

STRUCTURAL PATTERNS OF POLYACETYLENIC COMPOUNDS ISOLATED FROM THE PLANT FAMILY COMPOSITAE

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INTRODUCTION

The Compositae constitute one of the largest plant Families. No modern botanical treatment of the whole family exists, but a simplified survey of the Family, taken from the 70 years' old review by Hoffmann¹, is given in *Table I*. A few ordinary garden flowers or well-known weed genera are mentioned as examples, and, for simplification, some trivial tribus-designations are also given. Most botanists agree on a division of the Family into

Table I. Simplified survey of the Family of the Compositae

<i>Botanical Tribus</i>	<i>Common Genus</i>	<i>Trivial Tribus Designation</i>	<i>Approximate Number of Genera in Tribus</i>
I Vernoniaeae	<i>Vernonia</i>	Ironweeds	41
II Eupatoriaceae	<i>Eupatorium</i>	Thoroughworts	42
III Astereae	<i>Aster</i> (<i>Solidago</i>) (<i>Bellis</i>)	Aster (Goldenrods) (Daisy)	99
IV Inuleae	<i>Gnaphalium</i> <i>Antennaria</i> (<i>Inula</i>)	Everlastings	152
V Heliantheae	<i>Helianthus</i> (<i>Dahlia</i>) (<i>Cosmos</i>) (<i>Bidens</i>) (<i>Coreopsis</i>)	Sunflowers	144
VI Helenieae	<i>Helenium</i> (<i>Tagetes</i>)	Sneezeweeds (African Marigolds)	55
VII Anthemideae	<i>Chrysanthemum</i> (<i>Artemisia</i>) (<i>Matricaria</i>)	Chrysanthemum	49
VIII Senecioneae	<i>Senecio</i>	Groundsel	51
IX Calenduleae	<i>Calendula</i>	Marigolds	8
X Arctotideae	<i>Arctotis</i>		11
XI Cynareae	<i>Centaurea</i> (<i>Cirsium</i>) (<i>Arctium</i>)	Thistles	34
XII Mutisieae	<i>Gerbera</i>	Gerbera	57
XIII Cichorieae	<i>Taraxacum</i> (<i>Hieracium</i>)	Dandelions	63

Total: 806

13 tribes. It will be seen that, in 1889, the 13 tribes of the Compositae comprised more than 800 genera. Although monotypic genera also exist in the Compositae, most of the genera contain numerous species: some, for example *Senecio*, have more than 1000, and many contain more than 200 well-defined species. The definition of species in some cases, e.g. *Taraxacum* (dandelions) and *Hieracium* (hawkweeds), is among the most dubious known to botanists. Clearly no exact statement can be given of the number of species; depending on personal choice of definition, the number will be somewhere between 15,000 and 100,000. Perhaps some 250–300 good species have been investigated for the occurrence of acetylenic compounds. I hope this fact will show you the caution we shall have to exercise in taxonomic application of our really very preliminary results.

The botanist has long since used a phytochemical characteristic, the ability to produce a milksap, to divide Tribus XIII Cichorieae, to which both the dandelions and hawkweeds belong, from the rest of the Family. As far as present investigations go, this tribe seems to be devoid of the enzymatic systems leading to polyacetylenes, and so we can leave them out of consideration.

TYPES OF ACETYLENIC COMPOUNDS

Carboxylic acids

Derivatives of acids, viz. methyl esters and isobutylamides, constitute the simplest types of acetylenic compounds found in the Compositae.

In a pocketbook for chemists and druggists edited in 1826² by Bretz and Elieson, it is stated that the essential oil from the root of European mugwort, *Artemisia vulgaris*, deposits yellow crystals in the cold. For more than 100 years no chemist took interest in these crystals, and so the first observation of naturally occurring polyacetylenic compound in the solid state remained unheeded. In 1950, these slightly yellow crystals were shown by my collaborators to be the 2-methyldec-2-*cis*-ene-4,6,8-triynoate³, which was given the trivial name *cis*-dehydro-matricaria ester. Its constitution, together with those of the six other members of this series so far isolated from higher plants, is given in *Table 2*.

My naming of these esters may be heavily criticized. The 2-*cis*, 8-*cis*-matricaria ester has been found most abundantly and most frequently, and so this compound was named after *Matricaria inodora* L. (= *M. maritima* L.), the common scentless mayweed.

I prefer to retain a trivial name for the 8,9-dihydro- esters. The *cis*-isomer was isolated in 1935 by Viljams, Smirnov and Goljmov⁴ from the essential oil of *Lachnophyllum gossypinum* Bge. These Russian scientists established the constitution unambiguously with the aid of classical degradation methods. The *cis*-lachnophyllum ester was the first naturally occurring diacetylenic compound whose structure was elucidated. It is also most unusual in being a polyacetylenic compound which has been used in industry. Local Russian perfume industries transformed the odourless *cis*-lachnophyllum ester into soap perfumes by treatment with weak alkali. Curiously enough, these perfumes are still of unknown constitution.

STRUCTURAL PATTERNS OF POLYACETYLENES FROM THE COMPOSITAE

Table 2. Acetylenic-C₁₀ methyl esters from Compositae

Constitution of ester	Trivial name of ester	Genera in which ester has been found
H ₃ C·CH ₂ ·CH ₂ ·C:C·C:C·C·CH:CH·COOCH ₃	<i>cis</i> -lachnophyllum ester ⁴ <i>trans</i> -lachnophyllum ester ⁵	{ <i>Lachnophyllum</i> <i>Erigeron</i> <i>Bellis</i>
H ₃ C·CH:CH·C:C·C:C·C·CH:CH·COOCH ₃	2- <i>cis</i> ,8- <i>cis</i> -matricaria ester ⁶ 2- <i>trans</i> ,8- <i>cis</i> -matricaria ester ⁷	{ <i>Matricaria</i> (<i>Tripleurospermum</i>) <i>Erigeron</i> <i>Matricaria</i> (<i>Tripleurospermum</i>) <i>Amellus</i>
H ₃ C·CH:CH·C:C·C:C·C·CH ₂ ·CH ₂ ·COOCH ₃	8- <i>cis</i> -α,β-dihydro-matricaria ester ⁷	{ <i>Matricaria</i> (<i>Tripleurospermum</i>) <i>Amellus</i>
H ₃ C·C:C·C:C·C:C·C·CH:CH·COOCH ₃	<i>cis</i> -dehydro-matricaria ester ³ <i>trans</i> -dehydro-matricaria ester ⁸	{ <i>Artemisia</i> <i>Achillea</i> <i>Matricaria</i> (<i>Tripleurospermum</i>) <i>Achillea</i>

The compilation in Table 2 demonstrates that the configuration at the ethylenic bonds in these esters is frequently *cis*. The stability of the *cis*-configuration in these esters is remarkable; they remain unchanged when treated with iodine in the presence of light according to the standard techniques of isomerizing *cis*-carotenoids. Only the classical techniques for producing the light-induced equilibration of *trans*-stilbene with *cis*-stilbene cause a partial transformation, the conversion in this instance being from 2-*cis* to 2-*trans*.

In some of the Compositae, only *cis*-isomers occur; but others have mixtures of *cis*- with minor amounts of *trans*-isomers, and sometimes *trans*-dehydro-matricaria ester may even be found stereochemically pure. All these facts indicate that the *cis*- and *trans*-isomers are genuine components of these plants. It should be mentioned, however, that some of the crude chromatographic fractions show a rather strong allene peak at 1960 cm⁻¹, and, at least in the daisy, *Bellis perennis*, there occur components which give free *trans*-lachnophyllum acid on saponification⁵. These components have never been found in amounts sufficient for final purification, but, according to spectrographic studies, both the conjugated system of lachnophyllum acid and the *trans*-double-bond are produced during the saponification. I have mentioned this preliminary work on the acetylenes of the daisy to emphasize my belief that my collaborators have not as yet encountered all the variations which the Compositae produce on the simple theme of unsaturated C₁₀-acids.

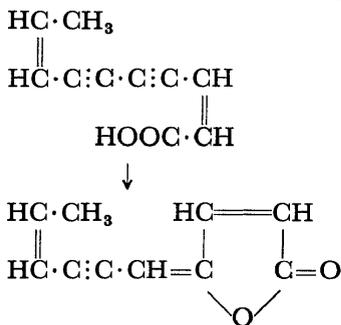
The methyl esters in Table 2, however, are easily recognized compounds; some of them crystallize extremely readily, and most of them possess very characteristic ultra-violet light absorption properties. In spite of this, these esters have so far only been isolated from 2 of the 13 tribes of the Compositae: *viz.*, III Astereae and VII Anthemideae. Although caution is necessary at this early stage of our investigation, I am inclined to

believe that this fact is connected with the taxonomic division of the Family. In the Aster tribe III, the few acetylenes found have all been C₁₀-compounds; but in the Chrysanthemum tribe VII, many different types of acetylenes have been found, with 10, 12, 13, 14, 15 and 17 carbon atoms per molecule.

Although investigations for acetylenic compounds in other plant Families have been few and accidental, it is remarkable that, so far, these compounds have been encountered only in the Basidiomycete group of the higher fungi, instanced by the finding of Jones and his collaborators that 2-*trans*,8-*trans*-matricaria ester is present in *Polyporus anthracophilus*⁹, and *trans*-dehydromatricaria acid in *Pleurotus ulmarius*¹⁰.

In the culture medium of these fungi, the acetylenic acids occur to some extent as methyl esters, but mostly as free acids. That free acids are synthesized also in the Compositae became clear when Christensen, in collaboration with the Jones school, elucidated the constitution of the so-called "Composit-cumulene I"¹¹ which was isolated in my laboratory in 1950 as a crude liquid from the leaves of scentless mayweed (see *Figure 1*, curve B). At that time I supposed it to be both a pure compound and a cumulene, though in fact it was neither.

In 1953 Miss Holme was able to isolate the main constituent of "Composit-cumulene I" as a few mg of a crystalline compound, m.p. 35.5°, from a *Chrysothamnus* species (see *Figure 1*, curve A). In connection with efforts to synthesize the naturally occurring 2-*cis*-isomers of the lachnophyllum, matricaria and dehydromatricaria esters, Bell, Jones and Whiting observed a rapid formation of lactones from the *cis*-acids in sodium bicarbonate solution. Christensen¹³ demonstrated that the 2-*cis*,8-*cis*-matricaria acid lactonizes very rapidly in all polar solvents, and that the transformation in water is completed in a few minutes at room temperature:



Hence, it is obvious that the free 2-*cis*-4-ynoic acids will never be found in a biological medium. The corresponding lactone from *cis*-lachnophyllum acid is a liquid. Christensen has demonstrated its presence in some of those Compositae which are rich in the corresponding ester, e.g. *Boltonia asteroides* (L.) L'Her and *Erigeron acris *rigidus* Fr.¹⁴.

Clearly the free acetylenic acids are also produced by the higher plants, but lactonization prevents them accumulating and, as is clear from *Figure 1*, causes spectral changes which hamper recognition of their acetylenic nature.

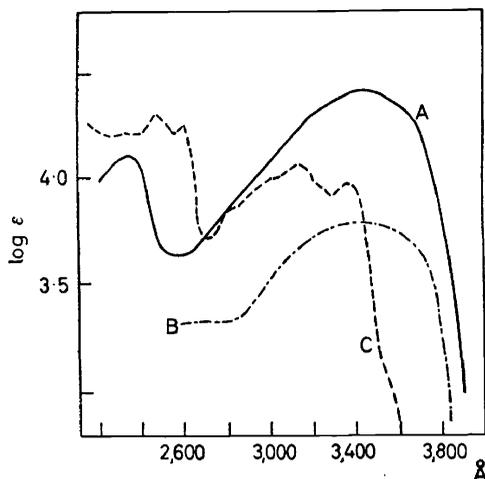
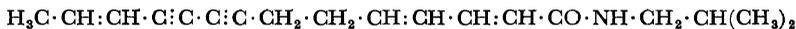


Figure 1. Ultra-violet light absorption spectra in hexane of: A. 4-hydroxy-deca-2,4,8-trien-6-ynoic acid, γ -lactone; B. "Composit-cumulene I", according to Sørensen and Stavholt¹¹; C. *cis,cis*-matricaria ester

The only other derivatives of acetylenic acids isolated from Compositae are isobutylamides. As a result of the work of Crombie, anacyclin and dehydro-anacyclin (two of the insecticidal compounds of the *Anacyclus pyrethrum* D.C. extract) have been shown to contain acetylenic bonds.



Anacyclin



Dehydro-anacyclin

The most potent isobutylamides known at the moment are those which have purely ethylenic unsaturation, but, on examination of side-fractions during systematic research on the isolation of potent insecticidal principles, co-existing acetylenic compounds may be discovered.

I might add that such compounds as anacyclin are also easily overlooked for two other reasons. Firstly, their acetylenic chromophore does not give rise to any readily recognizable strong band in the ultra-violet light absorption spectrum; and, secondly, the extraction of these amides requires rather special solvents. According to biological work, many members of the Compositae have a pyrethrum-effect similar to the isobutylamides, and so there is a distinct possibility that the acetylenic isobutylamide group is much more widespread than we appreciate today.

From a purely chemical point of view, the most interesting fact is the chain length and the degree of unsaturation. By both tokens anacyclin and dehydro-anacyclin are intermediate between the ordinary unsaturated fatty acids and the C_{10} -acids of the Compositae.

Alcohols

None of the other classes of acetylenic compounds are as simple as the carboxylic acids. Whereas the Basidiomycetes studied by the Jones school

very often produce a methyl ester as well as the free carboxylic acid and the corresponding primary alcohol, this has never been observed in higher plants.

As will be seen from *Table 3*, which gives a compilation of the primary alcohols isolated in my laboratory from Compositae, the alcohol corresponding to the matricaria ester has been found in two stereoisomeric forms, only one of them (the *2-trans,8-cis*) corresponding to the configuration of the methyl esters.

Table 3. Esters of acetylenic alcohols isolated from the Compositae

Constitution of acetylenic alcohol	Stereochemistry	Genus
$H_3C \cdot CH : CH \cdot C : C \cdot C : C \cdot CH : CH \cdot CH_2 \cdot O \cdot COCH_3$	$\left\{ \begin{array}{l} 2\text{-trans,8-trans} \\ 2\text{-trans,8-cis} \end{array} \right.$	<i>Aster</i>
$H_3C \cdot CH : CH \cdot C : C \cdot CH : CH \cdot CH : CH \cdot CH_2 \cdot O \cdot COCH_3$		<i>Xanthisma</i>
$H_3C \cdot C : C \cdot C : C \cdot CH : CH \cdot CH : CH \cdot CH : CH_2 \cdot CH_2 \cdot O \cdot COCH_3$	4-cis	<i>Brachycome</i>
$H_3C \cdot CH : C : C \cdot C : C \cdot C : C \cdot G : G \cdot CH : CH \cdot CH_2 \cdot O \cdot COCH_3$	5-cis	<i>Matricaria</i>
$H_2C : CH \cdot C : C \cdot C : C \cdot C : C \cdot CH : CH \cdot CH_2 \cdot O \cdot COCH_3$	trans	<i>Coreopsis</i>
$H_2C : CH \cdot CH : CH \cdot C : C \cdot C : C \cdot C : C \cdot CH : CH \cdot CH_2 \cdot O \cdot COCH_3$	10-cis	<i>Carlina</i>
 $-C : C : C : CH : CH \cdot CH_3 \cdot O \cdot COCH_3$	trans	<i>Coreopsis</i>

The matricarianol acetates have been isolated from certain members of the large genus *Aster*; they are especially abundant in *Grindelia* and *Xanthisma*. In the Compositae, the occurrence of these acetylenic alcohols seems to give clear-cut taxonomic clues. Morphologically similar species from different genera can be divided according to the type of C_{10} -acetylenes present. As an example I may mention *Erigeron peregrinus* (Pursh) Green and *E. salsuginosus* **glacialis* Gray. These are stated by most modern botanists to be closely related. Earlier botanists classified them in the genus *Aster*, but present-day authorities have transferred both to *Erigeron*. Since *E. peregrinus* contains, in all parts of the plant, *cis,cis*-matricaria ester together with small amounts of *cis*-lachnophyllum ester, it can be classified on a chemical basis as a genuine fleabane (*i.e.* *Erigeron*). *E. salsuginosus* **glacialis* contains *trans,trans*-matricarianol, and this only in the root, so that the chemist's answer this time is *Aster*¹⁸.

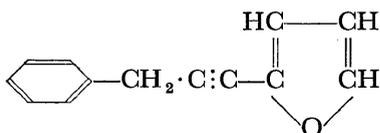
Most of the other acetylenic alcohols bear no relation to the naturally occurring acids, but are more closely related to the acetylenic hydrocarbons. This will be obvious from *Table 4*, which summarizes the remarkable results which Bohlmann²² in Braunschweig has achieved with the "Centaur X" and "Y" compounds. These compounds were first discovered in cornflower extracts by Løfgren²³ in Stockholm. The two C_{13} -hydrocarbons had been isolated earlier by my wife from some *Coreopsis* species^{21, 24}. The "3915"-hydrocarbon, which is found both as the *cis*- and the *trans*-isomers, is one of the most widely distributed acetylenic hydrocarbons in this plant Family, and one of those which occurs in reasonable amounts. Some species contain polar fractions which possess the same chromophore and which show peaks in the infra-red absorption spectrum which are characteristic of an acetyl group. Only once has the ester responsible been obtained pure; it is possible that higher homologues may occur in other cases, but this has not yet been proven.

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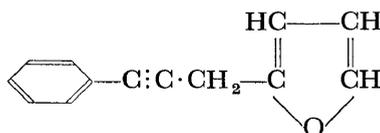
The second hydrocarbon in *Table 4* may be regarded as the parent compound of the acetate found by my wife in *Carlina vulgaris* (substitution of the methyl group), and also of the three derivatives of the C₁₃-glycol and chlorohydrin which are also shown in *Table 4*. These three chlorohydrin and α-glycol derivatives are supposed by Bohlmann to originate from epoxides. Acetylenic epoxides have so far been observed only in fungi²⁵; although some evidence exists for their presence in *Achillea*, definite proof of this is still lacking²⁶.

Of special interest in Bohlmann's elucidation of the cornflower polyacetylenes are the 1,3-glycol derivatives in the C₁₅-class, and the C₁₇-hydrocarbons. The latter, in chain-length and unsaturation, somewhat resemble the toxins from the umbelliferous plants *Oenanthe* and *Cicuta*, the constitutions of which were elucidated by the elegant work of Lythgoe and his group in Cambridge²⁷.

But let us return to the alcohol which results when a hydroxyl group is introduced into the methyl group of the 1,3,11-triene-5,7,9-triyne. As the acetate, this primary alcohol was found in one of the carline thistles, *Carlina vulgaris evulgaris* Holmboe, by my wife²⁰, who also established its constitution. The carline thistles are, however, the plant genus where naturally occurring acetylenes were originally found in the Compositae more than 60 years ago. Semmler isolated the main component of the essential oil of *Carlina acaulis* in 1889²⁸. He named it carlina oxide, established the formula C₁₂H₁₀O and restricted the constitutional possibilities to the three given:

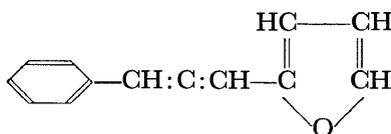


(I)



(II)

Carlina oxide

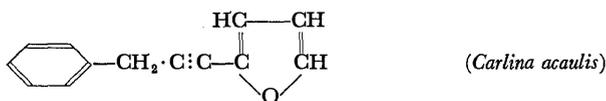
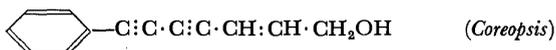
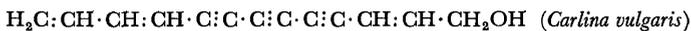


(III)

Faced with these alternatives, Semmler made the following statement: "Es ist von Hause aus sehr unwahrscheinlich, dass eine acetylenartige Verbindung vorliegt, sondern wir werden es mit der Verbindung (III) zu tun haben"; and it was not until the work of Gilman³⁰ in 1933, and of Pfau and his co-workers³¹ in 1935, that formula (I) was proven for carlina oxide.

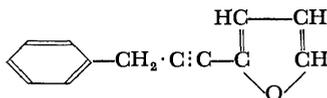
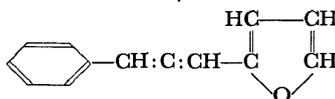
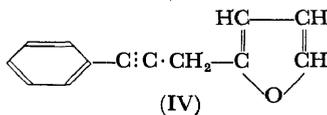
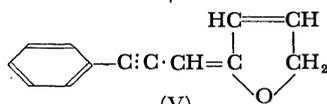
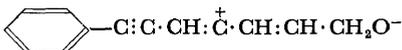
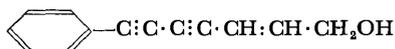
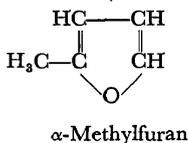
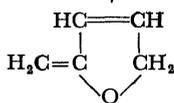
Carlina oxide, C₁₂H₁₀O, is isomeric with the tridecatrienetriynol isolated by my wife from *C. vulgaris*, and a third isomer is the phenylhept-

enediynol isolated as a crystalline acetate from several *Coreopsis* species by my collaborators²¹:



Jones pointed out at once that this *Coreopsis* alcohol, was, so to speak, an intermediate in the formation of carlina oxide from an aliphatic precursor.

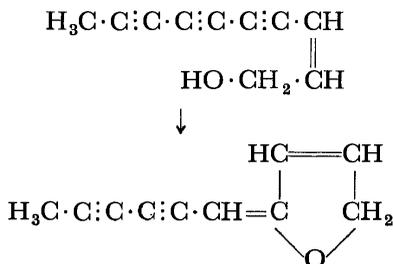
The smooth transformation of *trans*-pentenediynol with acids into α -methylfuran (see below) was realized by Heilbron³² in 1946. The expected transformation of the *Coreopsis* alcohol into iso-carlina oxide (IV), and thence through the Semmler allene formula to carlina oxide is given by:



Carlina oxide

Unfortunately, however, all efforts by the Jones group to cyclize the *trans*-isomer of phenylheptenediynol were in vain. In his recent Pedler lecture³³,

Christensen regards it as being the cyclization product of *cis*-dehydro-matricarianol:

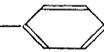


The *cis*-dehydro-matricarianol has not so far been found in nature, but I should be the first to admit that this fact may be my own fault; the *trans*-isomer has been isolated by the Jones group from the fungus *Pleurotus ulmarius*¹⁰. Thus the formation of heterocycles seems to be just as dependent on a 2-*cis*-configuration in the enyne alcohols as in the acids.

Hydrocarbons

As to the acetylenic hydrocarbons occurring in the Compositae, I have not much to add to the review which has already been given of Bohlmann's work on the cornflower acetylenes (*Table 4*). All hydrocarbons isolated in my own laboratory are C₁₃-compounds, and are listed in *Table 5*.

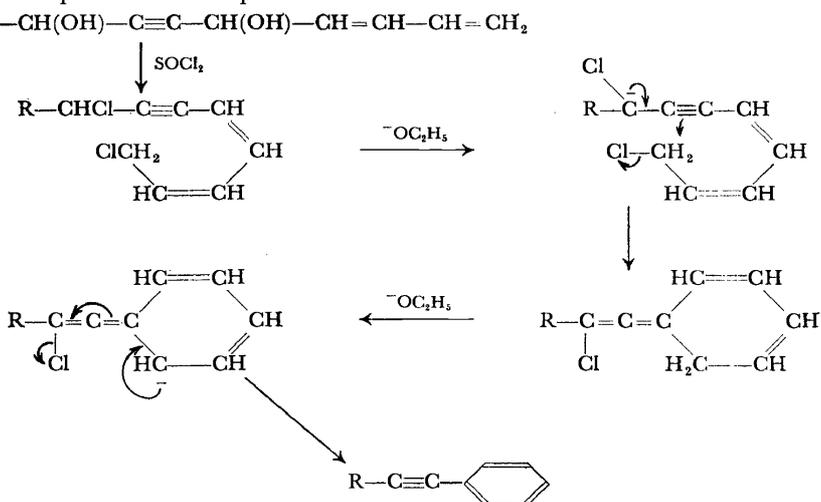
Table 5. Acetylenic hydrocarbons in Compositae (except *Centaurea*)

<i>Constitution of acetylenic hydrocarbon</i>	<i>Stereochemistry</i>	<i>Code no.</i>
H ₃ C·C:C:C:C:C:C:C:C:CH:CH ₂		" 4100 "
H ₃ C·CH:CH:C:C:C:C:C:C:C:C:CH:CH ₂	{ 11- <i>cis</i> 11- <i>trans</i> 3- <i>cis</i>	" 3915 "
H ₃ C·CH:CH:C:C:C:C:C:C:C:CH:CH:CH:CH ₂		
H ₃ C·CH:CH:C:C:C:C- 		
H ₃ C·C:C:C:C:C:C- 		
H ₃ C·CH:CH:C:C:C:C:CH:CH:CH:CH:CH:CH ₂		

The structure of the "4100"-hydrocarbon, our only naturally occurring penta-acetylene so far, has been confirmed synthetically by the Jones group³⁵. It forms yellow crystals which are stable for only a few minutes at room temperature. In the plant or in dilute solution the stability is surprising; it may still be found in dried plants which have been stored for months at room temperature. We have, however, never found this pentayne in any large quantity. It has been isolated in the solid state from about a dozen plants; in the numerous other cases where the very characteristic spectrum has been encountered, there is no proof that the enepentayne chromophore is not present in a longer aliphatic chain.

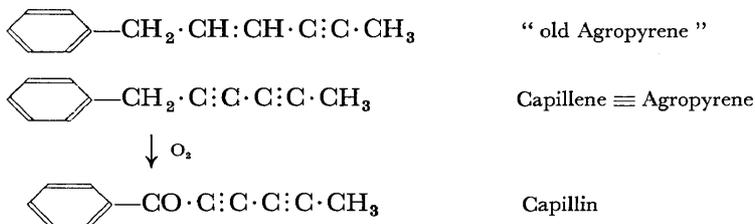
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Two of our hydrocarbons contain the phenyl residue, the first one bearing just the same relation to the foregoing aliphatic compound as the *Carlina vulgaris* alcohol to the *Coreopsis* alcohol. Without delving into the fascinating question of whether Compositae are able to transform a dienyne chain directly into a benzene ring, or whether both originate from a common oxygen-containing precursor. I should like to mention that, when Skattebøl and Sørensen³⁷ tried to synthesize the aliphatic trideca-1,3,11-triene-5,7,9-triyn, he obtained the phenylhept-5-ene-1,3-diyne as the main reaction product. The procedure which was selected:



is a standard route to polyacetylenes, and the cyclization seems to be a general reaction when the molecule contains a terminal butadienyl residue.

Beside carlina oxide itself, the capillene-agropyrene series constitute the classical phenylacetylenes of the Compositae. The constitutions of the three members known are given by:



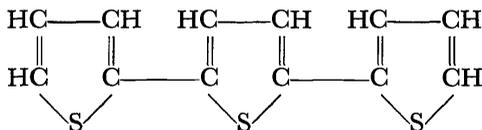
and their somewhat confused history may be summarized as follows. In 1922 Schimmel & Co.³⁸ prepared a sample of the essential oil of couchgrass, *Agropyron repens* (L.) PB. This oil was investigated by Treibs in 1944, and the main compound was stated by him to have the constitution which I have named “ old agropyrene ”³⁹. Meanwhile, early in 1920, Japanese chemists started work on the essential oil of the fungicidal mugwort *Artemisia capillaris*. In 1930, Arima and Okamoto⁴⁰ isolated a hydrocarbon “ capillene ” from this source and formulated it as C₁₃H₁₄. In 1954 this hydrocarbon was again isolated, by Harada⁴¹, who proposed a C₁₂-formula.

Harada at first supposed capillene to be an isomer of "old agropyrene", but, in a 1957 paper⁴², he corrected the formula to $C_{12}H_{10}$ and proved the structure given for capillene by synthesis. During the same period, Imai⁴³ and his collaborators isolated the fungicidal principle of *A. capillaris*. This they named capillin, and again the structure was confirmed by synthesis. In the meantime (1954), Cymerman-Craig⁴⁴ had synthesized the *trans*-isomers of "old agropyrene", and the properties of the synthetic compound indicated that the couch-grass compound could hardly have the constitution indicated by Treibs. In collaboration with Treibs, Cymerman-Craig in 1959 proved the identity of capillene and the couch-grass acetylene, and at the same time demonstrated the smooth autoxidation of capillene into capillin.

The reason that "old agropyrene" has not been omitted from the list is a paper published in 1958 by Goljmov and Afanesev⁴⁵. These authors isolated from the Russian mugwort, *Artemisia scoparia*, two hydrocarbons: one, $C_{12}H_{10}$, which was identical with capillene; the other, $C_{12}H_{12}$, which was stated to have the formula of "old agropyrene". An interesting point is that so far no C_{12} -aliphatic acetylene has been isolated from a mugwort. The only C_{12} -compound known from botanically related plants is a mono-thiophene, possibly derived from a parent hydrocarbon $C_{12}H_8$.

Thiophenes

The thiophenic acetylenes discovered in recent years appear to constitute one of the largest groups of naturally occurring acetylenes. The isolation, by Zechmeister and Sease in 1947, of terthienyl from a special variety of the African Marigold, *Tagetes erecta*, provided the first representative of this class:



Terthienyl itself apparently has no relation at all to aliphatic acetylenes. It is, however, noteworthy that Challenger and Holmes⁴⁶ suggested in 1953 that there should be a connection between the occurrence of aliphatic polyacetylenes and terthienyl in the same plant Family. That these relationships might, in some cases, be rather simple was shown, originally, more-or-less by accident. *Coreopsis grandiflora* Hogg ex Sweet gives an essential oil with an ultra-violet absorption spectrum which is completely dominated by the elegant spectrum of phenylheptatriyne (Figure 2). The phenylheptatriyne also possesses an unusually marked tendency to crystallize. On one occasion, my wife was chromatographing the oil and, as a matter of routine, she took the usual cuts in the eluent and obtained one crystalline fraction after the other. The melting points of the crystals from the later fractions were lower by a few degrees, and, fortunately, my wife determined their ultra-violet absorption spectra. That of the material from the later fractions is given by curve A in Figure 3. Curve B shows the spectrum of its tetrahydro-compound. The infra-red absorption

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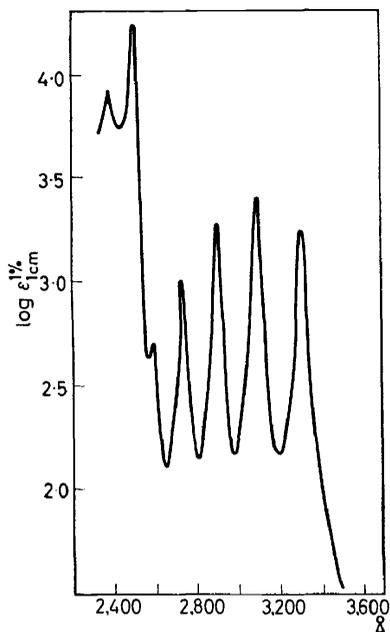


Figure 2. Ultra-violet light absorption spectrum of phenylheptatriyne

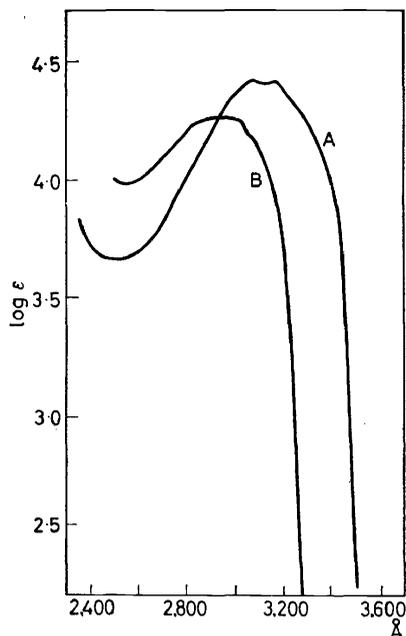
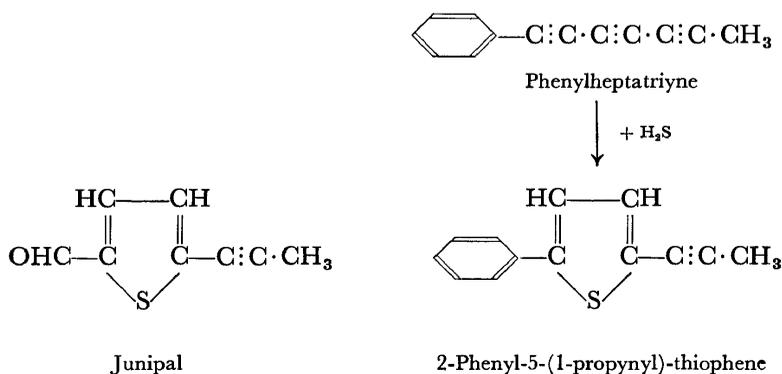
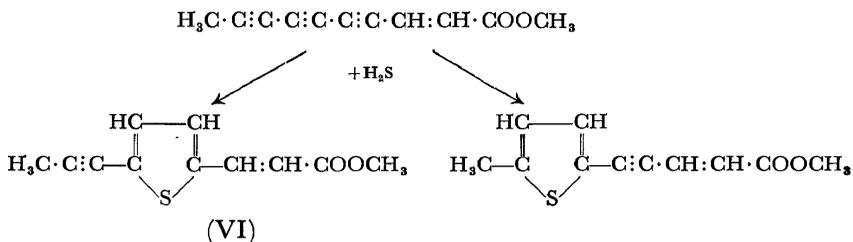


Figure 3. Ultra-violet light absorption spectra in hexane of: A. 2-phenyl-5-(1-propynyl)-thiophene; B. 2-phenyl-5-(n-propyl)-thiophene

spectrum revealed a monosubstituted phenyl residue, and a comparison with the curve that had just been published by Birkinshaw⁵⁰ for junipal, 5-(1-propynyl)-2-formylthiophene, indicated that there might also be a 2,5-disubstituted thiophene present. Due to the work of Birkinshaw on junipal, one of the odoriferous principles of the Basidiomycete, *Daedelia juniperina*, the rest of the constitutional work was easy: the compound was proved to be 2-phenyl-5-(1-propynyl)-thiophene. The formal relationship between phenylheptatriyne, 2-phenyl-5-(1-propynyl)-thiophene and junipal is shown as follows:

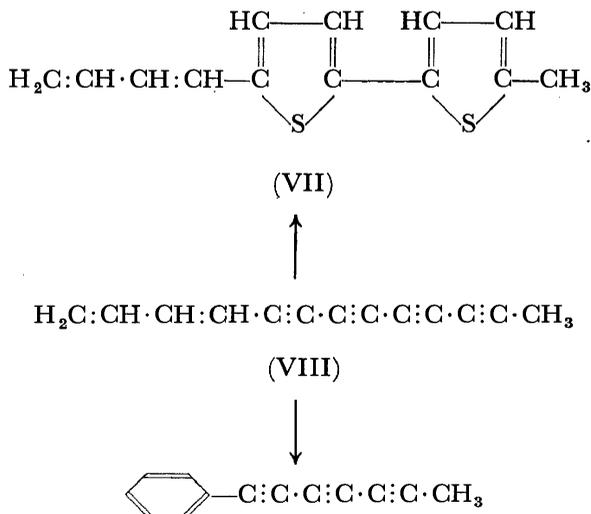


Dehydro-matricaria ester is formally related to two isomeric thiophenes, thus:



Guddal has demonstrated that two crystalline compounds in the root of tansy, *Chrysanthemum vulgare* Bernh., are the *cis*- and *trans*-isomers of one of these thiophenes (VI). By synthesis of the *trans*-isomer, Skattebøl has confirmed this constitution⁵²; the junipal of Birkinshaw was an intermediate in this synthesis.

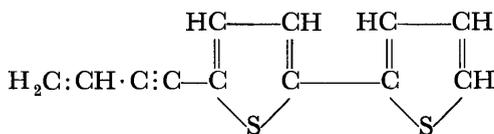
Another interesting member was isolated by Mrs Liaaen Jensen⁵³ from some *Bidens* species, viz. 5-methyl-5'-butadienyl-2,2'-dithienyl (VII). This was the first naturally occurring derivative of dithienyl to be discovered, and in this case also the constitution was confirmed synthetically by Skattebøl. The 5-methyl-5'-butadienyl-2,2'-dithienyl can be formally derived from the trideca-1,3-diene-5,7,9,11-tetrayne (VIII), which can also be regarded as the hypothetical precursor of the phenylheptatriyne found in a number of *Bidens* species:



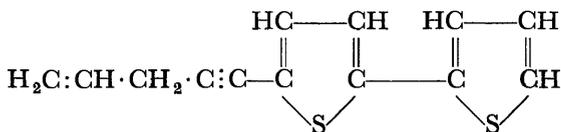
However, trideca-1,3-diene-5,7,9,11-tetrayne (VIII), which is a positional isomer of the "3915"-hydrocarbon, has not so far been isolated from plants.

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In 1959, Uehlenbrook⁵⁴ and his collaborators in the research laboratory of Philips-Roxane demonstrated that the terthienyl of Zechmeister was one of the nematocidal principles of extracts from *Tagetes* roots. More potent, however, than terthienyl was a liquid compound with a broad ultra-violet light absorption maximum at 3400 Å. These Dutch chemists gave this nematocidal principle the structure (IX). Fractions with similar ultra-violet and infra-red light absorption spectra had been isolated



(IX)

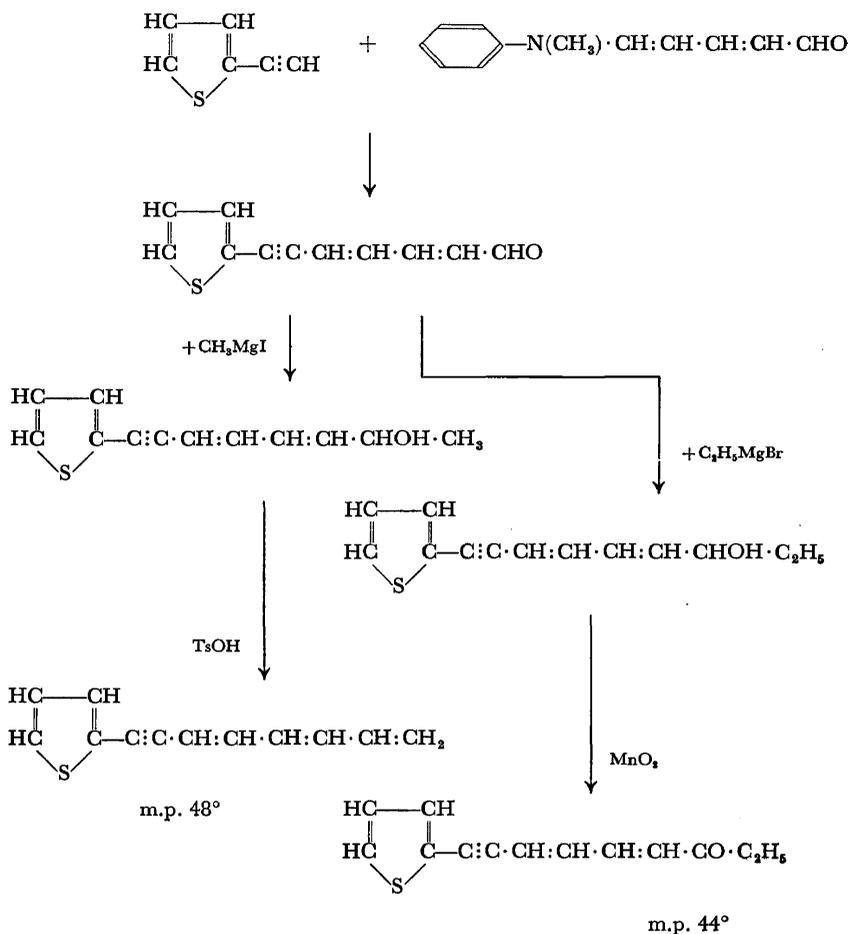


(X)

by my collaborators from the thistles *Berkheya macrocephala* and *Echinops sphaerocephalus*. Since these fractions possessed an ultra-violet light absorption maximum at a shorter wave-length than that of 5-methyl-5'-butadienyl-2,2'-dithienyl (VIII), but which is in good agreement with those of the monoethylene and monoacetylene derivatives of 2,2'-dithienyl, we favoured the C₁₃-structure (X) for the constituent of these fractions. Although some uncertainties thus remain as to the constitution of the nematocidal principle of *Tagetes*, this compound and the 5-methyl-5'-butadienyl-2,2'-dithienyl (VII) obviously provide intermediates which would encourage not only Professor Challenger, but also any other chemist, to postulate connections between aliphatic polyacetylenes and naturally occurring thiophenes.

Finally the scentless mayweed, with which my small group originally started work in the acetylene field, has also furnished some new thiophenes⁵⁵. In our 13th communication in 1954⁸, reporting the isolation of *trans*-dehydro-matricaria ester from members of the subgenus *Tripleurospermum* of Schulz-Bipontinus, Miss Holme and my wife described two crystalline compounds which, at that time, were characterized only by melting-point and ultra-violet light absorption spectra. When the work was resumed, my wife found a number of thiophenic compounds of which five have now been isolated in a pure state: one turned out to be identical with the *trans*-isomer of methyl-5-propynyl-2-thienylacrylate which had been isolated earlier by Guddal from tansy. The four others are new ones, and all are mono-substituted thiophenes. The synthesis of two of them with the aid of the

Jutz synthesis⁵⁶, one of the most elegant recent contributions to the synthesis of acetylenic compounds, is represented as follows:



The third of the new thiophenes from scentless mayweed might be the α,β -dihydro-derivative of the ketone. These new monosubstituted thiophenes bear interesting relationships to the acetylenes isolated earlier from *Matricaria* and the closely related mugworts (*Artemisia*). As will be obvious from Table 6, the monothiophenes may well be connected with the Centaur X₃ and the C₁₄-ketone of these species, by ω -oxidation and subsequent decarboxylation. The studies in Oxford on some aliphatic polyacetylenes of certain fungi have already made such ω -demethylations plausible⁵⁷.

These new members of the acetylene family present in scentless mayweed raise once again the question of whether or not these short-chain polyacetylenes originate as degradation products of unsaturated fatty acids. Bohlmann has discussed this problem in connection with his cornflower series, as has E. R. H. Jones on the basis of his fifty or so polyacetylenes from

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Table 6. Related compounds in the Tribus Anthemideae, subtribus Anthemidineae

	Chemical constitution	Stereochemistry	Source
C ₁₇	H ₃ C·C:C·C:C·C:C·C:C·CH:CH·CH·CH·CH ₂ ·CH ₂ ·CH ₂ ·CH ₂ ·CH ₂ ·CH:CH ₂ (Centaur X ₃)		<i>Artemisia</i> (<i>Matricaria</i>)
C ₁₄	H ₃ C·C:C·C:C·C:C·C:C·CH:CH·CH ₂ ·CH ₂ ·CO·CH ₂ ·CH ₃		<i>Artemisia</i> (<i>Matricaria</i>)
C ₁₀	H ₃ C·C:C·C:C·C:C·C:C·CH:CH·COOCH ₃	{ <i>cis</i> - <i>trans</i> - 2- <i>cis</i> ,8- <i>cis</i> - 2- <i>trans</i> ,8- <i>cis</i> - 8- <i>cis</i> - }	<i>Artemisia</i> <i>Matricaria</i> <i>Matricaria</i> <i>Matricaria</i>
	H ₃ C·CH:CH·C:C·C:C·C:C·CH:CH·COOCH ₃		
	H ₃ C·CH:CH·C:C·C:C·C:C·CH ₂ ·CH ₂ ·COOCH ₃		
C ₁₂	$ \begin{array}{c} \text{HC} \quad \text{CH} \\ \parallel \quad \diagdown \\ \text{C} \quad \text{C} \\ \diagup \quad \diagdown \\ \text{S} \quad \text{C} \end{array} $ C:C·CH:CH·CH·CH·CH:CH:CH ₂		<i>Matricaria</i> <i>inodora</i>
	$ \begin{array}{c} \text{HC} \quad \text{CH} \\ \parallel \quad \diagdown \\ \text{C} \quad \text{C} \\ \diagup \quad \diagdown \\ \text{S} \quad \text{C} \end{array} $ C:C·CH:CH·CH·CH·CO·CH ₂ ·CH ₃		<i>Matricaria</i> <i>inodora</i>
C ₁₃	$ \begin{array}{c} \text{HC} \quad \text{CH} \\ \parallel \quad \diagdown \\ \text{C} \quad \text{C} \\ \diagup \quad \diagdown \\ \text{S} \quad \text{C} \end{array} $ C:C·CH:CH·CH ₂ ·CH ₂ ·CO·CH ₂ ·CH ₃		<i>Matricaria</i> <i>inodora</i>

fungi. The answer is up to the biochemist: it is his privilege and his responsibility. The organic chemist will, from my experience, have his hands full with the isolation of numerous new members of the known structural groups of naturally occurring acetylenes, and, without doubt, with the elucidation of the structures of quite new types.

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