1957).
270. G. Ohloff, Annalen, 606, 100 (1957).
271. G. Ohloff, Parfümerie u. Kosmetik, 38, 431 (1957).
272. G. Ohloff, Parfumerie, Cosmét., Savon, 2, 15 (1959).
273. G. Ohloff, Chem. Ber., 90, 1554 (1957).
274. M. Mousseron-Canet, M. Mousseron, and J. Boch, Bull. Soc. chim. France, 601 (1959).
275. G. Ohloff, German P. 1 045 393 (1959).
276. M. Mousseron, M. Mousseron-Canet, and M. Granier, Compt. rend., 247, 564 (1958).
277. L. Ruzicka and C. Seidel, Helv. Chim. Acta, 33, 1285 (1950).
278. G. Ohloff, German P. 1 057 108 (1959); Chem. Abs., 9366 (1961).
279. V. E. Sibirtseva, G. V. Meleshkina, N. I. Skvortsova, and V. N. Belov, see Ref. 50, p. 209.
280. M. Mousseron-Canet and M. Mousseron, Bull. Soc. chim. France, 391 (1956).
281. G. Kitchens and P. Lake, U. S. P. 2 842 598 (1958).
282. I. Byers, Amer. Perf. Essent. Oil. Rev., 483 (1947).
283. R. Hüttel and G. Keicher, German P. 834 593 (1952); Chem. Abs., 47, 5446 (1953).
284. A. Weissenborn, East German P. 5051 (1954).
285. A. Weissenborn, East German P. 8201 (1954).
286. German P. 903 258, 903 259 (1954).
287. V. N. Belov and L. A. Kheifits, Zhur. Obshch. Khim., 27, 960 (1957).
288. V. Kabaivanov, M. Mikhailov, M. Natov, and L. Popova, Khim. i Ind., 31, No. 4, 107 (1959).
289. L. A. Kheifits, E. A. Simanovskaya, and V. N. Belov, Khim. Nauka i Prom., 3, 284 (1958).
290. L. A. Kheifits, E. A. Simanovskaya, Zh. A. Peregudova, V. N. Belov, E. S. Shapiro, and P. Z. Koretskaya, Masl.-zhirov. Prom., No. 11, 30 (1959).
291. L. A. Kheifits, G. I. Moldovanskaya, E. V. Broun, and V. N. Belov, Zhur. Obshch. Khim., 30, 1716 (1960).
292. L. A. Kheifits, L. M. Shulov, E. V. Broun, and V. N. Belov, Zhur. Obshch. Khim., 31, 672 (1961).
293. L. A. Kheifits, L. M. Shulov, I. V. Persianova, and V. N. Belov, Zhur. Obshch. Khim., 31, 723 (1961).
294. I. Yu. Kokoreva and V. M. Kazakova, Zhur. Obshch. Khim., 31, 371 (1961).
295. L. A. Kheifits, L. M. Shulov, A. V. Kokhmanskii, and V. N. Belov, Zhur. Obshch. Khim., 32, 2717 (1962).
296. L. A. Kheifits, L. M. Shulov, and V. N. Belov, Zhur. Obshch. Khim., 32, 1474 (1962).
297. V. N. Belov and L. A. Kheifits, Zhur. Obshch. Khim., 27, 1377 (1957).
298. V. N. Belov, E. I. Shepelenkova, and M. M. Pevzner, Trudy Vses. Nauch.-Issled. Inst. Sintet. Natural. Dushistykh Veshchestv, Pishchepromizdat, No. 1, 20 (1952).
299. L. A. Kheifits, E. A. Simanovskaya, V. N. Belov, P. V. Ivanov, E. S. Shapiro, and M. Ya. Braines, Masl.-zhirov. Prom., No. 6, 35 (1957).

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SECONDARY REACTIONS IN RADICAL POLYMERISATION

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INTRODUCTION

In recent years detailed studies of polymerisation processes of different types have established that the main reactions in these processes are accompanied by a number of supplementary secondary processes or reactions. The distinguishing feature of these secondary reactions is the participation of previously formed polymer chains. It is therefore natural that at low degrees of conversion of monomer, *i.e.* in the range in which polymerisation kinetics, etc. are usually studied, these reactions are almost non-existent and the polymer obtained under these conditions is the product of only the main or primary reactions.

On the other hand, at high degrees of conversion, particularly when the concentration of polymer becomes comparable with the concentration of monomer, the probability of secondary reactions in polymerisation systems is considerable and these reactions have a significant effect on the polymerisation product.