Translated from *Uspekhi Khimii*, **46**, 1002-1040 (1977) U.D.C. 547.913.5

Advances in the Chemistry of Azulene

V.B.Mochalin and Yu.N.Porshnev

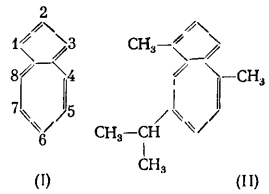
The chief methods of preparation and the chemical properties of azulene hydrocarbons are described. Attention is paid mainly to the most recent papers, not covered in previous reviews. Certain aspects of the application of azulene compounds are also considered. A list of 315 references is included.

CONTENTS

I.	Introduction	530
II.	Methods of preparation of azulene compounds	530
III.	Chemical properties of azulene compounds	537
IV.	Practical applications of azulene compounds	543

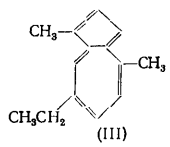
I. INTRODUCTION

Forty years have passed since Pfau and Plattner finally established the structure of azulene hydrocarbons[1]. The parent of this class of non-benzenoid aromatic compounds is bicyclo[5,3,0]decapentaene, azulene (I). Azulene hydrocarbons are present in various natural oils, where they are formed by the dehydrogenation and dehydration of bicyclic sesquiterpenoid alcohols. Specific names have been retained for many azulene hydrocarbons isolated from natural sources: guaiazulene (II) is 7-isopropyl-1,4-dimethylazulene, obtained by dehydrogenating the oil from the wood of *Guaiacum officinale* L., patchouli oil from *Pogostemon patchouli*, and eucalyptus oil from *Eucalyptus globulus*; chamazulene (III) is present in camomile oil from *Matricaria camimilla* L., oil of yarrow *Achillea millejolun* L., oil of wormwood *Artemisia absinthium* L., and certain other oils; lactaroviolin (IV) is an aldehyde contained in edible fungi; and vetivazulene (V) and zierazulene (VI) are dehydrogenation products of the sesquiterpenoid ketones vetivone and zierone[2]. Azulene hydrocarbons are also present in many other plant species, but in extremely small amounts.

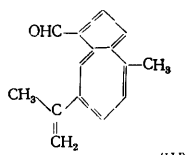


(I)

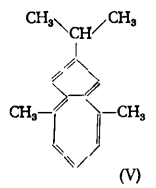
(II)



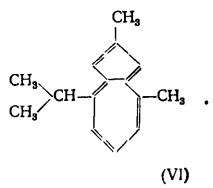
(III)



(IV)



(V)



(VI)

Azulene and its simple homologues are deeply coloured compounds of high boiling point, volatile in steam, which dissolve in hydrocarbon solvents and crystallise well. The simplest azulene hydrocarbons absorb light in the range 550–650 nm.[2,4] They are stable in air up to 300–350°C, and only above this temperature do they begin to be converted into valence isomers of benzenoid structure, naphthalene and its homologues[2]. Azulene compounds can also undergo photoisomerisation[5].

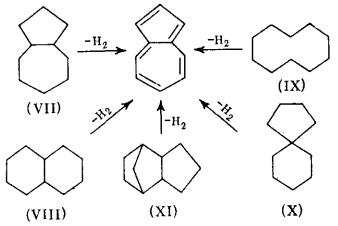
The unusual physical and chemical properties of azulene hydrocarbons have long attracted the attention of many investigators, but until the end of the 1950s these compounds were extremely inaccessible, and only after the development by Hafner and by Nozoe of effective methods for the synthesis of azulenes did their widespread study become possible. The most complete survey of the literature on the structure and the chemistry of azulenes appeared in 1959 [3] (translated into Russian in 1963 [2]). Subsequent reviews[6,7] contained data only on individual problems of the synthesis or the reactivity of azulenes. Therefore the present Review, devoted to methods of preparation, chemical properties, and prospects for the application of azulene derivatives, covers mainly the literature from 1959 to 1975. The large number of publications that appeared during this period prevent the inclusion of several aspects—(i) methods for the isolation, purification, and identification of azulene compounds, (ii) the physical and physicochemical characteristics of azulenes, and (iii) the chemical properties and methods of preparation of heteroazulene compounds, in which one or more methine groups have been replaced by heteroatoms[8]—which all, without doubt, deserve special discussion.

II. METHODS OF PREPARATION OF AZULENE COMPOUNDS

1. Methods involving Dehydrogenation

Dehydrogenation of bicyclic precursors of azulene having the bicyclo[5,3,0]decane structure (VII) or of the corresponding partly unsaturated compounds was historically the first (and for a long time the only) method for obtaining azulene and its alkyl homologues. Both natural oils containing sesquiterpenoid precursors and synthetic bicyclic derivatives were used. Although guaiazulene,

chamazulene, and vetivazulene have hitherto been obtained mainly by the dehydrogenation of natural oils, substituted bicyclo[5,3,0]decanes have rarely been used for preparing other azulene derivatives owing to the complexity and the multistage character of the process[2]. Azulenes have been obtained by dehydrogenation not only of bicyclo[5,3,0]-decane (VII) derivatives[9] but also of compounds of the cyclodecane (IX),[2,10,11] decahydronaphthalene (VIII),[12] tetrahydrodicyclopentadiene (XI),[12] and spiro[4,5]decane (X)[13] series.



However, the complexity of the preparation of most such compounds, the formation of mixtures of isomeric azulenes from substituted derivatives of (VIII)–(X), and—the most important—the low yields (1–10%) at the dehydrogenation stage have resulted in the extremely rare use of these methods also. Such yields are greatly increased when highly unsaturated hydrocarbons such as dihydroazulenes are used, so that "partial" dehydrogenation remains an important method of preparation in the chemistry of azulenes. Dehydrogenation is sometimes employed also to prove the structure of a sesquiterpene hydrocarbon.

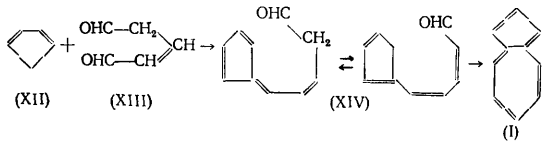
Sulphur, selenium, 5–10% palladium on carbon, chloranil, and diphenyl disulphide are widely employed as dehydrogenating agents. Dehydrogenation with sulphur is accomplished on heating (200°C), with yields usually not exceeding 10%[14,15] and only in isolated cases reaching 30–50%.[16,17] Acyl- and alkyl-azulenes may form thienoazulenes on dehydrogenation with sulphur[17–19]. The use of selenium[20–22] or palladium[23–25] for liquid-phase dehydrogenation requires higher temperatures (280–300°C), which often leads to migration of hydrocarbon substituents or even partial isomerisation of the azulene into the naphthalene system[26]. Yields of azulenes are 1–10%. Catalytic dehydrogenation in the gas phase over palladium on carbon, molybdenum sulphide, or other catalysts frequently gives higher yields, but requires careful selection of optimum conditions in each specific case[9,12,27]. Little information is available on the dehydrogenating action of diphenyl disulphide; it has been successfully used for the preparation of guaiazulene[28].

Recently chloranil has been the hydrogenating agent used most often[29–33]. Dehydrogenation occurs under very mild conditions, but a high degree of unsaturation is required in the compounds to be dehydrogenated.

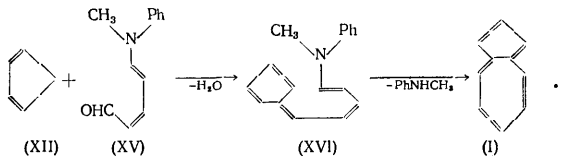
The complexity of the directed preparation of hydrogenated precursors of azulene and the low yields obtained in their dehydrogenation have led to the development of fundamentally new ways of obtaining azulene that avoid dehydrogenation.

2. Cyclisation of Polymethinium Salts and Fulvenes

In 1955 Ziegler and Hafner[34], and almost simultaneously Rösler and König[35], reported a new synthesis of azulene systems that eliminated the dehydrogenation stage. The general principle consisted in obtaining fulvene (XIV) from cyclopentadiene (XII) and glutaconaldehyde (XIII) and cyclising the product to azulene (I):

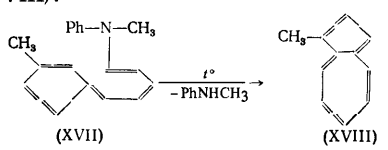


However, this form of the process has not yet been accomplished: in practice the relatively unstable glutaconaldehyde is replaced by a derivative, Zincke's aldehyde (XV), which is converted into the fulvene (XVI). In the presence of a base such as benzidine or trishydroxyethylamine at 200–300°C this fulvene is cyclised to azulene, which sublimes as it is formed:

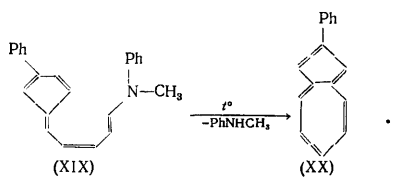


The high yield of azulene (up to 70%) makes this method most promising for industrial application[34].

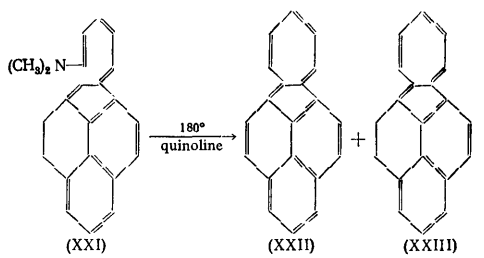
Azulenes substituted in the five-membered ring can be obtained by the same method. Cyclisation of the fulvene (XVII) obtained from methylcyclopentadiene gives 1-methylazulene (XVIII):[36]



However, the corresponding cyclisation of the phenylated fulvene (XIX) yields 2-phenylazulene (XX):[37]

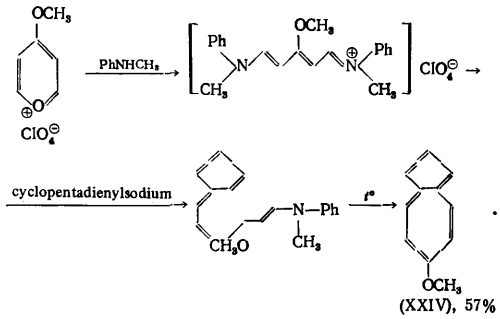


Such a difference in the course of cyclisation is probably due to both electronic and steric factors. A 62% yield of azuleno[1,2,3-*cd*]phenalene (XXII) has recently been obtained[38] by cyclisation of the corresponding fulvene (XXI), with separation of the dihydro-derivative (XXIII) as a byproduct:



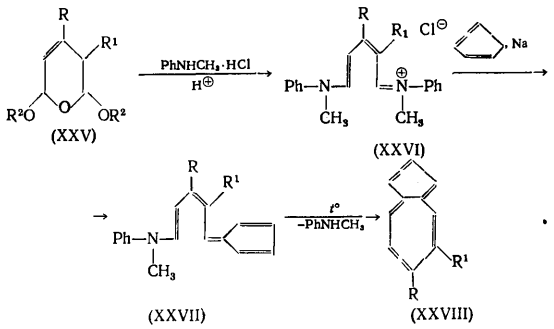
Azulenes substituted in the seven-membered ring can be obtained by reaction between cyclopentadiene and substituted Zincke aldehydes, but the cleavage of mono- and poly-alkylated pyridines to the desired glutaconaldehyde derivatives presents certain difficulties[39]. Since pyrylium salts are cleaved considerably more readily by amines, they may serve as convenient starting materials

for obtaining several difficultly accessible azulenes, e.g. 6-methoxyazulene (XXIV):[39]



(XXIV), 57%

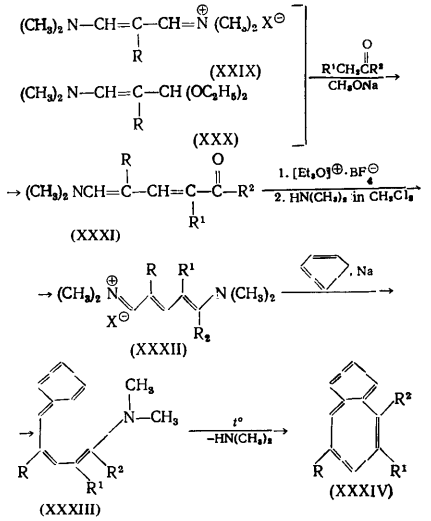
6(5)-Arylated azulenes (XXVIII) can be obtained from 2,6-dialkoxy-4(5)-aryl-Δ^3-dihydropyrans (XXV)[40] via the *N*-methyl chlorides (XXVI) and fulvenes (XXVII):



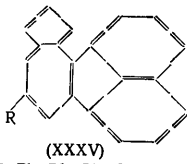
(XXV) (XXVI) (XXVII) (XXVIII)

This method has been used to obtain 6-phenyl-,[41] 6-thien-2′-yl-,[42] and 5-phenyl-azulenes[43].

Another method of obtaining substituted pentamethinammonium salts—derivatives of glutaconaldehyde—is based on condensation of a malonaldehyde derivative (XXIX) or (XXX) with a carbonyl compound containing an active methylene group[44]. The resulting amino-dienone (XXXI) is converted into the pentamethinammonium salt (XXXII) by treatment with triethyloxonium tetrafluoroborate followed by dimethylamine. The subsequent action of cyclopentadienylsodium forms the fulvene (XXXIII), which when heated to 180–190°C is converted into the azulene (XXXIV) substituted in the seven-membered ring (yield 15–35%):



(XXIX) (XXX) (XXXI) (XXXII) (XXXIII) (XXXIV)

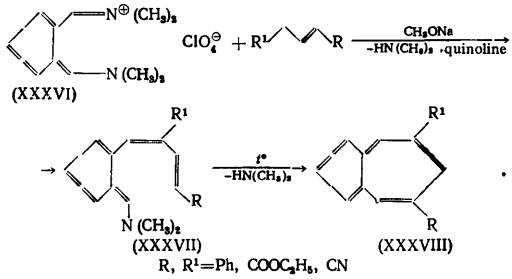


(XXXV)

R=H, Ph; R^1=Ph, CH_3; R^2=Ph.

The presence of bulky substituents R^1 and R^2 in the fulvene (XXXIII) prevents formation of an azulene, probably owing to hindrance to establishment of the *cis*-configuration necessary for cyclisation. Application of this method to acenaphthenone yields fused pentacyclic compounds of the azuleno[4,5-*a*]acenaphthylene series (XXXV).[44]

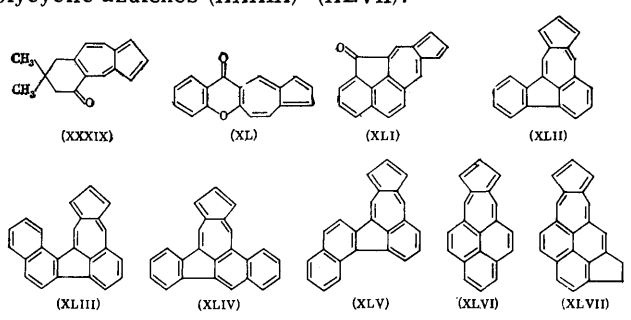
The salt (XXXVI), containing a dimethylaminofulvene group, became very valuable as initial compound for the synthesis of polycyclic azulene hydrocarbons[45–50]. It reacts with derivatives of glutaconic or 4-phenylbut-3-enoic acid in the presence of sodium methoxide to give fulvenes (XXXVII) capable of cyclisation with high yields into 5,7-disubstituted azulenes (XXXVIII):[44]



(XXXVI) (XXXVII) (XXXVIII)

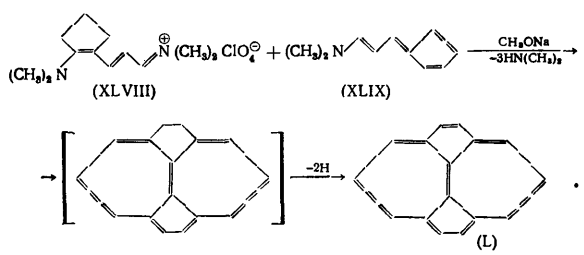
R, R^1=Ph, $COOC_2H_5$, CN

Replacement in this reaction of derivatives of glutaconic acid by isophorone, 2-methylchromone, acenaphthenone, fluorene, benzofluorenes[44], phenalene[51], and 1,2-dihydro-5*H*-cyclopenta[*c*, *d*]phenalene[52] gave the corresponding polycyclic azulenes (XXXIX)–(XLVII).



(XXXIX) (XL) (XLI) (XLII) (XLIII) (XLIV) (XLV) (XLVI) (XLVII)

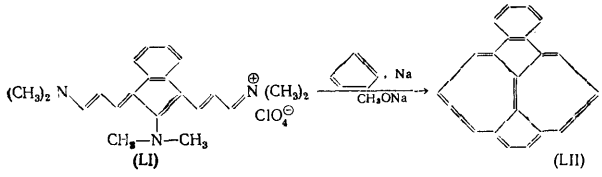
Jutz and Schweiger[53] suggested a method of double cyclisation of the pentamethinammonium salt (XLVIII)[54] with the fulvene (XLIX) in the presence of sodium methoxide to give an approximately 5% yield of the extremely difficultly accessible pyraceheptylene (L):



(XLVIII) (XLIX) (L)

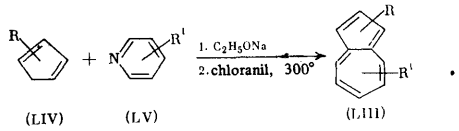
Condensation of cyclopentadiene with the salt (LI) obviously involves both formation of a fulvene and its subsequent

double cyclisation with the further elimination of two molecules of dimethylamine to give a 2.5% yield of benzo[*a*]-pyraceheptylene (LII):[53]



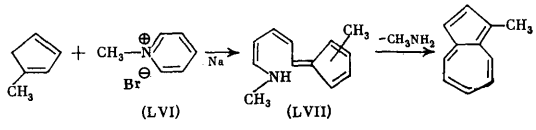
3. Syntheses from Pyridinium and Pyrylium Salts

The relationship between glutaconaldehyde and pyridine enabled Hafner[55] to synthesise azulene (LIII) by the condensation of substituted cyclopentadienes (LIV) with substituted pyridines (LV) followed by cyclisation and dehydrogenation at an elevated temperature:



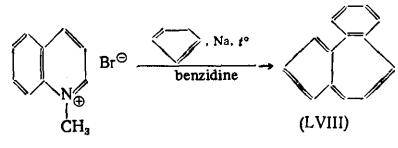
This method was used to obtain 1-, 4-, and 5-methylazulenes, 4,8-dimethylazulene, 1-isopropylazulene, 1-diphenylmethylazulene, and also 1,2-benzazulene,

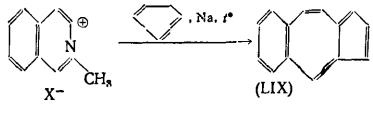
However, quaternary pyridinium and homologous salts have been more widely used. For example, reaction between *N*-methylpyridinium bromide (LVI) and methylcyclopentadienylsodium in liquid ammonia enabled Ziegler and Hafner to obtain the fulvene (LVII), which cyclised thermally into 1-methylazulene in 55% yield[56]:



1,2,3-Triphenylazulene was obtained similarly from 1,2,3-triphenylcyclopentadiene[57].

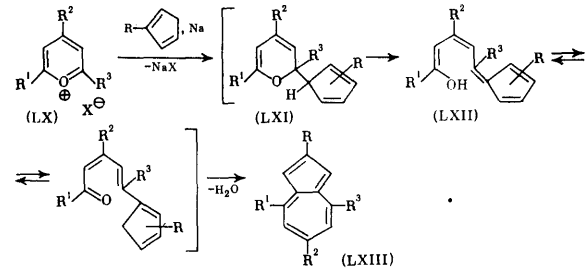
Cyclopentadienylsodium reacts with quinolinium[58] and isoquinolinium[59] salts to give low yields of respectively 4,5-benzazulene (LVIII) and 5,6-benzazulene (LIX):



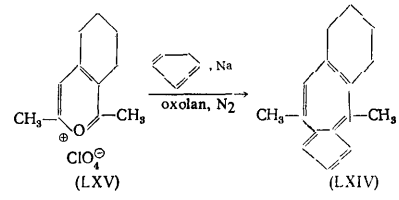


The syntheses are fairly complicated when used as methods of preparation, and published yields are not always reproducible.

Considerably better results are obtained by replacing pyridinium by pyrylium salts. Hafner showed[60] that several salts (LX) form with cyclopentadienylsodium even at room temperature azulenes substituted in the seven-membered ring, in yields that in individual cases are nearly theoretical. The hypothetical intermediate products (LXI) and (LXII) could not be isolated. The alkyl group in the cyclopentadiene appears at position 2 in the azulene (e.g. 2,4,6,8-tetramethylazulene (LXIII: R = R^1 = R^2 = R^3 = CH_3) is formed):

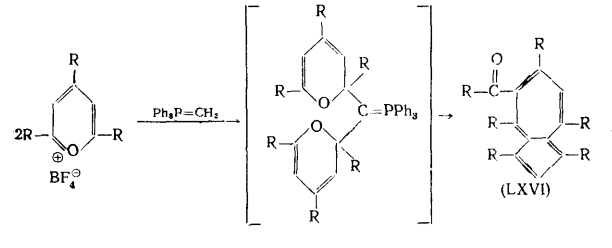


Various substituted azulenes—4,6,8-trimethyl, 4,8-dimethyl-6-t-butyl, 4-methyl-6,8-diphenyl, 4,8-dimethyl-6-phenyl, 6-methoxy-4,8-dimethyl, and several other analogues—have been obtained by this reaction[61], but it is not universally applicable to the synthesis of substituted azulenes. Thus 5,6,7,8-tetrahydro-4,10-dimethylbenz-[*f*]azulene (LXIV) was obtained from the salt (LXV) in only 3.3% yield[59]:



Unsubstituted pyrylium perchlorate[62] and 4-unsubstituted 2,6-dialkylpyrylium salts do not form azulenes when treated with cyclopentadienylsodium. Nor can 2,4,6-triphenylpyrylium and 4-phenyl-2,6-distyrylpyrylium perchlorates, as well as several other pyrylium salts, serve as sources of azulenes. Clearly, unsubstituted pyrylium salts on reaction with the cyclopentadienyl anion readily undergo condensation involving the carbon atoms at positions 2, 4, and 6, with the formation of a large number of unstable side-products. 2,4,6-Triarylated pyrylium salts do not undergo cleavage by the cyclopentadienyl anion under mild conditions, because of their stability due to conjugation[61].

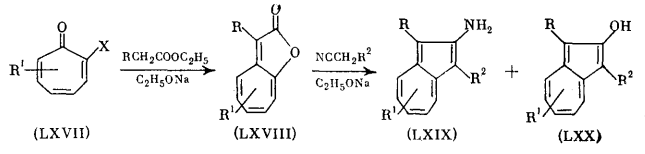
Another interesting route to azulene compounds was suggested in 1963 by Dimroth et al.[63] In this synthesis both azulene rings are formed from a pyrylium salt. The action of excess of methylenetriphenylphosphorane on a pyrylium salt produces in a single stage a substituted 5-acylazulene (LXVI) in ~30% yield:



Thus, despite certain limitations, the use of pyrylium salts provides a most effective method for synthesising azulenes, because of the acceptability of the initial compounds, the mild reaction conditions, and the high yields.

4. Tropones, Tropolones, and Heptafulvenes in the Synthesis of Azulenes

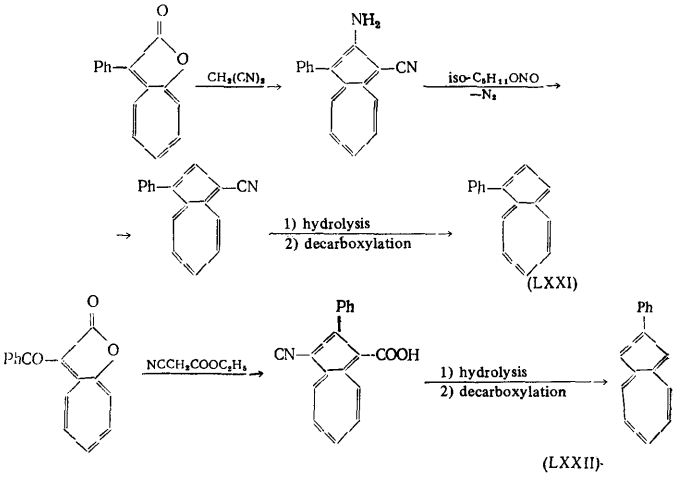
Another method of forming azulene compounds that has been studied in detail[64] involves closure of a five-membered ring in compounds that already contain a cycloheptatriene system. One such process is the action of esters containing an active methylene group on tropones substituted at the 2 position by halogen[64-68], arenesulphonyloxyl[69], or alkoxyl[70] (LXVII):



(LXVII) (LXVIII) (LXIX) (LXX)

X = Cl, Br, OSO_2Ar, OCH_3, OC_2H_5; R = CN, $COOC_2H_5$, C_6H_5, C_6H_5CO; R^1 = Alk, Ar; R^2 = CN, $COOC_2H_5$

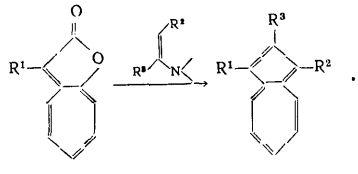
In the presence of sodium ethoxide substituted cycloheptafuranones (LXVIII) are readily formed, and are then converted into azulenamines (LXIX). Application of a twofold excess of cyanoacetic ester enables good yields of diethyl 2-aminoazulene-1,3-dicarboxylates (LXIX: R = R^2 = $COOC_2H_5$) to be obtained; the use of malononitrile gives the 1,3-dicyanoazulen-2-amine (LXIX: R = R^2 = CN). Low yields of the 2-hydroxy-derivatives (LXX: R = CN; R^2 = $COOC_2H_5$ or CN) are formed as secondary products. The nitrile and ester groups can be removed by hydrolysis followed by decarboxylation[66], and the amino-group replaced by hydrogen by diazotisation with isopentyl nitrite in alcohol in the presence of sulphuric acid[68]. These reactions can be illustrated by the preparation of 1- and 2-phenylazulenes (LXXI) and (LXXII):



(LXXI)

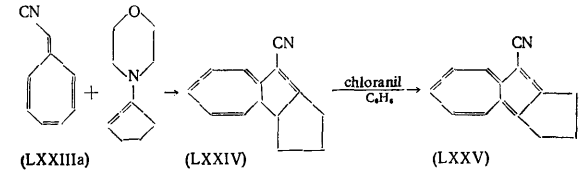
(LXXII)

Cycloheptafuranones (LXVIII) can be converted into azulenes by a different route—by cycloaddition with vinylamines[71,72]:



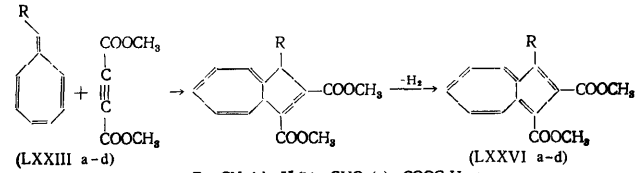
1,2-Propano-, 1,2,butano-, and 1,2-pentano-azulenes, 1- and 2-phenylazulenes[71], indeno[2,1-*a*]azulene, indeno-[1,2-*a*]azulene, and their 3-cyano-derivatives[72] have been obtained in this way.

Cycloheptafuranones (LXVIII) are heptafulvene derivatives. Heptafulvenes themselves are also able to undergo cycloaddition with enamines. For example, the condensation of 8-cyanoheptafulvene (LXXIIIa) with N-cyclopentenylmorpholine leads to formation of the dihydroazulene derivative (LXXIV), whose dehydrogenation by chloranil gives 3-cyano-1,2-propanoazulene (LXXV):[73]



(LXXIIIa) (LXXIV) (LXXV)

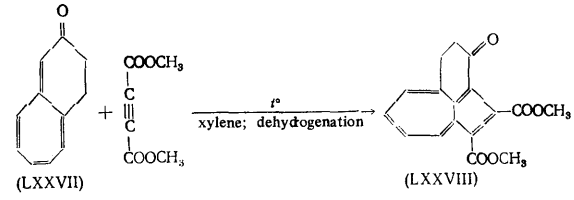
The 1,3-cycloaddition† of acetylenedicarboxylic esters to heptafulvene and its derivatives leads to formation of the five-membered ring of the dihydroazulene system, whose dehydrogenation readily gives azulene derivatives. Thus the heptafulvenes (LXXIIIa–d) have given the azulene-1,2-dicarboxylic ester (LXXVIb),[24] as well as the corresponding 3-aldehyde (LXXVIc), the tricarboxylic ester (LXXVId),[74] and the 3-cyano-derivative (LXXVIa):[73]



(LXXIII a–d) (LXXVI a–d)

R=CN (a), H(b), CHO (c), $COOC_2H_5$ (d)

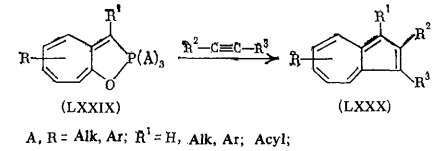
Similarly, the heptafulvene derivative (LXXVII) yields dimethyl 11-oxo-1,8-propanoazulene-2,3-dicarboxylate (LXVIII)



(LXXVII) (LXXVIII)

which is then converted into the fully conjugated tricyclic 3-benz[*c*, *d*]azulenone system[75].

The phosphoranes (LXXIX) are also able to undergo a similar reaction with acetylenes containing electron-accepting substituents, to form substituted azulenes (LXXX) with simultaneous elimination of trialkyl- or triarylphosphine oxides[76]:



(LXXIX) (LXXX)

A, R = Alk, Ar; R^1 = H, Alk, Ar; Acyl; R^2, R^3 = CN, COOR .

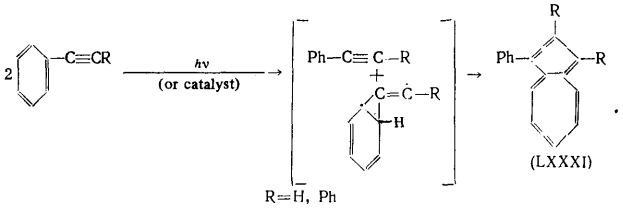
Methods based on the use of troponoid compounds readily yield azulene derivatives functionally substituted in the five-membered ring, and thus a useful supplement to preparations based on pyridinium, pyrylium, and Zincke salts. Many 2-substituted azulene derivatives—with chloro, iodo, amino, cyano, carboxy, methoxy,

† It would have been more correct to term this reaction *1,8-cycloaddition*, since it takes place at the ends of the conjugated chain (in heptafulvene this chain comprises eight atoms).

hydrazino, or other functional group—completely inaccessible by other routes, have been obtained from troponoid compounds[77]. Tri- and tetra-cyclic azulenoid systems, containing fused pyridine, pyridazine, pyrazole[78-80], and thophen[81] rings, have been obtained similarly.

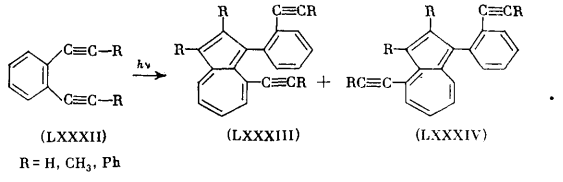
5. Cyclisation of Acetylenic Compounds and Other Methods

Formation of the azulene system from acetylenic compounds was observed as early as 1948 by Reppe and his coworkers[82], who reported the appearance of small quantities of azulene in the preparation of cyclo-octatetraene from acetylene. Such processes usually involve active species formed e.g. on cleavage of the benzene ring in phenylacetylene and similar in structure to heptafulvene; cycloaddition of such a species at the triple bond entails closure of the five-membered ring of the azulene system. The reactions are initiated photochemically, and sometimes can be accomplished also by means of certain catalysts. An illustration is the conversion of phenylacetylene into 1-phenylazulene (LXXXI: R = H):[83]

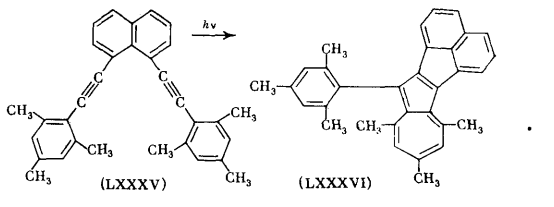


Diphenylacetylene undergoes a similar reaction also in the presence of 2,4-dinitrophenylsulphenyl chloride and anhydrous aluminium chloride or bromide, to give an approximately 25% yield of 1,2,3-triphenylazulene (LXXXI: R = C_6H_5).[84,85] The same reaction is effected also by palladium chloride, with which diphenylacetylene forms the complex compound $2C_6H_5C{:}CC_6H_5 \cdot PdCl_2 \cdot C_2H_5OH \cdot HCl$.[86] Cyclisation of acetylenes into azulenes can probably occur by both radical and ionic mechanisms.

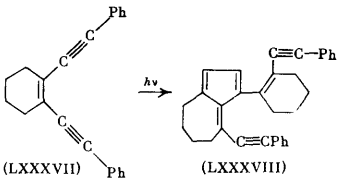
Diacetylenes (LXXXII) undergo an analogous reaction to form mixtures of the structurally isomeric azulene hydrocarbons (LXXXIII) and (LXXXIV):[87,88]



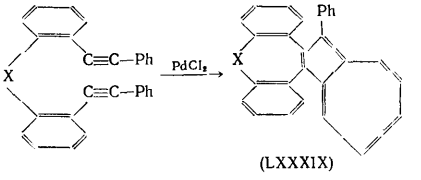
Intramolecular cyclisation of 1,8-dimesitylethynylnaphthalene (LXXXV) on ultraviolet irradiation gives the polycyclic azulene hydrocarbon (LXXXVI):[89]



In connection with the mechanism of such reactions it is interesting that 1,2-diphenylethynylcyclohexene (LXXXVII) is converted by radiation into a hydrogenated azulene derivative (LXXXVIII)[88]

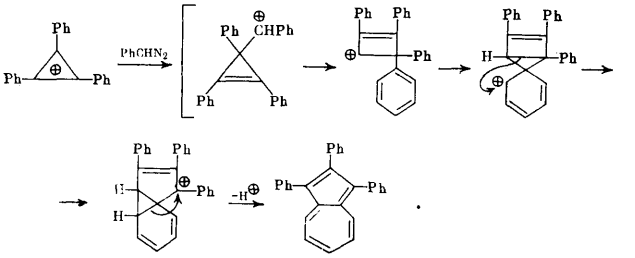


dehydrogenation of which by chloranil yields the corresponding azulene. Intramolecular cyclisation has been employed to obtain polycyclic azulene derivatives (LXXXIX) containing a silicon or sulphur atom in one of the fused rings[90,91]:

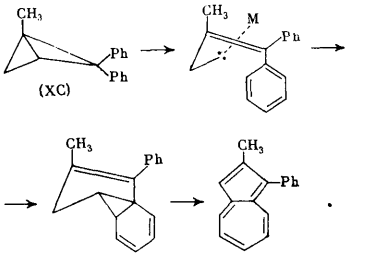


X=SO, Si $(CH_3)_2$.

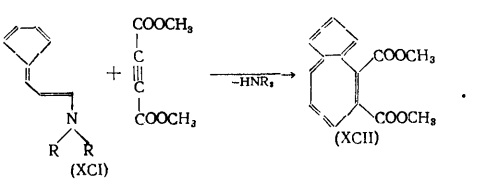
Another method of obtaining azulene derivatives—from arylcyclopropenylium salts[92-94]—also involves expanding the ring of a phenyl substituent:



A further synthetic approach to azulenes involving intramolecular cycloaddition is based on rearrangement of a phenylated bicyclo[1,1,0]butane (XC) initiated by a transition-metal carbonyl[95]:

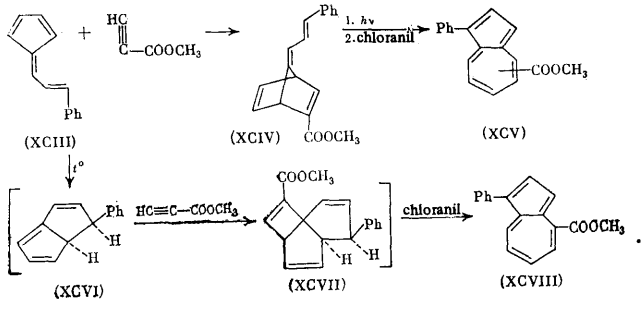


Like heptafulvenes (§II, 4) aminovinylfulvenes (XCI) are able to undergo cycloaddition with acetylenedicarboxylic esters, to give azulene-4,5-dicarboxylic esters (XCII):[96]

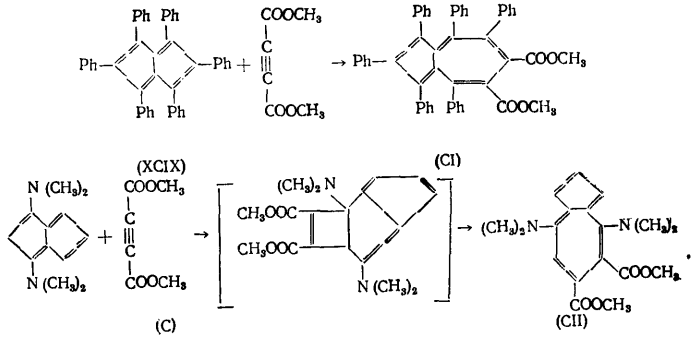


6-Styrylfulvene (XCIII) undergoes diene synthesis with methyl propiolate to form an adduct (XCIV) that rearranges into a mixture of phenyldihydroazulenecarboxylic esters;

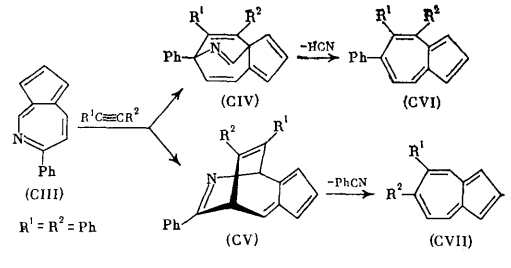
the latter are readily dehydrogenated by chloranil, forming a mixture of methyl 1-phenylazulene-4(8)-carboxylates (XCV). When heated the fulvene (XCIII) isomerises into phenyldihydropentalene (XCVI); cycloaddition of the propiolic ester produces the cyclobutene derivative (XCVII), which on dehydrogenation is converted into the individual methyl 1-phenylazulene-4-carboxylate (XCVIII).[29]



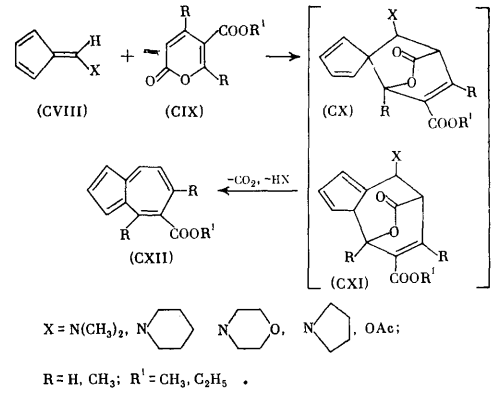
This mechanism is supported by the well known methods of converting the substituted pentalenes (XCIX) [97] and (C) [98] into the corresponding azulenes (CI) and (CII) by the action of acetylenedicarboxylic ester:



The cyclic analogue of styrylfulvene, 6-phenyl-5-azaazulene (CIII), also undergoes cycloaddition with acetylenic compounds[99], when both possible adducts (CIV) and (CV) are formed; these eliminate hydrocyanic acid or benzonitrile to give a mixture of the corresponding azulene derivatives (CVI) and (CVII):

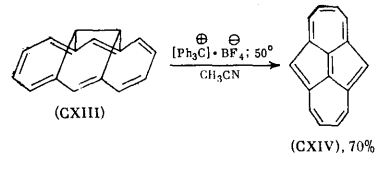


Cycloaddition of dialkylaminofulvenes (CVIII) to coumalic esters (CIX) gives the adducts (CX) and (CXI), which are aromatised into azulenes (CXII) with elimination of carbon dioxide and the dialkylamine[100]:

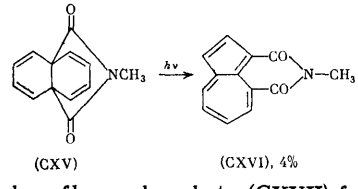


Syntheses of azulene compounds based on cycloaddition have been actively studied during recent years, and their possibilities are probably far from exhausted.

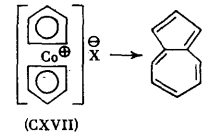
A few other methods of obtaining azulene compounds have been described which, although of no great synthetic value, provide a good illustration of the stability of the aromatic azulene system. Thus 1,6:8,13-ethanediylidene-[14]annulene (CXIII) is converted in high yield into dicyclohepta[*c*,*d*:*g*,*h*]pentalene (CXIV), a novel non-benzenoid isomer of pyrene[101]:



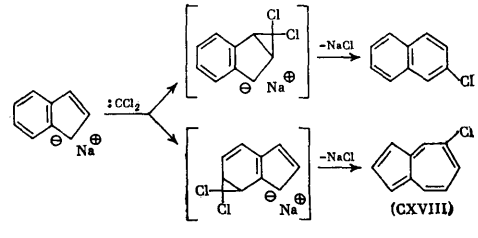
When the propellane (CXV) is exposed to ultraviolet radiation, *N*-methylazulene-1,8-dicarboximide (CXVI) is formed in 4% yield together with other compounds[102]:



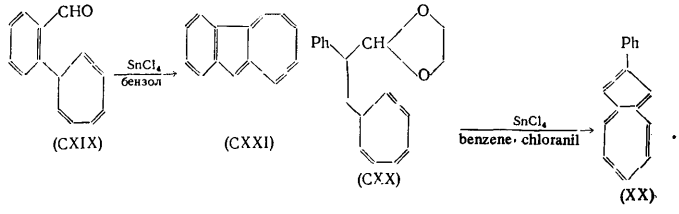
Cobalticinium hexafluorophosphate (CXVII) forms azulene in low yields when treated with bases[103]:



Parham and Reiff[104] studied the possibility of obtaining azulene compounds from indenylsodium by the addition of dichlorocarbene; they found the course of the reaction to be ambiguous, giving 5-chloroazulene (CXVIII) in only about 0.5% yield:

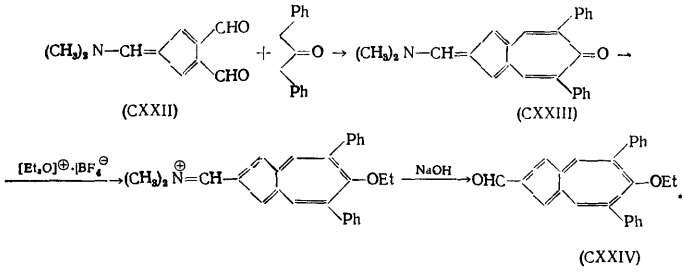


Syntheses of azulene compounds by closure of a five-membered ring in aldehydes or acetals of the cycloheptatriene series (CXIX) and (CXX) have also been reported[105]. Low yields of 1,2-benzazulene (CXXI) and 2-phenylazulene (XX) have been obtained by this method; in the latter case the intermediate dihydro-derivative was dehydrogenated by means of chloranil:



(CXIX) (CXXI) (CXX) (XX)

Another method of condensation of aldehydes involves closure of the seven-membered ring of the azulene system[48]. Borrowed from the chemistry of tropones, it converts the substituted cyclopentadiene dialdehyde (CXXII) into the azulenequinonemethide (CXXIII), which can then be transformed into the azulene derivative (CXXIV):



(CXXII) (CXXIII) (CXXIV)

The methods described in this Section have been used to synthesise various azulenoid polycyclic compounds containing 3–7 fused rings, not only carboxylic azulenoid systems[106–127] but also fused heterocyclic azulene compounds containing nitrogen[128–134], sulphur[135–140], or oxygen[141] as heteroatom.

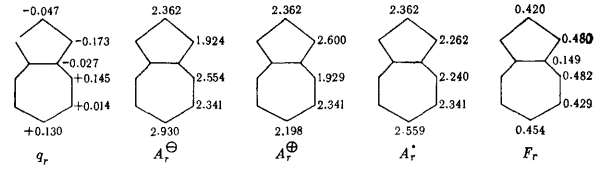
It must be noted in conclusion that no universal method is yet available for the synthesis of substituted azulene hydrocarbons. Many of the above processes cannot be used to prepare azulene and its homologues, both because of the inaccessibility of the initial compounds and because of the low yields. The search for effective new syntheses of azulenes is therefore still continuing at the present time.

III. CHEMICAL PROPERTIES OF AZULENE COMPOUNDS

1. Structure and Reactivity of Azulene

The chemistry of azulene compounds has been intensively developed mainly during the past two decades; certain theoretical views on the reactivity of the azulene system have been elaborated in parallel with or even preceding the synthetic investigations. In spite of the difficulties involved in assessing the contribution of polar structures, even the simplest LCAO-MO calculations[142–152] showed high electronegativity of the five-membered ring and a deficiency of electrons on the atoms of the seven-membered ring.

The charges q_r, localisation energies A_r, and free valency indices F_r calculated by the Hückel method are



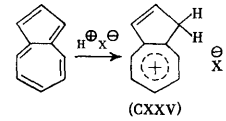
The calculated results lead to several conclusions: (i) the liability to electrophilic attack should decrease either in the sequence of carbon atoms 1(3) > 2 > 5(7) > 6 > 4(8) according to the charges, or in the sequence 1(3) > 5(7) > 2 > 4(8) > 6 according to the localisation energies; (ii) the reactivity towards nucleophilic attack should diminish in the sequence of carbon atoms 4(8) > 6 > 5(7) > 2 > 1(3); and (iii) homolytic reactions should take place at carbon atoms 4(8) [142] or 1(3).[153] As will be shown later, the results of synthetic investigations exhibit in the main good agreement with these theoretical ideas.

2. Electrophilic Substitution

A consequence of the high electron density on the carbon atoms forming the five-membered ring is that the aromatic azulene system is highly reactive towards various electrophilic reagents. Azulene and its derivatives readily form π complexes with various electron-deficient compounds—trinitrobenzene, trinitrotoluene, picric acid[4,154], tetracyanoquinodimethane[155], tetracyanoethylene[156,157], and several other similar compounds[158]—and trinitrobenzene complexes are often used for the isolation, purification, and identification of azulenes, since they readily break down into their components when chromatographed on aluminium oxide. Complexes of azulenes with metal carbonyls have also been described[159–162].

(*a*) Reactions of azulenes with acids

The strongly basic character of azulenes leads to the formation of azulenium salts (CXXV) on treatment with mineral acids[163–165]:



(CXXV)

The ability of azulene and its derivatives to dissolve with salt formation in 60% sulphuric and 85% phosphoric acids[15] is used in several cases to isolate azulene compounds, since dilution of the acid solution with water leads to hydrolysis of the salt with separation of the initial azulene. Salts can be formed by azulenes also with aprotic acids[166], which leads in several cases to the appearance of secondary products when Friedel–Crafts catalysts are used.

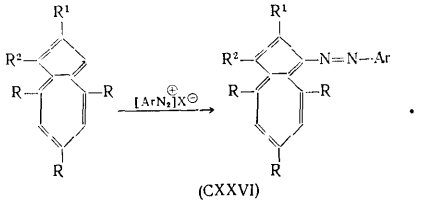
The active hydrogen atoms at positions 1 and 3 exchange readily for deuterium[167,168], whereas the remaining hydrogen atoms exchange only under severe conditions[169].

(*b*) Nitration, nitrosation, and azo-coupling

Because of the sensitivity of the ring system to strong acids, azulene and its homologues cannot be nitrated with a nitrating mixture. However, the nitration of unsubstituted azulene can be easily accomplished by means of acetyl[170], copper[171], or urea[172] nitrate. The use of tetranitromethane in pyridine is especially convenient[173]. With urea nitrate azulene gives both 1-mono-.and 1,3-di-nitroderivatives, whereas with tetranitromethane only 5-nitroazulene is formed. Azulene derivatives containing isopropyl and t-butyl substituents at positions 1 and 3 are nitrated at position 5 in ~25% yield[32].

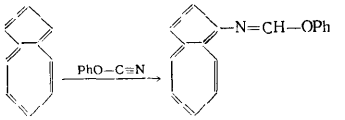
Azulene is nitrosated at position 1 by nitrosyl perchlorate to give the unstable 1-nitrosoazulene[174]. The corresponding nitroso-derivative of 4,6,8-trimethylazulene, obtainable in high yield, is considerably more stable. Nozoe et al.[175] effected the nitrosation of ethyl 2-aminoazulene-1-carboxylate with isopentyl nitrite with formation of ethyl 2-amino-3-nitrosoazulene-1-carboxylate.

1(3)-Unsubstituted azulene derivatives are able to undergo azo-coupling with such weak electrophiles as diazonium salts to give high yields of azo-dyes (CXXVI):[171,176-179]



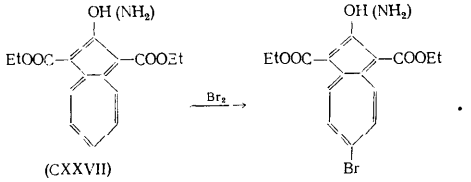
(CXXVI)

These dyes are readily reduced to azulenamines[179,180]. Azulene reacts also with phenyl cyanate[181]:



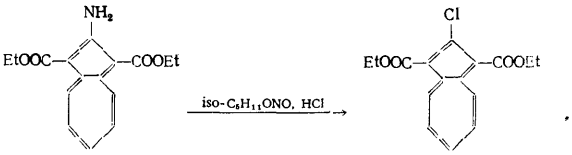
(*c*) Halogenation

The best halogenating agents for obtaining 1(3)-mono- and 1,3-di-halogenated azulenes are *N*-chlorosuccinimide[182-184], *N*-bromosuccinimide[183-185], and *N*-iodosuccinimide[184], which give high yields. Chlorinating agents producing good results are t-butyl hypochlorite[183], phosphorus pentachloride[183,186], phosphoryl chloride[183], and copper(II) chloride[187]; sulphur monochloride in the presence of aluminium chloride also has a chlorinating action[178]. Azulene compounds can be brominated also by means of dioxan dibromide[183], phosphorus pentabromide[183], phosphoryl bromide, pyridinium bromide–perbromide, cyanogen bromide[185], and copper(II) bromide[187]. 1,3-Dibromoazulene can be obtained also by the hypobromination of 1,3-diacetylazulene[170]. Unusually, dialkyl 2-hydroxy- and 2-amino-azulene-1,3-dicarboxylates (CXXVII) are brominated at the 6 position[188,189]:



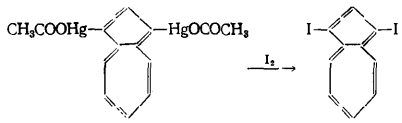
(CXXVII)

1,3-Dichloroazulene can be chlorinated by *N*-chlorosuccinimide at position 5 to give a 17% yield of 1,3,5-trichloroazulene[243]. 2-Chlorinated azulenes have been obtained by diazotising diethyl 2-aminoazulene-1,3-dicarboxylates in the presence of hydrochloric acid[190]:



6-Chloro-derivatives have been obtained from the corresponding azulen-6-ols[183].

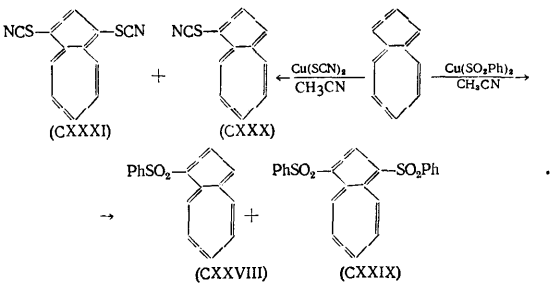
A complex of iodine chloride in dioxan[183] and iodine in the presence of copper acetate[187] have been used to obtain 1(3)-mono- and 1,3-di-iodoazulenes. Another method is exchange substitution of acetoxymercuric groups by treatment with iodine[46]:



1(3)-Halogenoazulenes form normal organomagnesium derivatives[4] and are able to exchange their halogen for the thiocyanato- or cyano-group when heated with the copper or silver salts[183]. Nucleophilic exchange of the halogen has been studied in 6-chloroazulenes[183] and 2-chloroazulenes[191].

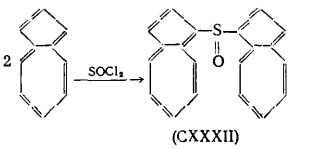
(*d*) Sulphonation, thiocyanation, and other reactions

Azulene is sulphonated by a solution of sulphuric acid in acetic anhydride or by dioxan–sulphur trioxide to the 1,3-disulphonic acid[185,192]. 1-Monosulpho-derivatives of azulene and its homologues have been obtained by sulphonation with copper sulphate in acetic anhydride[193] and with dioxan–sulphur trioxide[194]. The action of copper benzenesulphinate on azulene gives the azulenyl phenyl sulphone (CXXVIII) and the corresponding 1,3-disulphone (CXXIX);[193] methanesulphonyl chloride reacts with azulene to form azulenyl methyl sulphone[195]; and copper thiocyanate gives good yields of 1-cyanatoazulene (CXXX) and 1,3-dithiocyanatoazulene (CXXXI),[193] which had been obtained earlier from azulene and thiocyanogen[178]:



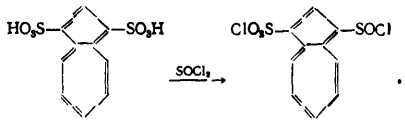
(CXXXI) (CXXX) (CXXVIII) (CXXIX)

At low temperatures azulene reacts with thionyl chloride to form diazulenyl sulphoxide (CXXXII), which on oxidation with sodium periodate is converted into diazulenyl sulphone[196]:



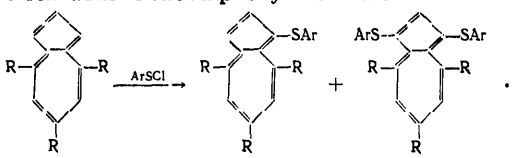
(CXXXII)

An unusual reaction takes place when the 1,3-disulphonic acid is treated with excess of thionyl chloride, for 3-chlorosulphinylazulene-1-sulphonyl chloride (CXXXIII) is formed[192]:



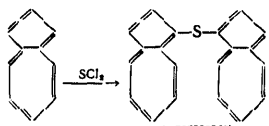
(CXXXIII)

Azulene and its derivatives readily give the 1-sulphides (CXXXIV) and the corresponding 1,3-bis-sulphides (CXXXV) on interaction with arenesulphenyl chlorides[174,178,195,197]:



(CXXXIV) (CXXXV)

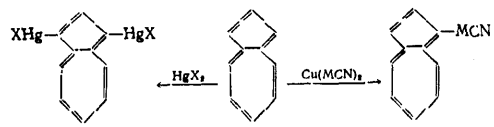
At −78°C sulphur dichloride acts on azulene to give diazulenyl sulphide (CXXXVI):[196]



(CXXXVI)

(*e*) Organoelementary azulene derivatives

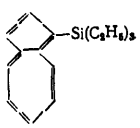
Azulene is readily mercurated by mercury(II) chloride to form azulene-1,3-dimercuric dichloride (CXXXVII):[198]



(CXXXVII) (CXXXVIII)

X=Cl, $OCOCH_3$; M=Se, Te

Mercury acetate is equally effective[192]. Monomercurated derivatives can also be obtained by varying the proportions of the reactants. The chloromercuri-derivatives are converted quantitatively into halogeno- or thiocyanato-derivatives by the action of copper(II) chloride, bromide, or thiocyanate[193]. Copper selenocyanate and tellurocyanate give good yields of the corresponding seleno- and telluro-cyanatoazulenes (CXXXVIII).[199] The organosilicon azulene derivative

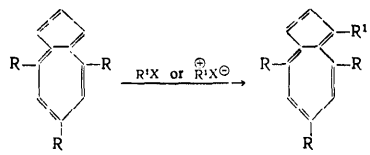


(CXXXIX)

was synthesised indirectly, not by direct substitution[200].

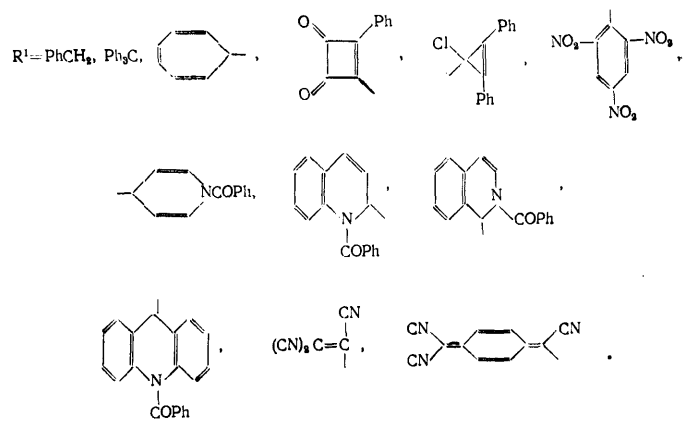
(*f*) Alkylation

Alkylation of azulene and its homologues under the conditions of Friedel–Crafts reaction takes place at positions 1 and 3, but such reactions give by no means high yields owing to the great sensitivity of azulenes to catalysts[166,198]: for example, benzyl chloride forms 1-benzylazulene in only 5.6% yield[198]. Alkyl halides give still poorer results[201,202]. However, compounds capable of forming stable carbonium ions—such as triphenyl chloromethane[203], tropylium bromide[204], 3-bromo-4-phenylcyclobutene-1,2-dione[205], and 3,3-dichloro-1,2-diphenylcyclopropene[206]—readily alkylate azulene at positions 1 and 3. Good results have been obtained by the action of picryl chloride and *p*-chloronitrobenzene on azulene hydrocarbons[166]; the condensation of azulene with pentaacetylbromoglucose has been described[207].



X=Cl, Br, CN;

R=H, CH_3;

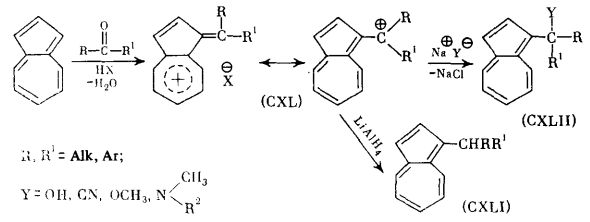


Di- and tri-phenylmethanols, their ethers or esters, or arylated ethylenes capable of forming stable carbonium ions have been used as alkylating agents[203,208] instead of alkyl halides. Tropylium and triphenylmethyl perchlorates are also effective alkylating agents[174,209]. 1-Ethyl-4,6,8-trimethylazulene has been obtained by alkylating 4,6,8-trimethylazulene with triethyloxonium tetrafluoroborate[174], but such a reaction could not be accomplished with unsubstituted azulene[198]. Yields of 40–60% have recently been obtained in the heteroarylation of azulene and its homologues with *N*-acylated pyridinium, quinolinium, isoquinolinium, and acridinium salts[210,211]. The π complexes of azulene hydrocarbons with tetracyanoethylene and tetracyanoquinodimethane are converted into the 1-tricyanovinyl derivatives with the elimination of hydrogen cyanide[155–157].

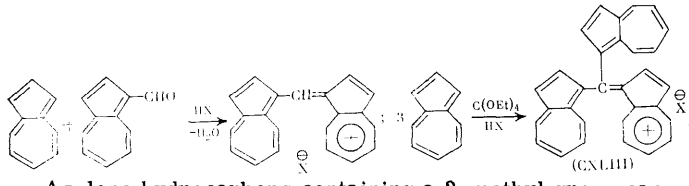
(*g*) Reactions with carbonyl compounds

In the presence of various mineral and organic acids azulene hydrocarbons condense with aromatic[165,212–219], heterocyclic[217,218,220,221], aliphatic[222,223], polyene[222,224], and azulene[212,214,222] aldehydes, ketones[208,225], and several dicarbonyl compounds[222]. The resulting mesomeric cations (CXL) can easily be reduced to the corresponding

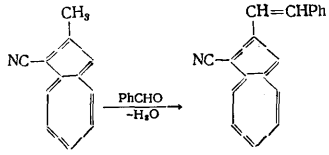
1-alkylazulenes (CXLI),[219,223] and are converted by bases into compounds of type (CXLII):[223]



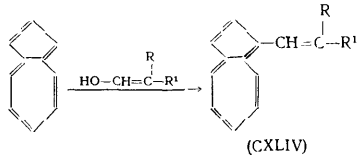
This reaction has been used to obtain azulenoid polymethine dyes[220,221]. Saltlike dyes of the diazulenylmethane series have been obtained by the interaction of azulene and 1-formylazulene[214,215,218,222]; and a triazulenylmethane dye (CXLIII) is produced by condensing azulene with orthocarbonic ester in acid medium[214]:



Azulene hydrocarbons containing a 2-methyl group can be condensed with benzaldehyde to form 2-styrylazulenes[226].

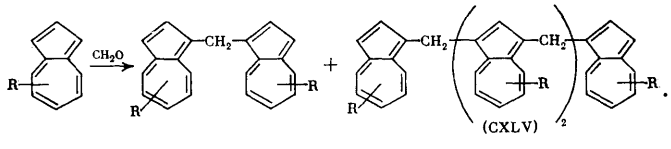


Enols alkylate azulene and its homologues in acid media with the elimination of water and the formation of vinyl derivatives (CXLIV):[222]

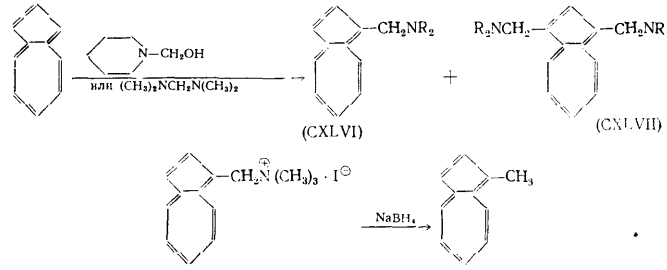


(*h*) Aminomethylation

Chloromethylation and hydroxymethylation of azulene and guaiazulene by means of formaldehyde yield only products of diazulenylmethane structure[216] or of further condensation (CXLV),[227] not the corresponding chloromethyl or hydroxymethyl derivatives:



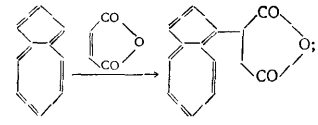
However, the use of mild aminomethylating agents, such as aminomethanols[227,228] and methylenebisdialkylamines[229], made it possible to accomplish the Mannich reaction. Azulene is aminomethylated at positions 1 and 3 to give the unstable dialkylaminomethyl derivatives (CXLVI) and (CXLVII); with methyl iodide these form the more stable quaternary salts, which can be reduced by sodium tetrahydroborate to methylazulenes:



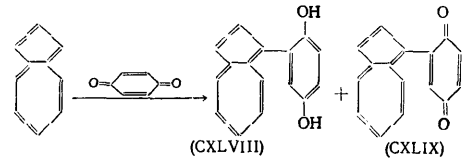
Reactions of these salts with alkali-metal phenoxides and cyanides have been described, as well as several other transformations of aminomethyl derivatives[137,228,230-232].

(*i*) 1,2-Addition

Azulenes do not undergo diene condensation, but are able to add to active dienophiles—acetylenecarboxylic and azo-dicarboxylic esters[233], maleic anhydride[233,234], benzoquinone[233,234], 1,2-naphthaquinone[181]—with the formation of 1,2-addition products: e.g.



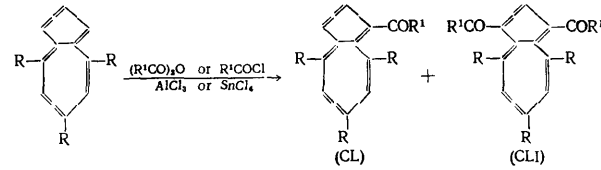
The product (CXLVIII) formed initially by the addition of benzoquinone to azulene may be oxidised by excess of the former reactant to the substituted quinone (CXLIX):[235]



Azulene adds also to phenyl isocyanate to form azulene-1-carboxyanilide[181].

(*j*) Acylation

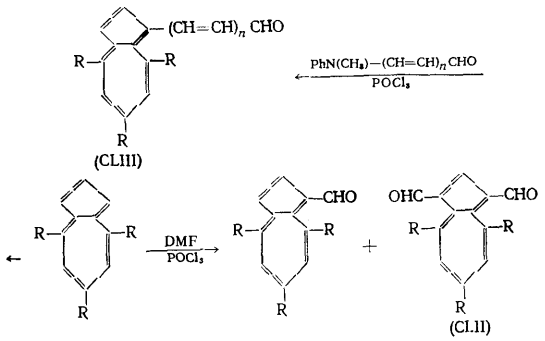
Azulene is acylated by chlorides and anhydrides of carboxylic acids in the presence of aluminium chloride[171,201], perchloric acid[225], or tin tetrachloride[170] with the formation of 1-mono- and 1,3-di-acyl derivatives (CL) and (CLI):



With trifluoroacetic anhydride the reaction goes almost quantitatively in the absence of a catalyst[236,237]. Acylation has been achieved with oxalyl[238-240], malonyl[241,242], and phenylacetyl[244] chlorides or bromides. Under the conditions of the Friedel–Crafts reaction carbonyl chloride forms diazulenyl ketones[212]. Guaiazulene may be formylated under the conditions of the Gattermann reaction[239]. In all the above cases acylation occurs at positions 1 and/or 3, at which the greatest electron density is concentrated; when these are occupied, position 5 becomes acylated.

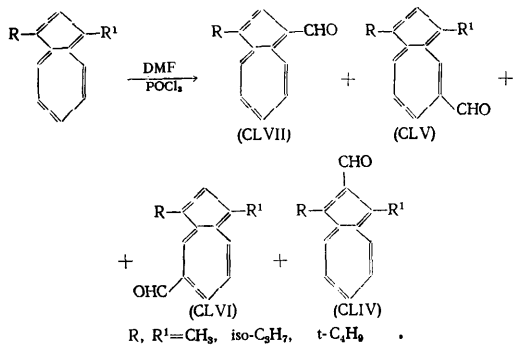
Substituents already present at the former positions—chloro[182,243], isopropyl[173], t-butyl[174]—often exchange simultaneously for an acyl group. 1- and 3-Acetyl groups may in turn be displaced by other electrophilic reagents[174], e.g. when heated with alcohols in acid media[225].

The Vilsmeier–Haack reaction is mostly used at the present time to obtain acyl and especially formyl derivatives of azulene hydrocarbons. Many diverse 1(3)-formyl derivatives of azulene have been prepared by this method[4,203,245-250]. The corresponding 1,3-dialdehydes (CLII) have also been obtained in good yields, and application of the reaction to unsaturated amino-aldehydes yields vinylogues of 1-formylazulene (CLIII):[117,224]



R=H, CH_3; n=1, 2 .

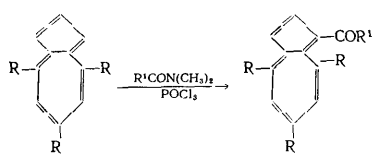
Treatment of 1,3-dialkylated azulenes with a complex of dimethylformamide and phosphoryl chloride gives a mixture of the 2-, 5-, and 7-formyl derivatives (CLIV)–(CLVI) together with the product (CLVII) of replacement of an alkyl by a formyl group[173]:



R, R^1=CH_3, iso-C_3H_7, t-C_4H_9 .

At a high temperature the formylating complex is able to displace the bromine atoms in 1,3-dibromoazulene[251] (see below).

Azulene can be formylated also by means of orthoformic ester in acid media[214]. Aldehydes have been obtained also by oxidising 1-dialkylaminomethylazulenes[228] and 1-methylazulene[260] with potassium permanganate. Treatment of azulene hydrocarbons with acylating complexes obtained from dimethylamides of acetic[18,127,248], chloroacetic[254], oxalic[253], benzoic[127,248], and several other acids have been used to prepare the corresponding 1(3)-acylazulenes (CL):



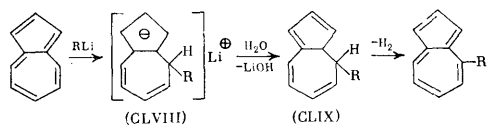
R=H, CH_3; R^1=CH_3, CH_2Cl, $CON(CH_3)_2$, C_6H_5 .

Azulene aldehydes and ketones are used as initial compounds for obtaining various classes of derivatives containing the azulene ring system[81,107,110,116-118,120,127,131,132,254-259].

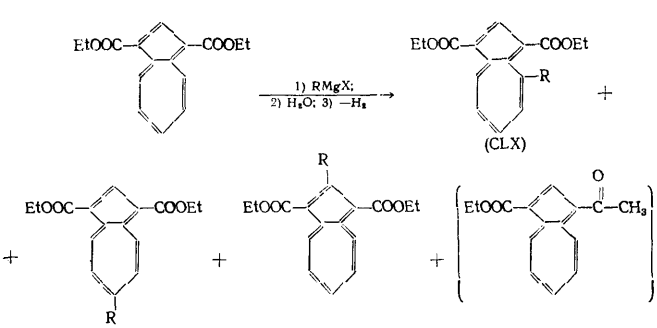
Displacement of substituents at positions 1 and 3 in the ring system is met quite often in the chemistry of azulene compounds and occurs readily under conditions of electrophilic attack. This phenomenon especially often accompanies formylation[173,251] and acylation[173,174,243], although it has been observed also during halogenation[186], nitrosation[175], and azo-coupling[174]. Groups that give stable carbonium cations are very easily replaced. Thus the ease of substitution of alkyl groups increases on passing from methyl to isopropyl, t-butyl, and then to triphenylmethyl and cycloheptatrienyl. Either one or both groups at positions 1 and 3 may undergo substitution. Not only alkyl groups but also the acetyl group[174] and halogens[243,251] may be replaced.

3. Nucleophilic Substitution

Considerably less study has been made of nucleophilic than of electrophilic substitution in azulene compounds. As LCAO-MO calculations have predicted, nucleophilic attack takes place at carbon atoms 4(8) and 6. Thus azulene reacts with organolithium compounds to give addition products (CLVIII), which on hydrolysis yield colourless dihydroazulene derivatives (CLIX), whose dehydrogenation by chloranil produces 4-substituted azulenes[30,32]:

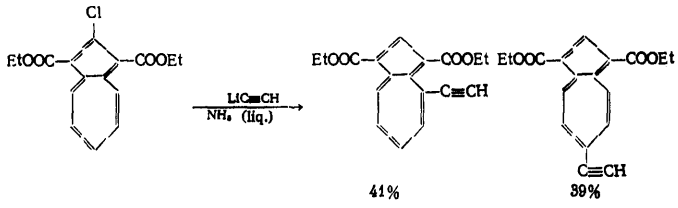


in which R = CH_3, $(CH_3)_3C$, C_6H_5, 1-$C_{10}H_7$, $C_6H_5CH_2$, 2-C_4H_3S, 2-C_5H_4N, or 2-$C_5H_4NCH_2$. 4,8-Disubstituted azulenes can be obtained similarly. It is interesting that diethyl azulene-1,3-dicarboxylate reacts with aliphatic and aromatic organomagnesium compounds without involvement of the ester groups, to form after hydrolysis and dehydrogenation a mixture of 4-, 6-, and 2-substituted azulenes (CLX)–(CLXII),[31,262] and in only one case has the product of interaction between an organomagnesium compound and an ethoxycarbonyl group (CLXIII) been detected:



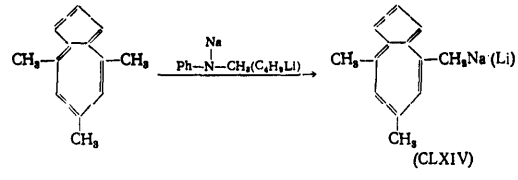
R=Alk, Ar .

An ethynyl group is readily introduced into the azulene ring system by the action of lithium acetylenide in liquid ammonia on 2-chloroazulenecarboxylic esters[261]:



Here, too, ethoxycarbonyl groups are unaffected, though their electron-accepting effect activates the azulene system to nucleophilic attack: unsubstituted azulene does not undergo such a reaction with acetylenides. The presence of halogen at position 2 makes it possible to eliminate the dehydrogenation stage, since the aromatic azulene structure is regenerated, by dehydrochlorination under the influence of ammonia, from the intermediate dihydro-derivatives formed by addition.

Metal derivatives of alkylated azulenes have been obtained by the action of the sodium derivative of *N*-methylaniline or of butyl-lithium on 4- or 6-methylated azulenes[244,262]:

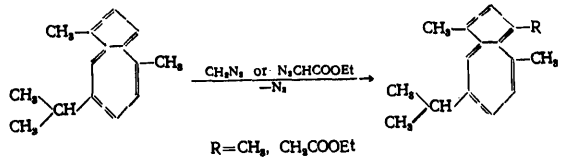


(CLXIV)

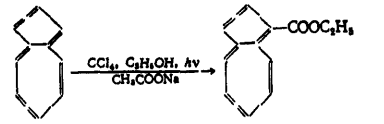
The organometallic derivatives (CLXIV) undergo the usual reactions with alkyl halides, carbon dioxide, and carbonyl compounds, forming various 4-substituted azulene derivatives[116,120,244,262-265]. Azulene is aminated at position 4 in low yield by sodamide[185]. Various nucleophilic reactions involving exchange of halogen in halogenated azulenes have been studied[183,266-268].

4. Radical Substitution

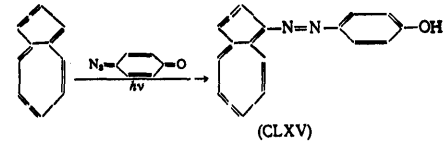
Calculated localisation energies suggest that radical reactions should occur at position 4 in azulene compounds[269], but the difference in energy of localisation at positions 1 and 4 is insignificant, and almost all known radical reactions take place at the 1-carbon atom. Such reactions, which have been studied with the alkylation of guaiazulene by diazomethane and diazoacetic ester as example[270], yield the corresponding substitution products:



A 15% yield of 1-phenylazulene has been obtained[216] by the action of nitrosoacetanilide on azulene. The radical benzylation of azulene[271] gives a mixture of the 1- and 2-isomers, the latter probably formed by secondary migration of the benzyl group under the severe reaction conditions (see below). Of preparative interest is the photoalkyoxycarbonylation of azulene[272] to give a 52% yield of ethyl azulene-1-carboxylate:

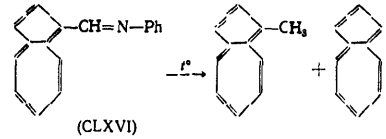


A high yield of the azo-dye (CLXV) is obtained by the action of *p*-diazoquinone on azulene during exposure to ultraviolet radiation[273]:



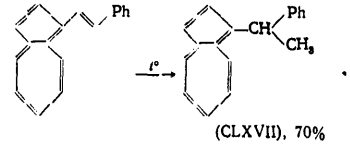
(CLXV)

Several thermal reactions of azulene derivatives resulting in modification of 1-substituents are probably also radical in character. Thus the Schiff base (CLXVI) when heated is converted into a mixture of 1-methylazulene and azulene in 36% and 24% yield respectively[274]:



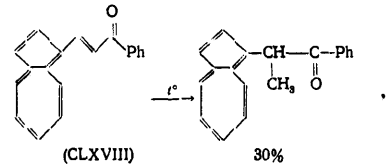
(CLXVI)

1-Styrylazulene is transformed in high yield into 1-α-methylbenzylazulene (CLXVII):[275]



(CLXVII), 70%

Azulenylvinyl phenyl ketone (CLXVIII) undergoes analogous rearrangement[276]:



(CLXVIII) 30%

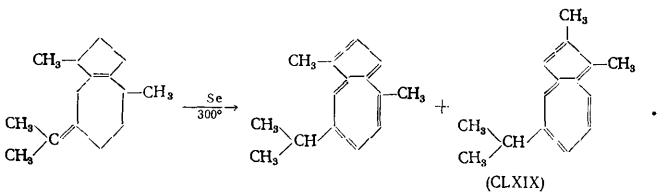
Reduction of the rearranged products is a consequence of partial decomposition of the azulene compounds. Although the yields in these processes are not always high, such reactions enable several difficultly accessible azulene derivatives to be obtained.

On irradiation 1-nitroazulene exchanges its nitro-group for a cyano- or a methoxy-group[277,278], a reaction of especial interest for obtaining the difficultly accessible 1-methoxyazulene. It is quite likely that the migration of various groups from 1 to the 2 position in the azulene ring system has a radical mechanism.

5. Migration of Substituents

The most common specific migration of groups is the conversion of 1- into 2-substituted azulenes, first observed by Plattner[279]; it has now been studied on several examples, and provides a route to 2-substituted azulenes, which are

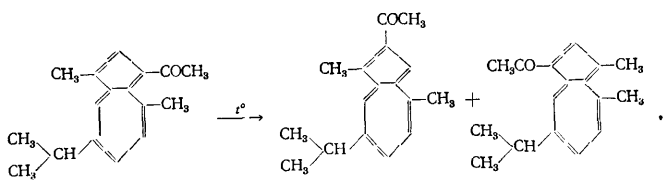
extremely difficult to obtain by other methods, although the yield is often diminished by secondary processes due to the high temperature of conversion. Dehydrogenation of guaiene with selenium at 300°C yields not only guaiazulene (II) but also the isomeric (CLXIX):[279,280]



(CLXIX)

Isopropyl[282], t-butyl[283], phenyl[281], acetyl[19,285,286], benzoyl[284], and formyl[252] groups migrate in this way. Ease of migration increases on passing from methyl to t-butyl[283].

This isomerisation is promoted by substituents at positions 4 and 8. Thus 1-formylazulene does not isomerise into the 2-aldehyde, whereas 1-formyl-4,6,8-trimethylazulene is converted into the 2-formyl derivative in 16% yield[252,287]. The reaction may be accompanied by exchange of the migrating group for hydrogen[283] and by intermolecular alkylation. A case of the simultaneous migration of two substituents is known[286]:



IV. PRACTICAL APPLICATIONS OF AZULENE COMPOUNDS

Two main trends in the practical application of azulene derivatives have developed during recent years: the first is based on the broad spectrum of biological activity exhibited by azulenes and has led to the production of various medicinal preparations; the second exploits the peculiar electronic structure of azulene hydrocarbons, which enables these compounds to be used as dyes, optical sensitisers, and perhaps photosemiconductors. Many plants that are natural sources of azulene compounds have long been employed in folk and official medicine. A broad study of natural and synthetic azulenes has established that many of them possess high bacteriostatic[288,289], anti-inflammatory[290-295], antipyretic[70,129,133], sedative[134,296-298], antiallergic, antasthmatic[299-302], and several other types of activity. During recent years preparations possessing antineoplastic activity have been based on azulene compounds[141,179,204,303,304], although no statistical data on their application have appeared. The high anti-inflammatory activity of several azulene compounds has led to their widespread introduction as components of toothpastes, creams, and several other cosmetic materials[306]. For this purpose methods have been developed for producing stable emulsions and water-soluble formulations[295]. Azulene analogues of known medicinal preparations have been synthesised[307,308]. The influence of azulene compounds on several enzyme systems was studied[309] in order to elucidate the mechanism of their biological action. The carcinogenic effect of several fused polycyclic azulenes has been examined[310,311].

The ability of azulene derivatives to absorb in the visible led to an intensive study of azulene analogues of triphenylmethane[107] and polymethine[221,255,312] dyes, including those based on azulenylthiazole[254]. Photoconduction by azulene crystals has been studied[313]. Certain substituted heterocyclic azulenes are used as stabilisers for polymers[314]. The use of azulene in analytical chemistry has been reported[315].

In assessing the practical utilisation of azulenes we must emphasise that research on their application was held back for a long time by the absence of effective methods of synthesis, which have been developed only during the past two decades[305]. However, the results already available suggest that great prospects lie before this class of non-benzenoid aromatic compounds.

REFERENCES

1. A. S. Pfau and P. A. Plattner, Helv. Chim. Acta, **19**, 858 (1936).
2. D. Ginsburg (Editor), "Non-benzenoid Aromatic Compounds" (Translated into Russian), Inostr. Lit., Moscow, 1963.
3. D. Ginsburg (Editor), "Non-benzenoid Aromatic Compounds", Interscience, New York, 1959.
4. K. Hafner, Angew. Chem., 70, 419 (1958).
5. M. Comtet and H. P. Mettee, Mol. Photochem., 63 (1970).
6. M. E. Vol'pin, Uspekhi Khim., 29, 298 (1960) [Russ. Chem. Rev., No. 3 (1960)].
7. T. Nozoe and I. Murata, "Aromatic Compounds", London, 1973, p. 201.
8. K. Hafner, Fifth International Congress on the Chemistry of Heterocyclic Compounds, Abstracts of Papers, Ljubljana, 1975, p. 17.
9. E. Kovats, H. H. Günthard, and P. A. Plattner, Helv. Chim. Acta, **37**, 2123 (1954).
10. L. Ružicka and V. Prelog, US P. 2 838 560; Chem. Abs., **52**, 17 224 (1958).
11. V. Prelog and S. Polyak, Suomen Kem., **B31**, 95 (1958).
12. K. F. Lang and M. Froitheim, US P. 2 823 239 (1958); Chem. Abs., **52**, 11 944 (1958).
13. M. Sauerbier, Chem. Ztg., **97**, 91 (1973).
14. L. Mangoni and G. Bandiera, Gazzetta, **90**, 947 (1960).
15. W. Treibs, C. Vollard, and M. Reimann, Annalen, **634**, 111 (1959).
16. T. M. Jakob, P. A. Vatakencherry, and Sukh Dev, Tetrahedron, **20**, 2815 (1964).
17. S. Hayashi, S. Kurokawa, and T. Matsuura, Bull. Chem. Soc. Japan, **41**, 2182 (1968).
18. S. Hayashi, S. Kurokawa, and T. Matsuura, Bull. Chem. Soc. Japan, **42**, 1404 (1969).
19. S. Kurokawa, Bull. Chem. Soc. Japan, **43**, 509 (1970).
20. G. Chiurdoglu and M. Deschamps, Chem. and Ind., 1377 (1959).
21. G. Chiurdoglu and M. Deschamps, Tetrahedron, 8, 217 (1960).
22. H. A. Silverwood and M. Orchin, J. Org. Chem., **27**, 3401 (1962).
23. L. T. Scott, Chem. Comm., 882 (1973).
24. W. E. Doering and D. W. Wiley, Tetrahedron, **11**, 183 (1960).
25. A. J. Birch, D. J. Collins, A. R. Penfold, and J. P. Turnbull, J. Chem. Soc., 792 (1962).
26. V. Herout, M. Holub, L. Novotny, F. Sorm, and V. Sykora, Chem. and Ind., 622 (1960).

27. W. Treibs and J. Hiebsch, DDR P. 16 712 (1959); Chem. Abs., **54**, 19 630 (1960).
28. J. P. Morizur and R. Polland, Compt. rend., **251**, 2043 (1960).
29. H. Prinzbach and H.-I. Herr, Angew. Chem., **84**, 117 (1972).
30. K. Hafner, C. Berhard, and R. Müller, Annalen, **650**, 35 (1961).
31. N. Abe, T. Morita, and K. Takase, Tetrahedron Letters, 3883 (1973).
32. K. Hafner and H. Weldes, Annalen, **606**, 90 (1957).
33. W. Treibs and M. Quarg, Annalen, **598**, 38 (1956).
34. K. Ziegler and K. Hafner, Angew. Chem., **67**, 301 (1955).
35. W. König and H. Rösler, Naturwiss., **42**, 211 (1955).
36. D. Lloyd and F. Rowe, J. Chem. Soc., 3718 (1953).
37. Yu. N. Porshnev, E. M. Tereshchenko, and V. A. Churkina, Zhur. Org. Khim., **10**, 881 (1974).
38. I. Murata, K. Nakasuji, K. Yamamoto, T. Nakazawa, Y. Kayane, A. Kimura, and O. Hara, Angew. Chem., **87**, 170 (1975).
39. K. Hafner and K.-D. Asmus, Annalen, **671**, 31 (1964).
40. S. M. Makin, V. M. Likhosherstov, and M. I. Shelemina, Zhur. Obshch. Khim., **34**, 1809 (1964).
41. Yu. N. Porshnev, E. M. Tereshchenko, V. V. Titov, and V. B. Mochalin, Zhur. Org. Khim., **8**, 1942 (1972).
42. Yu. N. Porshnev, E. M. Tereshchenko, and V. B. Mochalin, Khim. Geterotsikl. Soed., 1329 (1974).
43. Yu. N. Porshnev, E. M. Tereshchenko, V. B. Mochalin, and V. V. Titov, Zhur. Org. Khim., **10**, 853 (1974).
44. C. Jutz, E. Schweiger, H.-G. Löbering, A. Kraatz, and W. Kosbahn, Chem. Ber., **107**, 2956 (1974).
45. K. Hafner and K.-H. Vöpel, Angew. Chem., **71**, 672 (1959).
46. K. Hafner and M. Kreuder, Angew. Chem., **73**, 657 (1961).
47. Z. Arnold, Coll. Czech. Chem. Comm., **25**, 1313 (1960).
48. K. Hafner, K.-H. Vöpel, G. Ploss, and C. König, Annalen, **661**, 52 (1963).
49. K. Hafner, K. H. Häfner, C. König, M. Kreuder, G. Ploss, G. Schulz, E. Sturm, and K.-H. Vöpel, Angew. Chem., **75**, 35 (1963).
50. U. Müller-Westerhoff and K. Hafner, Tetrahedron Letters, 4341 (1967).
51. C. Jutz, R. Kirchlechner, and H.-J. Seidel, Chem. Ber., **102**, 2301 (1969).
52. N. P. Buu-Hoi, P. Jacquignon, J.-P. Hoeffinger, and C. Jutz, Bull. Soc. chim. France, 2514 (1972).
53. C. Jutz and E. Schweiger, Angew. Chem., **83**, 886 (1971).
54. H. E. Nikolajewski, S. Dähne, D. Leupold, and B. Hirsch, Tetrahedron, **24**, 6685 (1968).
55. K. Hafner, BRD P. 1 027 200 (1958); Chem. Abs., **54**, 10 901 (1960).
56. K. Ziegler and K. Hafner, US P. 2 805 266 (1957); Chem. Abs., **52**, 6409 (1958).
57. N. R. Slobodkin, J. Org. Chem., **25**, 273 (1960).
58. K. Ziegler and K. Hafner, US P. 2 766 304 (1956); Chem. Abs., **51**, 12, 981 (1957).
59. C. W. Muth, M. L. De Matte, A. R. Urbanik, and W. G. Isner, J. Org. Chem., **31**, 3013 (1966).
60. K. Hafner, Angew. Chem., **69**, 393 (1957).
61. K. Hafner and H. Kaiser, Annalen, **618**, 140 (1958).
62. F. Klages and H. Träger, Chem. Ber., **86**, 1327 (1953).
63. K. Dimroth, K. H. Wolf, and H. Wache, Angew. Chem., **75**, 860 (1963).
64. T. Nozoe, S. Matsumura, Y. Murase, and S. Seto, Chem. and Ind., 1257 (1955).
65. G. Sunagawa and H. Nakao, Chem. and Pharm. Bull. (Japan), **13**, 443 (1965).
66. T. Nozoe, K. Takase, and S. Fukuda, Bull. Chem. Soc. Japan, **44**, 2210 (1971).
67. T. Nosoe, K. Takase, and S. Fukuda, Bull. Chem. Soc. Japan, **44**, 2215 (1971).
68. S. Matsumura, Chem. and Pharm. Bull. (Japan), **10**, 1024 (1962).
69. T. Nozoe, K. Takase, K. Kato, and T. Nogi, Tetrahedron, **27**, 6023 (1971).
70. T. Nozoe, T. Nukai, T. Toda, and H. Horino, Jap. P. 00 710 (1968); Chem. Abs., **69**, 67 389 (1968).
71. P.-W. Yang, M. Yasunami, and K. Takase, Tetrahedron Letters, 4275 (1971).
72. A. Chen, M. Yasunami, and K. Takase, Tetrahedron Letters, 2581 (1974).
73. M. Oda and Y. Kitahara, Synthesis, 367 (1971).
74. M. Oda and Y. Kitahara, Chem. and Ind., 920 (1969).
75. S. Kuroda, M. Funamizu, and Y. Kitahara, Tetrahedron Letters, 3197 (1975).
76. N. Soma and I. Kawamoto, Jap. P. 11 220 (1974).
77. T. Nozoe, S. Seto, and S. Matsumura, Bull. Chem. Soc. Japan, **35**, 1990 (1962).
78. T. Nozoe, K. Takase, T. Nakazawa, S. Sugita, and M. Saito, Bull. Chem. Soc. Japan, **47**, 1750 (1974).
79. T. Nozoe, T. Asao, and M. Kobayashi, Bull. Chem. Soc. Japan, **46**, 3161 (1973).
80. T. Nozoe, K. Takase, and M. Tada, Bull. Chem. Soc. Japan, **36**, 1016 (1963).
81. K. Matsui, Nippon Kagaku Zasshi, **82**, 1517 (1961); Chem. Abs., **59**, 3863 (1963).
82. W. Reppe, O. Schlichting, and H. Meister, Annalen, **560**, 93 (1948).
83. D. Bryce-Smith and J. E. Lodge, J. Chem. Soc., 695 (1963).
84. S. J. Assony and N. Kharash, Chem. and Ind., 1388 (1954).
85. H. J. de Liefde Meijer, U. Pauzenga, and F. Jellinek, Rec. Trav. chim., **85**, 634 (1966).
86. R. C. Cookson and D. W. Jones, J. Chem. Soc., 1881 (1965).
87. E. Müller, M. Sauerbier, and G. Zountsas, Tetrahedron Letters, 3003 (1969).
88. E. Müller and G. Zountsas, Tetrahedron Letters, 4531 (1970).
89. H. A. Staab and J. Ipaktschi, Chem. Ber., **104**, 1170 (1971).
90. E. Müller and G. Zountsas, Chem.-Ztg, **97**, 447 (1973).
91. E. Müller and G. Zountsas, Chem.-Ztg, **98**, 41 (1974).
92. R. Breslow and M. Battiste, J. Amer. Chem. Soc., **82**, 3626 (1960).
93. H. H. Freedman, J. Org. Chem., **27**, 2298 (1962).
94. T. Shono, T. Toda, and R. Oda, Tetrahedron Letters, 369 (1970).
95. P. G. Gassman and T. Nakai, J. Amer. Chem. Soc., **93**, 5897 (1971).
96. R. W. Alder and G. Whittaker, J. Chem. Soc., 776 (1971).
97. E. Le Goff, J. Amer. Chem. Soc., **84**, 3975 (1962).
98. K. Hafner, Pure Appl. Chem., **28**, 156 (1971).
99. K. Hafner, J. Häring, and W. Jäkel, Angew. Chem., **82**, 135 (1970).

100. M. Sato, S. Ebine, and Y. Tsunetsugu, Tetrahedron Letters, 2769 (1974).
101. H. Reel and E. Vogel, Angew. Chem., 84, 1064 (1972).
102. J. Altman, E. Babad, D. Ginsburg, and M. B. Rubin, Israel J. Chem., 7, 435 (1969).
103. C. J. Attridge, S. J. Baker, and A. W. Parkins, Organometallic Chem. Syn., 1, 183 (1971).
104. W. E. Parham and H. E. Reiff, J. Amer. Chem. Soc., 77, 1177 (1955).
105. T. Watanabe and N. Soma, Chem. and Pharm. Bull. (Japan), 19, 2215 (1971).
106. E. Kloster-Jensen, E. Kovats, A. Eschenmoser, and E. Heilbronner, Helv. Chim. Acta, 39, 1051 (1956).
107. W. Treibs, M. Quarg, and E. Poppe, Annalen, 598, 32 (1956).
108. K. Hafner, Angew. Chem., 67, 302 (1955).
109. W. Ried and J. Ehret, Annalen, 737, 61 (1970).
110. W. Ried, W. Merkel, and H.-J. Herrmann, Annalen, 750, 91 (1971).
111. W. K. Gibson, D. Leaver, J. E. Roff, and C. W. Cumming, Chem. Comm., 214 (1967).
112. N. Abe, T. Morita, and K. Takase, Tetrahedron Letters, 4755 (1973).
113. N. Abe, T. Morita, and K. Takase, Tetrahedron Letters, 3621 (1974).
114. P. D. Gardner, E. C. Wulfman, and C. L. Osborn, J. Amer. Chem. Soc., 80, 143 (1958).
115. M. Saito, T. Morita, and K. Takase, Chem. Letters, 955 (1974).
116. K. Hafner, Pure Appl. Chem., 28, 168 (1971).
117. K. Hafner and J. Schneider, Annalen, 624, 37 (1959).
118. J. Murata, K. Yamamoto, and M. Tamura, Chem. Letters, 307 (1974).
119. W. Ried and H. J. Herrmann, Chem. Ber., 107, 152 (1974).
120. K. Hafner, K.-P. Meinhardt, and W. Richarz, Angew. Chem., 86, 235 (1974).
121. R. S. D. Mittal, S. C. Sethi, and S. Dev, Tetrahedron, 29, 1321 (1973).
122. A. G. Anderson, A. F. Montana, A. A. Macdonald, and G. M. Masada, J. Org. Chem., 38, 1445 (1973).
123. L. A. Kapicak and M. A. Battiste, Synthesis, 153 (1971).
124. K. Hafner and R. Fleischer, Angew. Chem., 82, 217 (1970).
125. R. Munday and I. O. Sutherland, J. Chem. Soc. C, 1427 (1969).
126. K. Hafner, G. Hafner-Schneider, and F. Bauer, Angew. Chem. Internat. Edn., 7, 808 (1968).
127. K. Hafner and K. F. Bangert, Annalen, 650, 98 (1961).
128. T. Nozoe, K. Takase, T. Nakazawa, S. Sugita, and M. Satto, Bull. Chem. Soc. Japan, 47, 1750 (1974).
129. T. Nozoe and K. Kikuchi, Jap. P. 18 039 (1964); Chem. Abs., 62, 5258 (1965).
130. Yu. N. Porshnev and E. M. Tereshchenko, Zhur. Org. Khim., 10, 1315 (1974).
131. L. L. Replogle, J. Amer. Chem. Soc., 86, 3137 (1964).
132. L. L. Replogle, K. Katsumoto, T. C. Morrill, and C. A. Minor, J. Org. Chem., 33, 823 (1968).
133. T. Nozoe and K. Takase, Jap. P. 25 678 (1963); Chem. Abs., 60, 5510 (1963).
134. T. Nozoe and K. Takase, Jap. P. 3439 (1964); Chem. Abs., 61, 3116 (1964).
135. H. L. Ammon, L. L. Replogle, P. H. Watts, K. Katsumoto, and J. M. Stewart, J. Amer. Chem. Soc., 93, 2196 (1971).
136. L. L. Replogle, K. Katsumoto, and T. C. Morrill, Tetrahedron Letters, 1877 (1965).
137. K. Matsui, Nippon Kagaku Zasshi, 82, 1667 (1961).
138. K. Matsui, Nippon Kagaku Zasshi, 82, 1522 (1961).
139. G. Fischer and E. J. Poppe, Z. Chem., 3, 26 (1963).
140. T. C. Morrill, R. Opitz, L. L. Replogle, K. Katsumoto, W. Schröder, and B. A. Hess, Tetrahedron Letters, 2077 (1975).
141. M. Hitoshi, Jap. P. 5537 (1967); Chem. Abs., 67, 54 032 (1967).
142. R. D. Brown, Trans. Faraday Soc., 44, 984 (1948).
143. C. A. Coulson and H. C. Longuet-Higgins, Rev. Sci. Instr., 85, 929 (1947).
144. M. J. S. Dewar, J. Amer. Chem. Soc., 74, 3341 (1948).
145. A. Pullman and G. Berthier, Compt. rend., 227, 677 (1948).
146. B. Pullman, M. Mayot, and G. Berthier, J. Chem. Phys., 18, 257 (1950).
147. K. Rüdenberg and C. W. Scherr, J. Chem. Phys., 21, 1565 (1953).
148. R. D. Brown and M. L. Heffermann, Austral. J. Chem., 13, 38 (1960).
149. A. Rosowsky, H. Fleischer, S. T. Young, R. Partch, W. H. Saunders, and V. Boekelheide, Tetrahedron, 11, 121 (1960).
150. A. Julg and P. Francois, J. Chim. phys., 59, 339 (1962).
151. A. Streitwieser, J. Amer. Chem. Soc., 82, 4123 (1960).
152. K. Fukui, C. Nagata, and T. Yonesawa, Bull. Chem. Soc. Japan, 34, 37 (1961).
153. C. A. Coulson and H. C. Longuet-Higgins, Trans. Faraday Soc., 43, 87 (1947).
154. K. B. Dutt, S. Dev, and P. C. Guha, J. Indian Chem. Soc., 30, 473 (1953).
155. B. P. Bespalov, A. A. Pankratov, and V. V. Titov, Zhur. Org. Khim., 10, 134 (1974).
156. K. Hafner and K.-L. Moritz, Annalen, 650, 92 (1961).
157. K. Hafner and K.-L. Moritz, Angew. Chem., 72, 918 (1960).
158. E. I. du Pont de Nemours and Co., B. P. 882 138 (1961); Chem. Abs., 57, 15 296 (1962).
159. R. Burton, L. Pratt, and G. Wilkinson, J. Chem. Soc., 4290 (1960).
160. R. Burton, M. L. H. Green, E. W. Abel, and G. Wilkinson, Chem. and Ind., 1592 (1958).
161. M. R. Churchill, F. R. Scholer, and J. Wormald, J. Organometallic Chem., 28, C21 (1971).
162. R. Burton and G. Wilkinson, Chem. and Ind., 1205 (1958).
163. E. C. Kirby and D. H. Reid, Chem. and Ind., 1217 (1960).
164. D. H. Reid, W. H. Stafford, and J. P. Ward, J. Chem. Soc., 1193 (1955).
165. F. N. Stepanov and A. G. Yurchenko, Zhur. Org. Khim., 2, 150 (1966).
166. W. Treibs, K. Jost, C. Kurpjun, and G. Grunduez-Schroth, Chem. Ber., 94, 1728 (1961).
167. A. Van Tets and H. H. Günthard, Helv. Chim. Acta, 44, 692 (1961).
168. J. Colapietro and F. A. Long, Chem. and Ind., 1056 (1960).
169. A. Van Tets and H. H. Günthard, Helv. Chim. Acta, 45, 457 (1962).
170. A. G. Anderson, R. Scotoni, E. J. Cowles, and C. G. Fritz, J. Org. Chem., 22, 1193 (1957).
171. A. G. Anderson, J. A. Nelson, and J. J. Tazuma, J. Amer. Chem. Soc., 75, 4980 (1953).

172. W. Treibs, Angew. Chem., 67, 76 (1955).
173. K. Hafner and K.-L. Moritz, Annalen, 656, 40 (1962).
174. K. Hafner, A. Stephan, and C. Bernhard, Annalen, 650, 42 (1961).
175. T. Nozoe, P.-W. Yang, H. Ogawa, and T. Toda, Bull. Chem. Soc. Japan, 41, 2095 (1968).
176. W. Treibs and W. Ziegenbein, Annalen, 586, 194 (1954).
177. W. Treibs and B. Streckenbach, Chem. Ber., 94, 1734 (1961).
178. A. G. Anderson and R. N. McDonald, J. Amer. Chem. Soc., 81, 5669 (1959).
179. K. Takase and T. Nazoe, Jap. P. 12 503 (1965); Chem. Abs., 63, 13 182 (1965).
180. T. Nozoe, K. Takase, and M. Toda, Bull. Chem. Soc. Japan, 39, 1948 (1966).
181. W. Triebs, Chimia, 24, 440 (1970).
182. A. G. Anderson and L. L. Replogle, J. Org. Chem., 25, 1275 (1960).
183. K. Hafner, H. Patzelt, and H. Kaiser, Annalen, 656, 24 (1962).
184. A. G. Anderson and B. M. Steckler, J. Amer. Chem. Soc., 81, 4941 (1959).
185. W. Treibs and W. Schroth, Annalen, 586, 202 (1954).
186. T. Toda and A. Yamanouchi, Bull. Chem. Soc. Japan, 43, 2181 (1970).
187. V. A. Nefedov, Zhur. Org. Khim., 9, 783 (1973).
188. T. Nozoe, T. Asao, and M. Oda, Bull. Chem. Soc. Japan, 47, 681 (1974).
189. T. Nozoe, H. Seto, and S. Matsumura, Jap. P. 2977 (1959); Chem. Abs., 54, 13 089 (1960).
190. T. Nozoe, H. Seto, and S. Matsumura, Jap. P. 4818 (1959); Chem. Abs., 54, 15 347 (1960).
191. K. Matsui and T. Nozoe, Chem. and Ind., 1302 (1960).
192. A. G. Anderson, D. J. Gale, R. N. McDonald, R. G. Anderson, and R. C. Rhodes, J. Org. Chem., 29, 1373 (1964).
193. V. A. Nefedov, Zhur. Obshch. Khim., 38, 2185 (1968).
194. S. Miyazaki, C. Ukita, and H. Watanabe, Jap. P. 3065 (1959); Chem. Abs., 54, 13 090 (1960).
195. L. L. Replogle and J. R. Maynard, J. Org. Chem., 32, 1909 (1967).
196. L. L. Replogle, G. C. Peters, and J. R. Maynard, J. Org. Chem., 34, 2022 (1969).
197. L. L. Replogle, R. M. Arluck, and J. R. Maynard, J. Org. Chem., 30, 2715 (1965).
198. A. G. Anderson, E. J. Cowles, J. J. Tazuma, and J. A. Nelson, J. Amer. Chem. Soc., 77, 6321 (1955).
199. V. A. Nefedov, Zhur. Obshch. Khim., 38, 3191 (1968).
200. W. Treibs and K. Gründel, Chem. Ber., 91, 143 (1958).
201. A. G. Anderson and J. A. Nelson, J. Amer. Chem. Soc., 72, 3824 (1950).
202. Y. Ohtani, K. Kawase, and K. Nakamura, Yakugaku Zasshi, 91, 674 (1971); Chem. Abs., 75, 63 485 (1971).
203. J. H. Franke and M. Mühlstädt, J. prakt. Chem., 35, 249 (1967).
204. K. Takase and T. Nozoe, Jap. P. 12 502 (1965); Chem. Abs., 63, 13 181 (1965).
205. W. Ried and W. Kunstmann, Chem. Ber., 102, 1431 (1969).
206. B. Föhlisch and P. Bürgle, Annalen, 705, 164 (1967).
207. W. Treibs, Naturwiss., 48, 378 (1961).
208. J. H. Franke and M. Mühlstädt, J. prakt. Chem., 35, 262 (1967).
209. E. C. Kirby and D. H. Reid, Tetrahedron Letters, 1 (1960).
210. A. K. Sheinkman, G. V. Samoilenko, S. N. Baranov, and N. R. Kal'nitskii, Khim. Geterotsikl. Soed., 1368 (1975).
211. A. K. Sheinkman, G. V. Samoilenko, and S. N. Baranov, Zhur. Obshch. Khim., 70, 413 (1958).
212. K. Hafner, Angew. Chem., 70, 413 (1958).
213. D. H. Reid, W. H. Stafford, W. L. Stafford, G. McLenan, and A. Voigt, J. Chem. Soc., 1110 (1958).
214. K. Hafner, H. Pelster, and J. Schneider, Annalen, 650, 62 (1961).
215. F. N. Stapanov and N. A. Aldanova, Zhur. Obshch. Khim., 29, 339 (1959).
216. H. Arnold and K. Pahls, Chem. Ber., 89, 121 (1956).
217. W. Treibs and A. Bhramaramba, Tetrahedron, 8, 165 (1966).
218. E. C. Kirby and D. H. Reid, J. Chem. Soc., 494 (1960).
219. Studiengesellschaft Kohle m.b.H., B. P. 971 913 (1964); Chem. Abs., 62, 504 (1965).
220. E. J. Poppe and W. Treibs, Naturwiss., 45, 517 (1958).
221. W. Treibs, R. Zimmer-Goller, and C. Jutz, Chem. Ber., 93, 2542 (1960).
222. E. C. Kirby and D. H. Reid, J. Chem. Soc., 3579 (1961).
223. K. Hafner and H. Pelster, Angew. Chem., 72, 781 (1960).
224. C. Jutz, BRD P. 1 079 629 (1960); Chem. Abs., 55, 19 883 (1961).
225. F. N. Stepanov and A. G. Yurchenko, Zhur. Obshch. Khim., 34, 901 (1964).
226. M. Saito, T. Morita, and K. Takase, Chem. Letters, 289, 307, 955 (1974).
227. W. Treibs, M. Mühlstädt, and K. D. Köhler, Naturwiss., 45, 336 (1958).
228. M. Mühlstädt, W. Treibs, and J. Mohr, Chem. Ber., 94, 808 (1961).
229. K. Hafner and W. Senf, Annalen, 656, 34 (1962).
230. K. Hafner, BRD P. 1 064 509 (1959); Chem. Abs., 55, 15448 (1961).
231. J. O. Currie, R. A. LaBar, R. D. Breazeale, and A. G. Anderson, Annalen, 166 (1973).
232. A. G. Anderson and R. C. Rhodes, Org. Prep. Proceed., 1, 249 (1969).
233. W. Treibs and K. El Azem, Annalen, 740, 112 (1970).
234. W. Treibs, Naturwiss., 47, 156 (1960).
235. S. Itô, H. Takeshita, and T. Makino, Bull. Chem. Soc. Japan, 44, 1982 (1971).
236. A. G. Anderson and R. G. Anderson, J. Org. Chem., 27, 3578 (1962).
237. A. G. Anderson, R. G. Anderson, and L. L. Replogle, Proc. Chem. Soc., 72 (1960).
238. W. Treibs, H. Orttmann, R. Schlimper, and C. Lindig, Chem. Ber., 92, 2152 (1959).
239. D. H. Reid, W. H. Stafford, and W. L. Stafford, J. Chem. Soc., 1118 (1958).
240. W. Treibs and H. Orttmann, Naturwiss., 45, 85 (1958).
241. W. Treibs and B. Streckenbach, Chem. Ber., 94, 1734 (1961).
242. W. Treibs, Naturwiss., 47, 179 (1960).
243. A. G. Anderson and L. L. Replogle, J. Org. Chem., 28, 2578 (1963).
244. K. Hafner, H. Pelster, and H. Patzelt, Annalen, 650, 80 (1961).
245. W. Treibs, A. Hiebsch, and H. J. Neupert, Naturwiss., 44, 352 (1957).

246. K. Hafner and C. Bernhard, Angew. Chem., 69, 533 (1957).
247. K. Hafner and C. Bernhard, BRD P. 1 059 447 (1957); Chem. Abs., 55, 7379 (1961).
248. K. Hafner and C. Bernhard, Annalen, 625, 108 (1959).
249. M. Miyazaki, M. Hashi, and C. Ukita, Chem. and Pharm. Bull. (Japan), 8, 140 (1960).
250. Yu. N. Porshnev and M. I. Cherkashin, Izv. Akad. Nauk SSSR, Ser. Khim., 2322 (1975).
251. Yu. N. Porshnev and E. M. Tereshchenko, Zhur. Org. Khim., 11, 701 (1975).
252. Yu. N. Porshnev and E. M. Tereshchenko, Zhur. Org. Khim., 11, 462 (1975).
253. A. G. Anderson and R. D. Breazeale, Org. Prep. Proced., 1, 117 (1969).
254. J. Brunken and E. J. Poppe, Chem. Ber., 93, 2572 (1960).
255. E. C. Kirby and D. H. Reid, J. Chem. Soc., 163 (1961).
256. E. C. Kirby and D. H. Reid, J. Chem. Soc., 1724 (1961).
257. M. Scholz, D. Klötzel, W. May, and M. Mühlstädt, Z. Chem., 5, 237 (1965).
258. R. N. McDonald and W. S. Stewart, J. Org. Chem., 30, 270 (1965).
259. G. N. Dorofeenko, Yu. A. Zhdanov, A. D. Semenov, V. A. Palchkov, and S. V. Krivun, Zhur. Obshch. Khim., 36, 1728 (1966).
260. K. Kohara, Bull. Chem. Soc. Japan, 42, 3229 (1969).
261. T. Fujita, T. Morita, and K. Takase, Tetrahedron Letters, 2585 (1974).
262. Belg. P. 612 288 (1962); Chem. Abs., 57, 15 034 (1962).
263. N. Abe and K. Takase, Tetrahedron Letters, 4739 (1973).
264. L. L. Replogle, K. Katsumoto, and T. C. Morrill, Tetrahedron Letters, 1877 (1965).
265. M. Scholz, L. N. Vien, G. Fischer, B. Tschapke, and M. Mühlstädt, Chem. Ber., 100, 375 (1967).
266. T. Nozoe, T. Asao, H. Susumago, and M. Ando, Bull. Chem. Soc. Japan, 47, 1471 (1974).
267. T. Nozoe, K. Takase, and M. Toda, Bull. Chem. Soc. Japan, 38, 247 (1965).
268. T. Masao, Bull. Chem. Soc. Japan, 39, 1954 (1966).
269. R. D. Brown, Quart. Rev., 6, 63 (1952).
270. W. Treibs, Annalen, 603, 149 (1957).
271. J. F. Tilney-Bassett and W. A. Waters, J. Chem. Soc., 2123 (1959).
272. T. Yshigami, T. Akiyama, H. Watanabe, T. Kato, and A. Sugimori, Chem. Comm., 871 (1973).
273. A. G. Anderson and R. C. Rhodes, J. Org. Chem., 30, 1616 (1965).
274. Yu. N. Porshnev and E. M. Tereshchenko, Zhur. Org. Khim., 9, 641 (1973).
275. Yu. N. Porshnev and E. M. Tereshchenko, Zhur. Org. Khim., 8, 1992 (1972).
276. Yu. N. Porshnev, E. M. Tereshchenko, V. A. Dobryak, and K. Z. Ogorodnik, Zhur. Org. Khim., 9, 1078 (1973).
277. C. M. Lok, J. Lugtenburg, J. Cornelisse, and E. Havinga, Tetrahedron Letters, 4701 (1970).
278. C. M. Lok, M. E. de Boer, J. Cornelisse, and E. Havinga, Tetrahedron, 29, 867 (1973).
279. P. A. Plattner, Helv. Chim. Acta, 24, 283E (1941).
280. W. T. House and M. Orchin, J. Amer. Chem. Soc., 82, 639 (1960).
281. P. A. Plattner, A. Fürst, M. Gordon, and K. Zimmermann, Helv. Chim. Acta, 33, 1910 (1950).
282. W. Herz, J. Amer. Chem. Soc., 75, 73 (1953).
283. W. Herz, J. Amer. Chem. Soc., 80, 1243, 3139 (1958).
284. Yu. N. Porshnev, E. M. Tereshchenko, and K. Z. Ogorodnik, Zhur. Org. Khim., 8, 2201 (1972).
285. Yu. N. Porshnev, N. A. Andronova, E. M. Tereshchenko, and K. Z. Ogorodnik, Zhur. Org. Khim., 10, 2602 (1974).
286. S. Kurokawa, Tetrahedron Letters, 3567 (1969).
287. S. Kurokawa, T. Sato, T. Noguchi, and K. Yano, Bull. Chem. Soc. Japan, 48, 1559 (1975).
288. K. H. Anell, Arzneim.-Forsch., 5, 721 (1955).
289. H. Willstaedt and B. Zetterberg, Svensk kem. Tidskr., 58, 306 (1946).
290. U. Bogs and J. Meinhard, Pharmazie, 10, 653 (1955).
291. W. Heubner and W. Albath, Arch. exp. Path. Pharmakol., 192, 383 (1939).
292 F. Jung, H. Arnold, W. Schoetensack, and G. Bruno, Klin. Wochenschr., 27, 571 (1949).
293. P. Zierz and W. Kiessling, Deut. med. Wochenschr., 78, 166 (1953).
294. K. L. Schmidt, Strahlentherapie, 94, 2 (1954).
295. H. Schindler, BRD P. 1 227 896 (1966); Chem. Abs., 66, 28 585 (1967).
296. B. P. 1 081 647 (1967); Chem. Abs., 68, 69 209 (1968).
297. A. J. Frey and E. E. Galantay, US P. 3 459 806 (1969); Chem. Abs., 71, 112 694 (1969).
298. A. J. Frey and E. E. Galantay, US P. 3 526 665 (1970); Chem. Abs., 73, 109 585 (1970).
299. S. Blaszo, Schweiz. med. Wochenschr., 81, 110 (1951).
300. F. J. Ertzinger, French P. M4204, M4205 (1966); Chem. Abs., 67, 84 832 (1967).
301. I. G. Boldina, Farmakol. Toksikol., 29, 672 (1966).
302. F. J. Ertzinger, French P. M4110 (1966); Chem. Abs., 68, 33194 (1968).
303. M. A. Kraul and F. Schmidt, Arch. Pharm., 290, 66 (1957).
304. K. Takase and T. Nozoe, Jap. P. 12 501 (1965); Chem. Abs., 63, 13 181 (1965).
305. K. Hafner, Annalen, 606, 79 (1957).
306. B. Sanquirico, Rev. ital. Essenze, Profumi, Piante offic., Olii veget., Saponi, 41, 224 (1959).
307. T. J. Speaker and G. D. Redman, J. Pharm. Sci., 55, 479 (1966).
308. P. H. Doukas and T. J. Speaker, J. Pharm. Sci., 60, 184 (1971).
309. H. Mathiees and M. Böhme, Med. Monatsschr., 14, 517 (1960).
310. N. P. Buu Hoi, Hoi Nguyen Ba Giao, and C. Jutz, Naturwiss., 57, 499 (1970).
311. H. Dannenberg, Z. Krebsforsch., 33, 102 (1960).
312. G. Fischer and E. J. Poppe, Veröff. wiss. Photo-Lab. Wolfen, 10, 123 (1965).
313. T. Y. Sonnonstine, A. Wiglesworth, and A. M. Hermann, J. Chem. Phys., 59, 3865 (1973).
314. A. K. Sheinkman and G. V. Samoilenko, USSR P. 434 076 (1972); Byull. Izobr., No. 24, 38 (1974).
315. E. Sawicki, T. W. Stanley, and J. Pfass, Chemist-Analyst, 51, 9 (1962).

Lomonosov Moscow Institute of
Fine Chemical Technology