Synthesis of Ketols of the Natural Pyrethrins *†

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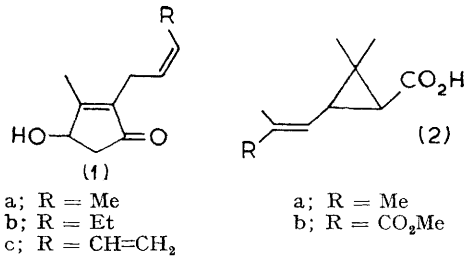
A stereospecific five-stage synthesis of (±)-*cis*-pyrethrolone is described, involving *cis*-octa-1,3-dien-7-one as the key intermediate. The ethylene acetal of this ketone was made by a Wittig reaction, under ' salt-free ' conditions, with vaporised acraldehyde. The overall yield for the synthesis was 21%, and it provides highly pure (±)-*cis*-pyrethrolone for the first time. The material is spectrally identical with a sample of natural (+)-pyrethrolone.

Improved syntheses of both (±)-*cis*-cinerolone and (±)-*cis*-jasmololone are reported. The *cis*-side chains are introduced by Wittig reactions or by selective hydrogenation of acetylenic intermediates.

An allenic formulation, entertained for natural pyrethrolone in the early literature, is synthesised.

The keto-alcohols cinerolone (1a), jasmololone (1b) and pyrethrolone (1c), known collectively as rethrolones, are the alcohol components of the insecticidally active constituents of the flower-heads of *Chrysanthemum cinerariaefolium* (pyrethrum). Severally combined with chrysanthemic acid (2a) and pyrethric acid (2b), they form the six active principles (the ' pyrethrins '), cinerin I (3a), cinerin II (3b), jasmolin I (3c), jasmolin II (3d), pyrethrin I (3e), and pyrethrin II (3f).[1]

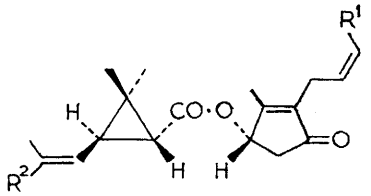


(1)

a; R = Me
b; R = Et
c; R = CH=CH$_2$

(2)

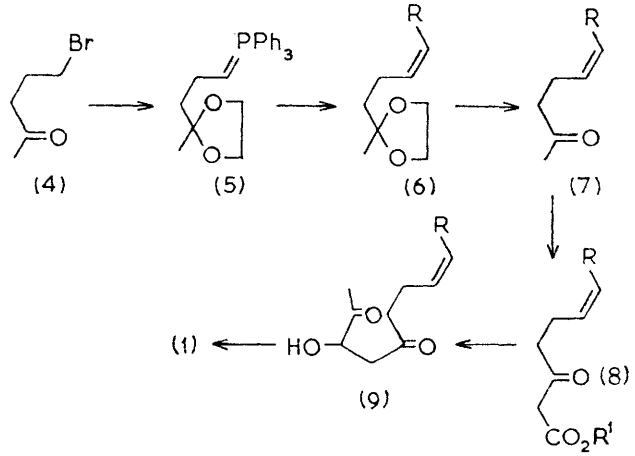
a; R = Me
b; R = CO$_2$Me



(3)

a; R^1 = R^2 = Me
b; R^1 = Me, R^2 = –CO$_2$Me
c; R^1 = Et, R^2 = Me
d; R^1 = Et, R^2 = CO$_2$Me
e; R^1 = CH=CH$_2$, R^2 = Me
f; R^1 = CH=CH$_2$, R^2 = CO$_2$Me

The stereochemical detail now accepted for the pyrethrins is shown in (3). The *cis*-geometry of the side-chain in natural rethrolones (1) has been established by synthesis and spectral studies.[1] In earlier synthetic work on rethrolones by Crombie and Harper and their collaborators this *cis*-side chain has been introduced, in the cases of cinerolone (1a) and pyrethrolone (1c), by partial hydrogenation of acetylenic intermediates.[2,3] In the case of pyrethrolone (1c), however, which contains a sensitive *cis*-vinyl-diene system, the hydrogenation of conjugated enyne precursors was not as selective as desired, and the product was contaminated with over- and under-hydrogenated materials.[3] The overall yield for the synthesis was low (>0·2%), and the purity of the high b.p. liquid was not known with certainty. Identity with a sample of naturally derived racemic pyrethrolone (pyrethrolone B-2) was based on its closely similar i.r. spectrum [that of the (±)-*trans*-compound is clearly distinguishable], and the mixed m.p. of the semicarbazone derivatives. Both cinerolone (1a) and jasmololone (1b), the latter synthesised from ' leaf-alcohol ' (*cis*-n-hex-3-en-1-ol),[4] were obtained essentially stereochemically pure with respect to their *cis*-side chains, but the overall yields (*ca.* 1%) for the syntheses were not high. This paper describes a new synthesis of pyrethrolone (1c) which has novel features, is completely stereospecific, and provides the (±)-*cis*-material in an overall yield of 21%. Improved syntheses of both (±)-*cis*-cinerolone (1a) and (±)-*cis*-jasmololone (1b) are also described.



(4) (5) (6) (7) (8) (9) (1)

a; R = Me. b; R = Et. c; R = CH=CH$_2$

Wittig reaction between the phosphorane (5) derived from the bromo-ketone (4), and acraldehyde, under ' salt-free ' conditions,[5] gave the *cis*-diene (6c) almost exclusively. Its configuration followed from spectral properties, and from its recovery unchanged (spectrally) after treatment with *p*-benzoquinone. Hydrolysis of (6c) gave the *cis*-diene-ketone (7c) which was both physically and spectrally quite different from an authen-

* Preliminary communication, L. Crombie, P. Hemesley, and G. Pattenden, *Tetrahedron Letters*, 1968, **26**, 3021.

† Presented at the 5th International (IUPAC) Symposium on the Chem. of Natural Products, London, July, 1968.

[1] L. Crombie and M. Elliott, *Fortschr. Chem. org. Naturstoffe*, 1961, **19**, 121.

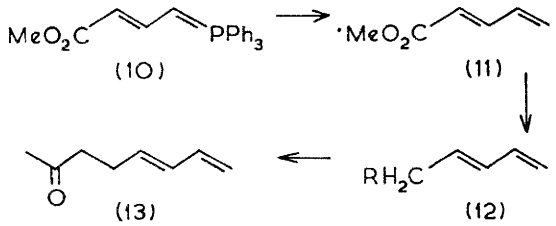
[2] L. Crombie and S. H. Harper, *J. Chem. Soc.*, 1950, 1152.

[3] L. Crombie, S. H. Harper, and F. C. Newman, *J. Chem. Soc.*, 1956, 3963.

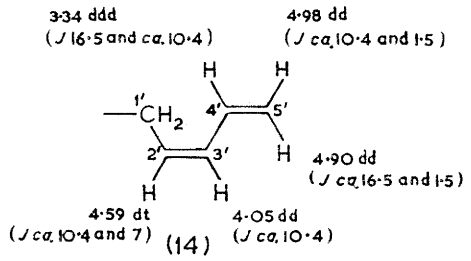
[4] L. Crombie, S. H. Harper, R. E. Stedman, and D. Thompson, *J. Chem. Soc.*, 1951, 2445.

[5] M. Schlosser, G. Muller, and K. F. Christmann, *Angew. Chem.*, 1966, **78**, 677; M. Schlosser and K. F. Christmann, *Annalen*, 1967, **708**, 1.

tic sample of the *trans*-diene-ketone (13)[6] obtained, during this study, from the *trans*-phosphorane (10)[7] by Wittig reaction with formaldehyde to give (11), then reduction of (11) to the alcohol (12; R = OH), followed by conversion into the chloride (12; R = Cl), and acetoacetate condensation.



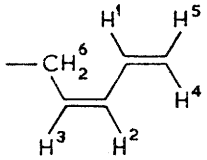
The configuration assigned to the diene Wittig product (6c) follows conclusively from its n.m.r. spectrum, where the observed multiplicities, and the coupling constants of the olefinic protons are consistent only with a *cis*-geometry. The n.m.r. data for the olefinic protons of (6c) are summarised in formula (14). The geminal protons resonate at highest field, and both give rise to double doublets with geminal coupling *ca.* 1·5 c./sec., and vicinal couplings 10·4 (*cis*) and 16·5 (*trans*) c./sec. The geminal proton *trans* to the proton on C-4′ resonates at lower field (τ 4·9) than the other geminal proton (τ 4·98) presumably because of its *cis*-relationship to the neighbouring double-bond. The proton at C-4′ should give rise to a doublet of double doublets, but because two of the vicinal couplings are of comparable magnitude



(*ca.* 10·4 c./sec.) only six lines are seen. It is significant that the proton at C-3′ gives a double doublet with the two vicinal couplings of the same magnitude; the observed *cis*-vicinal coupling (10·4 c./sec.) is characteristic of *cis*-double bonds.[8] If the double bond had a *trans*-geometry then this same proton should give rise to a four line signal since *trans*-vicinal coupling is greater (*J ca.* 16 c./sec.) than the corresponding *cis*-vicinal coupling.[8] The proton at C-2′ gives a doublet (*J ca.* 10·4 c./sec.) of triplets (*J ca.* 7 c./sec.) centred at τ*ca.* 4·59, although this resonance is obscured by the geminal proton signals. The resonances of the olefinic protons of the corresponding ketone (7c) were similar and are summarised in Table 1. Unfortunately, it was not possible adequately to compare the n.m.r. resonances of the olefinic protons of the *cis*-ketone (7c) with those of the corresponding *trans*-compound (13), since the protons of the latter gave a complex multiplet distributed over *ca.* 75 c./sec.; a complete analysis was not possible.

TABLE 1

N.m.r. data for the olefinic protons of the *cis*-dienes (7c), (8c), and (9c), and pyrethrolone (1c)



	H^1 ddd $J_{1,4}$ 16·5 $J_{1,5} \sim J_{1,2}$ ~10·4	H^2 dd $J_{1,2} \sim J_{2,3}$ ~10·4	H^3 dt $J_{2,3}$ ~10·4 $J_{3,6}$ ~7	H^4 dd $J_{1,4}$ ~16·5 $J_{4,5}$ ~1·5	H^5 dd $J_{1,5}$ ~10·4 $J_{4,5}$ ~1·5
(7c)	3·35	4·07	4·70	4·88	4·96
(8c; R^1 = Me)	3·38	4·06	4·68	4·86	4·93
(9c)	3·40	4·06	4·68	4·88	4·92
(1c)	3·20	3·98	4·68	4·79	4·85

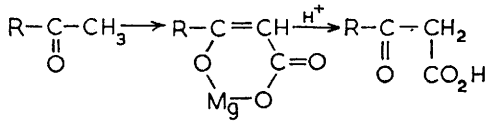
In view of the ease with which acraldehyde polymerises in the presence of strong base, it is perhaps not surprising that previously reported Wittig reactions involving acraldehyde and reactive phosphoranes of the type (5) have given low yields of the corresponding olefins. Bohlmann and Mannhardt[9] for example, obtained <1% yield of polyene from condensation of acraldehyde with the phosphorane derived from deca-2,8-diene-4,6-diynyltriphenylphosphonium bromide, and Hauser *et al.*[10] report yields of 6—30% for similar condensations involving acraldehyde. Condensation of the less basic stable phosphorane derived from methyl α-bromopropionate with acraldehyde is reported[11] to give the corresponding olefin in 60% yield. We have found that the yield of diene product (6c) from Wittig reaction between acraldehyde and the reactive phosphorane (5) could be increased by passing the vapour of acraldehyde in nitrogen over a stirred and 'salt-free' benzene solution of the phosphorane over long periods. In this way we consistently obtained diene yields of *ca.* 50%.

The stereochemistry of the previously reported[9,10] diene products from Wittig reactions between acraldehyde and reactive phosphoranes has not been discussed. On the other hand House and Rasmusson[11] observed complete *trans*-olefination in a Wittig synthesis with acraldehyde and the stable phosphorane derived from methyl α-bromopropionate. The stereochemistry of Wittig reactions involving reactive phosphoranes of the type (5) and aldehydes has been extensively investigated in recent years,[5,12,13] and the almost exclusive *cis*-olefination observed in the Wittig reaction described

[6] L. Crombie, S. H. Harper, and D. Thompson, *J. Chem. Soc.*, 1951, 2906.
[7] E. Buchta, and F. Andree, *Chem. Ber.*, 1959, **92**, 3111.
[8] 'Nuclear Magnetic Resonance for Organic Chemists,' ed. D. W. Mathieson, Academic Press, 1967.
[9] F. Bohlmann and H. J. Mannhardt, *Chem. Ber.*, 1955, **88**, 1330.
[10] C. F. Hauser, T. W. Brooks, M. L. Miles, M. A. Raymond, and G. B. Butler, *J. Org. Chem.*, 1963, **28**, 372.
[11] H. O. House and G. H. Rasmusson, *J. Org. Chem.*, 1961, **26**, 4278.
[12] L. D. Bergelson, L. I. Barsukov, and M. M. Shemyakin, *Tetrahedron*, 1967, **23**, 2709.
[13] H. O. House, V. K. Jones, and G. A. Frank, *J. Org. Chem.*, 1964, **29**, 3327.

above deserves comment. Studies of the effect of solvent and additives on the steric course of the Wittig reaction [5,12,13] have established that saturated non-stabilised phosphoranes, in the absence of inorganic salts (i.e. 'salt-free' conditions) condense with aldehydes to give predominantly (>90%) *cis*-olefination products. Presumably the steric course of such reactions is controlled by kinetic factors, and the initial combination of the phosphorane and aldehyde leads to a 'betaine' intermediate with a preferred '*erythro*' conformation which then collapses to give the *cis*-olefin. (For extensive discussion on this subject see refs. 5 and 12.) Stereochemical results obtained during these studies with the phosphorane (5) and various aldehydes, under 'salt-free' conditions, confirm these general findings (see also following paper).

Direct carboxylation of the methyl ketone (7c) with magnesium methyl carbonate (MMC) [14] gave an essentially quantitative yield (determined by titration) of the corresponding β-keto-acid (8c; $R^1 = H$). The acid was isolated as the potassium salt (8c; $R^1 = K$) by titration with potassium hydroxide, and was characterised as the methyl ester. MMC has been used previously for the carboxylation of aryl methyl ketones,[15] cyclic ketones,[15,16] and nitroalkanes,[17] but to our knowledge it has not been employed for the carboxylation of saturated acyclic methyl ketones. Use of the reagent has a number of advantages over more usual methods, such as those involving strong base and diethyl carbonate.[18] It appears to lead to exclusive formation of mono-1-carboxylated ketones, *via* an intermediate magnesium chelate of the type (15).[15]



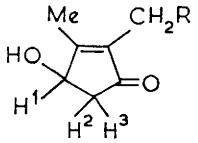
(15)

The reagent has special value in our synthetic scheme since it furnishes the free carboxylic acid directly, isolated as the potassium salt, and it is this salt which is required for the next stage. Reagents such as diethyl carbonate give an ester of the β-keto-acid which then has to be hydrolysed before further reaction (*cf.* refs. 2 and 3).

Condensation of the potassium salt (8c; $R^1 = K$) of the β-keto-acid with pyruvaldehyde [19,20] at pH 8·2 gave the hydroxy-dione (9c) which was then cyclised with ethanolic sodium hydroxide to give racemic *cis*-pyrethrolone (1c). The stereochemistry of the *cis*-double bond introduced at (6c) by a Wittig synthesis was preserved throughout this series of transformations, and the final product (21% overall yield) was both chromatographically (g.l.c. and t.l.c.) and spectrally (u.v., i.r., and n.m.r.) indistinguishable from natural (+)-pyrethrolone, isolated according to the crystalline hydrate method of Elliott.[21] The n.m.r. data for the olefinic protons of the *cis*-diene systems in the intermediates (8c) and (9c) and in synthetic pyrethrolone (1c) are summarised in Table 1. The n.m.r. assignments of the cyclopentenone ring protons in synthetic pyrethrolone are collected in Table 2 and agree with those for natural pyrethrolone.[22]

TABLE 2

N.m.r. data for the cyclopentenone ring protons of synthetic rethrolones



	H^1 dm $J_{1,2}$ *ca.* 6	H^2 dd $J_{1,2}$ 6 $J_{2,3}$ 18	H^3 dd $J_{2,3}$ 18 $J_{1,3}$ 2	CH_2 d *J* 6—7	CH_3	OH
(1a) R = CH=CHMe	5·3	7·22	7·79	7·07	7·9	6·27
(1b) R = CH=CHEt	5·33	7·24	7·81	7·09	7·91	6·27
(1c) R = CH=CH–CH=CH_2	5·3	7·20	7·77	6·91	7·87	6·67
(24) R = CH=C=CHMe	5·27	7·21	7·76	7·13m	7·89	6·37

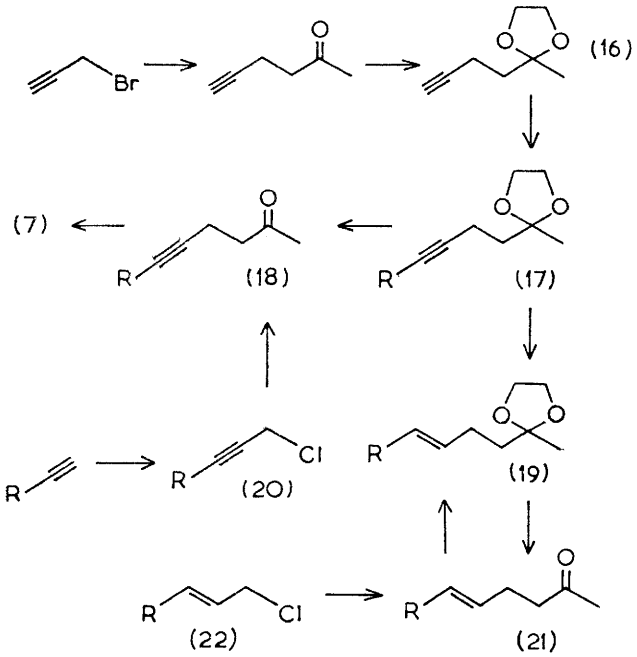
Wittig reaction between the phosphorane (5) and either acetaldehyde or propionaldehyde, under 'salt-free' conditions,[5] provided the *cis*-precursors (6a) and (6b) for cinerolone (1a) and jasmololone (1b) syntheses; here the Wittig products contained *ca.* 6—8% of the corresponding *trans*-olefins. Hydrolysis of the ethylene acetals (6a) and (6b) gave the ketones (7a) and (7b) respectively, which were then converted (*ca.* 16% overall yield) into racemic *cis*-cinerolone (1a) and racemic *cis*-jasmololone (1b), respectively, by transformations similar to those used previously in the synthesis of racemic *cis*-pyrethrolone. The synthetic cinerolone (1a) had physical and spectral (u.v., i.r., and n.m.r.) properties closely similar to those reported previously for the natural (+)-material, and for a sample of (±)-*cis*-material obtained by an earlier synthesis.[2,4]

Jasmololone (1b) has not been isolated from the hydrolysis of pyrethrum extract, principally because it is present only in small quantity, and also because it can be separated only with difficulty from cinerolone (1a). Indeed, the jasmolins I (3c) and II (3d) have only

[14] H. L. Finkbeiner and M. Stiles, *J. Amer. Chem. Soc.*, 1963, **85**, 616.
[15] M. Stiles, *J. Amer. Chem. Soc.*, 1959, **81**, 2598.
[16] S. W. Pelletier, R. L. Chappel, P. C. Parthasarathy, and N. Lewin, *J. Org. Chem.*, 1966, **31**, 1747.
[17] M. Stiles and H. L. Finkbeiner, *J. Amer. Chem. Soc.*, 1959, **81**, 505.
[18] V. H. Wallingford, A. H. Homeyer, and D. M. Jones, *J. Amer. Chem. Soc.*, 1941, **63**, 2252; S. B. Solway and F. B. LaForge, *ibid.*, 1947, **69**, 2677.
[19] M. S. Schechter, N. Green, and F. B. LaForge, *J. Amer. Chem. Soc.*, 1949, **71**, 3165; J. Farkaš, H. Komrsová, J. Krupička, and J. J. K. Novák, *Coll. Czech. Chem. Comm.*, 1960, **25**, 1834.
[20] L. Crombie, A. J. B. Edgar, S. H. Harper, M. W. Lowe, and D. Thomson, *J. Chem. Soc.*, 1950, 3552.
[21] M. Elliott, *J. Chem. Soc.*, 1964, 5225.
[22] A. F. Bramwell, L. Crombie, P. Hemesley, G. Pattenden, M. Elliott, and N. F. Janes, *Tetrahedron*, in the press.

recently [23] been recognised as minor active constituents of pyrethrum extract, though jasmololone (1b) and jasmolin I (3c) were synthesised much earlier in an investigation of the insecticidal activity of cinerin homologues.[4] The synthetic jasmololone was readily separated from cinerolone on mixed g.l.c., but their u.v. and i.r. spectral properties were very similar. The n.m.r. spectral data for the cyclopentenone ring protons of both cinerolone (1a) and jasmololone (1b) are summarised in Table 2. In addition cinerolone (1a) showed an olefinic proton multiplet at τ 4·6 and a vinyl-methyl doublet (J 6 c./sec.) at τ 8·31, and jasmololone (1b) showed an olefinic proton multiplet at τ 4·72, a vinyl-methylene multiplet at τ 7·85, and a saturated methyl triplet (J 7·3 c./sec.) at τ 9·04.

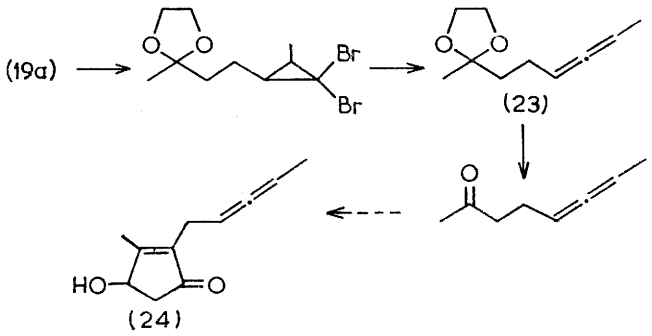
The *cis*-ketones (7a) and (7b) required for cinerolone (1a) and jasmololone (1b) syntheses were more conveniently prepared (stereochemical purity >98%) from acetylene (18) by reduction over a Lindlar catalyst. In the case of an unconjugated acetylene this can be made highly selective and stereospecific. The acetylenic ketones (18a) [4] and (18b) were obtained from the chloride (20) by an acetoacetate condensation, or better, by alkylation of the terminal acetylene (16) [24] with methyl or ethyl iodide, followed by hydrolysis; acetylenes (20) and (16) were prepared as indicated. The corresponding *trans*-ketones (21) and *trans*-ethylene acetals (19), required for comparison purposes, were obtained from



a; R = Me. b; R = Et

chloride (22) by an acetoacetate condensation, and from acetylene (17) by reduction with sodium in liquid ammonia.

Historically an allene side chain was accepted for pyrethrolone for many years.[25] The evidence for such a formulation was the production of acetaldehyde on ozonolysis, shown later [6] to be due to contamination with cinerolone (1a). Structure (24) was synthesised during the present study by converting the *trans*-ethylene acetal (19a) into the corresponding allene (23), by the von Doering method,[26] and by application of the ring construction method already described for other rethrolone syntheses. The allene (24) (allenolone) was separated from natural pyrethrolone by mixed g.l.c. analysis, and the two materials were spectrally (u.v., i.r., and n.m.r.) non-identical. The n.m.r. spectral data



for the allenolone (24) are collected in Table 2; the compound also showed an olefinic proton multiplet (2H) at τ 4·94 and a vinyl methyl double doublet (J 6·5 c./sec.) centred at τ 8·4.

The keto-alcohols (1) have been separately esterified with the acid chlorides of both (+)-*trans*-chrysanthemic acid (2a) and (+)-*trans*-pyrethric acid (2b) to give the six principles (3a—f). The physical and spectroscopic (u.v. and i.r.) properties of the cinerins (3a and b), and of the pyrethrins (3e and f), were similar to those reported for the natural materials.[1] The n.m.r. spectra of the synthetic and natural pyrethrins were also closely similar, apart from the expected duplication of some resonances in the synthetic materials, associated with the n.m.r. non-equivalence of signals from epimerically related protons. Since the n.m.r. spectra of the pyrethrins and related compounds are the subject of a separate communication,[22] however, this topic will not not be dealt with further here. The u.v. and i.r. spectra of the synthetic jasmolins were closely similar to those of the corresponding synthetic and natural cinerins. The n.m.r. data of the jasmolins, apart from the differences already mentioned, were similar to those quoted for the naturally derived materials.[23]

Esterification of synthetic allenolone (24) with both *trans*-chrysanthemoyl chloride and *trans*-pyrethroyl chloride gave the corresponding allene-rethrins (as diastereoisomeric mixtures), which, together with the

[23] P. J. Godin, R. J. Sleeman, M. Snarey, and E. M. Thain, *J. Chem. Soc.* (*C*), 1966, 332.
[24] G. Stork and R. Borch, *J. Amer. Chem. Soc.*, 1964, **86**, 935.
[25] H. Staudinger and L. Ruzicka, *Helv. Chim. Acta*, 1924, **7**, 212.
[26] W. von E. Doering and P. M. LaFlamme, *Tetrahedron*, 1958, **2**, 75.

synthetic natural pyrethrins are under insecticidal assay; the results will be published elsewhere.*

EXPERIMENTAL

Melting points are corrected. Unless stated otherwise, n.m.r. spectra were determined with a Perkin-Elmer R10 spectrometer for dilute solutions in carbon tetrachloride with tetramethylsilane as internal standard. Bands were observed as sharp singlets, except where one of the following designations is used: d, doublet; t, triplet; q, quartet; m, multiplet; dd, doublet of doublets; ddd, doublet of double doublets; qt, quartet of triplets. Band positions are given on the τ scale and coupling constants (J) in c./sec.; many of the assignments are summarised in the Tables. The J values quoted refer to the observed separation between appropriate lines. I.r. spectra were measured for liquid films, and u.v. spectra for solutions in absolute ethanol. Mass spectra were measured with an A.E.I. MS9 double-focussing spectrometer.

Ethereal solutions were dried over magnesium sulphate prior to evaporation.

3-(2-*Methyl*-1,3-*dioxolan*-2-*yl*)*propyltriphenylphosphonium Bromide*.—3-(2-Methyl-1,3-dioxolan-2-yl)propyl bromide, prepared from 5-bromopentan-2-one [27] had b.p. 92—95°/12 mm., n_D^{18} 1·4747, $\nu_{max.}$ 1050, 947, and 865 cm.$^{-1}$, τ 6·1 (2 × CH_2·O), 6·58 (t, J 6, CH_2Br), 7·78—8·47 (m, CH_2·CH_2), and 8·74 (Me) (Found: C, 40·0; H, 6·2; Br, 38·5. Calc. for $C_7H_{13}BrO_2$: C, 40·2; H, 6·2; Br, 38·2%) (lit.,[28] b.p. 83—84°/10 mm.). The bromide was treated with triphenylphosphine in benzene solution (80°; 48 hr.) to give the phosphonium salt, m.p. 220—221° (from methylene chloride-ethyl acetate), τ ($CDCl_3$) 2·25 (m, aryl CH), 5·93—6·38 (m, CH_2·$\overset{+}{P}$), 6·16 (2 × CH_2·O), 7·84—8·6 (m, CH_2·CH_2), and 8·8 (Me) (Found: C, 63·2; H, 5·9; Br, 17·2; P, 6·8. Calc. for $C_{25}H_{28}BrO_2P$: C, 63·7; H, 5·6; Br, 17·0; P, 6·6%) (lit.,[28] m.p. 219—220°).

Wittig Syntheses with 3-(2-*Methyl*-1,3-*dioxolan*-2-*yl*)*propyltriphenylphosphonium Bromide: General Procedure*.—The finely powdered phosphonium salt (*ca.* 30 g.) was added, during 0·25 hr., to a stirred suspension of sodamide [from sodium (1 g. atom equiv.)] in liquid ammonia (250 ml.) under nitrogen. The mixture was stirred for 2 hr., and then the ammonia was allowed to evaporate. The residue was treated with dry benzene (350 ml.) and the mixture was then boiled under reflux for 0·5 hr. The mixture was cooled and the solids were allowed to separate. The deep-red benzene solution of the phosphorane was then decanted in an atmosphere of nitrogen into a flask fitted with stirrer, drying tube, and delivery tube. Nitrogen was passed over the freshly distilled aldehyde (*ca.* 3 mol.) contained in an external vessel, and the vapour of the aldehyde was passed in nitrogen *via* the delivery tube over the surface of the stirred phosphorane solution for 12 hr.

The solids which separated were filtered off, and the filtrate was evaporated. Distillation of the residue then gave the *cis*-olefin.

cis-6-(2-*Methyl*-1,3-*dioxolan*-2-*yl*)*hexa*-1,3-*diene* (6c). In accordance with the general procedure, the salt (28·8 g.) was added to sodamide [from sodium (1·57 g.)] and the phosphorane was then transferred into benzene solution and treated with acraldehyde (5 g.) during 12 hr. After isolation as described, distillation gave the cis-*diene* (5·1 g., 50%), b.p. 95—102°/13 mm., n_D^{22} 1·4460—1·4768. An analytical sample had b.p. 97°/14 mm., n_D^{22} 1·4760, $\lambda_{max.}$ 227·5 mμ (ε 20,500), $\nu_{max.}$ 1645, 1595, 1060, 1002, 950, 908, 865, and 780 cm.$^{-1}$, τ (neat) see formula (14) and 6·19 (2 × CH_2·O), 7·48—7·98 (m, CH_2·CH·), 8·17—8·53 (m, ·CH_2·), and 8·74 (Me) [Found: C, 71·7; H, 9·6%; M (mass spectrum), 168. $C_{10}H_{16}O_2$ requires C, 71·4; H, 9·6%; M, 168].

The crude product (3 g.) was added to a solution of *p*-benzoquinone (0·1 g.) in ether (2 ml.) and the mixture was kept at 20° for 3 days under nitrogen. Evaporation of the solution followed by chromatography of the residue in light petroleum (b.p. 60—80°) on alumina (Grade I), gave the diene (2 g., 70% recovery), b.p. 96—97°/14 mm., n_D^{22} 1·4757, $\lambda_{max.}$ 227·5 mμ (ε 20,100), i.r. and n.m.r. spectra identical with those prior to treatment with *p*-benzoquinone.

cis-5-(2-*Methyl*-1,3-*dioxolan*-2-*yl*)*pent*-2-*ene* (6a). In accord with the general procedure, the salt (29·9 g.) was added to sodamide [from sodium (1·72 g.)] and the phosphorane was then transferred into benzene solution and treated with acetaldehyde (6·3 g.) during 12 hr. After isolation as described, distillation gave the *olefin* (3·46 g., 35%), b.p. 70—75°/18 mm., n_D^{25} 1·4445. A sample purified by preparative g.l.c. (30% XF-1150; 115°) had b.p. 80° (bath)/18 mm., n_D^{24} 1·4428, $\nu_{max.}$ 1660, 1055, 945, and 860 cm.$^{-1}$, τ 4·66 (m, ·CH=CH·), 6·16 (2 × CH_2·O), 7·6—8·6 (1H, m), and 8·76 [MeC(O·)·O] [Found: C, 69·0; H, 10·4%; M (mass spectrum), 156. $C_9H_{16}O_2$ requires C, 69·2; H, 10·3%; M, 156]. G.l.c. analysis (5% saturated silver nitrate in ethylene glycol; 25°) showed that the *cis*-olefin (eluted second) was contaminated with 6% of the *trans*-olefin (eluted first).

cis-6-(2-*Methyl*-1,3-*dioxolan*-2-*yl*)*hex*-3-*ene* (6b). In accordance with the general procedure, the salt (29 g.) was added to sodamide [from sodium (1·75 g.)] and the phosphorane was then transferred into benzene solution and treated with propionaldehyde (8·2 g.) during 12 hr. After isolation as described, distillation gave the *olefin* (6·5 g., 63%), b.p. 74—80°/12 mm., n_D^{23} 1·445. A sample purified by preparative g.l.c. (30% XF-1150; 120°) had b.p. 90° (bath)/12 mm., n_D^{23} 1·4442, $\nu_{max.}$ 1660, 1060, 945, and 860 cm.$^{-1}$, τ 4·78 (m, ·CH=CH·), 6·19 (2 × CH_2·O), 7·76—8·6 (6H, m), 8·79 [MeC(O·)·O], and 9·06 (t, J 7·5, CH_3·CH_2). [Found: C, 70·7; H, 10·8%; M (mass spectrum), 170. $C_{10}H_{18}O_2$ requires C, 70·5; H, 10·7%; M, 170]. G.l.c. analysis (5% saturated silver nitrate in ethylene glycol; 25°) showed that the *cis*-olefin (eluted second) was contaminated with 6% of the *trans*-olefin (eluted first).

1-*Chlorobut*-2-*yne* (20a).—But-2-yn-1-ol, prepared according to the method of Crombie *et al.*,[4] had b.p. 138—145°, n_D^{23} 1·4474—1·4499, $\nu_{max.}$ 3330, 2290, 2218, and 1010 cm.$^{-1}$, τ 5·89 (q, J 2, CH_2·O), 6·41 (OH), and 8·16 (t, J 2, Me) (lit.,[4] n_D^{20} 1·4530). Treatment with phosphorus trichloride in pyridine gave the chloride, b.p. 103—105°, n_D^{22} 1·4566—1·4577, $\nu_{max.}$ 2340 and 2255 cm.$^{-1}$, τ 5·96 (q, J 2·5, ·CH_2·), and 8·13 (t, J 2·5, Me) (lit.,[4] n_D^{20} 1·4592).

1-*Chloropent*-2-*yne* (20b).—Pent-2-yn-1-ol had b.p. 65—72°/17 mm., n_D^{25} 1·4493, $\nu_{max.}$ 3340, 2240, and 1015 cm.$^{-1}$, τ 5·86 (t, J 2, CH_2·O), 6·22 (OH), 7·78 (qt, J 7 and 2, CH_2·CH_3), and 8·86 (t, J 7, Me) (lit.,[29] n_D^{17} 1·4518). Treat-

*Synthetic (±)-penta-*cis*-2′-dienylrethronyl-(+)-*trans*-chrysanthemate was 57% as toxic (LD_{50}) to houseflies as natural (+)(+)-pyrethrin I. We thank P. Needham (Rothamstead Experimental Station) for this information.

[27] T. Bacchetti and A. Fiecchi, *Gazzetta*, 1953, **83**, 1071.
[28] E. A. Obol'nikova and G. I. Somokhvalov, *Zhur. obshchei. Khim.*, 1963, **33**, 1860.
[29] J. M. Conia, *Bull. Soc. chim. France*, 1955, 1449.

ment with phosphorus trichloride in pyridine gave the chloride, b.p. 110—112°, n_D^{22} 1·4540—1·4559, $\nu_{max.}$ 2250 and 690 cm.$^{-1}$, τ 5·93 (t, J 2, CH_2Cl), 7·76 (qt, J 7 and 2, $CH_2{\cdot}CH_3$), and 8·83 (t, J 7, Me).

4-(2-*Methyl*-1,3-*dioxolan*-2-*yl*)*but*-1-*yne* (16).—Hex-5-yn-2-one, prepared (66%) from prop-2-ynyl bromide and ethyl acetoacetate according to the method of Gaudemar,[30] had b.p. 50—60°/15 mm., n_D^{25} 1·4315—1·4339, $\nu_{max.}$ 3290, 2130, and 1725 cm.$^{-1}$, τ 7·2—7·8 (4H, m), 7·87 (Me), and 8·12 (t, J 2·5, ≡CH) (lit.,[31] n_D^{18} 1·4380—1·4355). The ethylene acetal was prepared (80%) from hex-5-yn-2-one, and had b.p. 72—80°/17 mm., n_D^{23} 1·4469—1·4500, $\nu_{max.}$ 3290, 2115, 1059, 945, and 860 cm.$^{-1}$, τ 6·15 (2 × $CH_2{\cdot}O$), 7·6—8·38 (5H, m), and 8·74 (Me) (lit.,[24] b.p. 75—76°/15 mm.). G.l.c. analysis (10% XF-1150; 75°) showed one peak only.

5-(2-*Methyl*-1,3-*dioxolan*-2-*yl*)*pent*-2-*yne* (17a).—Methylation of 4-(2-methyl-1,3-dioxolan-2-yl)but-1-yne (71 g.) with methyl iodide (108 g.) in the presence of sodamide [from sodium (12·2 g.)] in liquid ammonia (500 ml.), followed by the usual isolation procedure gave the pentyne (78%), b.p. 93—94°/17 mm., n_D^{25} 1·4538—1·4545, $\nu_{max.}$ 1060, 947, and 860 cm.$^{-1}$, τ 6·17 (2 × $CH_2{\cdot}O$), 7·64—8·46 (4H, m), 8·30 (t, J 2·3, ≡CMe), and 8·78 (Me) (lit.,[32] n_D^{18} 1·4592).

6-(2-*Methyl*-1,3-*dioxolan*-2-*yl*)*hex*-3-*yne* (17b).—Ethylation of 4-(2-methyl-1,3-dioxolan-2-yl)but-1-yne (50 g.) with ethyl iodide (61 g.) in the presence of sodamide [from sodium (8·5 g.)] in liquid ammonia (500 ml.), followed by the usual isolation procedure, gave the hexyne (70%), b.p. 106—108°/16 mm., n_D^{27} 1·4527—1·4532, $\nu_{max.}$ 1060 cm.$^{-1}$, τ 6·16 (2 × $CH_2{\cdot}O$) 7·69—8·42 (6H, m), 8·76 (Me), and 8·91 (t, J 8, $CH_2{\cdot}CH_3$).

Hept-5-*yn*-2-*one* (18a).—A mixture of 5-(2-methyl-1,3-dioxolan-2-yl)pent-2-yne (48 g.) and 2N-hydrochloric acid (100 ml.) was shaken with ether (100 ml.) at 25° for 3 hr. It was extracted with ether, and the extracts were washed (H_2O) and dried. Distillation gave the ketone (33 g., 96%), b.p. 67—70°/19 mm., n_D^{26} 1·4460—1·4463, $\nu_{max.}$ 1723 cm.$^{-1}$, τ 7·3—8·06 (4H, m), 7·92 (Me), 8·3 (t, J 2·5, Me) [Found: C, 76·2; H, 9·4%; M (mass spectrum), 110. Calc. for $C_7H_{10}O$: C, 76·3; H, 9·2%; M, 110] (lit.,[4] n_D^{20} 1·4495). This procedure for hydrolysis of ethylene acetals was also used in the preparations of ketones (7) and (18b) (see later). The same material was obtained (35%) by an acetoacetate condensation with 1-chlorobut-2-yne, according to the method of Crombie *et al.*[4]

Oct-5-*yn*-2-*one* (18b).—Hydrolysis of 6-(2-methyl-1,3-dioxolan-2-yl)hex-3-yne gave (90%) the ketone b.p. 80—85°/12 mm., n_D^{26} 1·4454, $\nu_{max.}$ 1725 cm.$^{-1}$, τ 7·3—8·1 (6H, m), 7·93 (Me), and 8·93 (t, J 8, Me). G.l.c. analysis (10% XF-1150; 85°) showed one peak only. The same material was obtained (39%) by an acetoacetate condensation with 1-chloropent-2-yne.

cis-*Octa*-5,7-*dien*-2-*one* (7c).—Hydrolysis of *cis*-6-(2-methyl-1,3-dioxolan-2-yl)hexa-1,3-diene gave (89%) the ketone, b.p. 74—80°/12 mm., n_D^{24} 1·4722—1·4742, $\lambda_{max.}$ 227·5 mμ (ε 17,900), $\nu_{max.}$ 1718, 1645, 1595, 1000, 963, 907, and 784 cm.$^{-1}$, τ (neat) as in Table 1 and 7·4—7·8 (4H, m) and 7·98 (3H) [Found: C, 77·2; H, 9·9%; M (mass spectrum), 124. Calc. for $C_8H_{12}O$: C, 77·4; H, 9·75%; M, 124] (lit.,[3] b.p. 78—82°/9 mm., n_D^{20} 1·4730). The spectroscopic (i.r., u.v., and n.m.r.) properties of the ketone remained unchanged after treatment with *p*-benzoquinone, as described for the corresponding ethylene acetal.

cis-*Hept*-5-*en*-2-*one* (7a).—Hydrolysis of *cis*-5-(2-methyl-1,3-dioxolan-2-yl)pent-2-ene (from a Wittig synthesis) gave (80%) the ketone, b.p. 44—46°/16 mm., $n_D^{22·5}$ 1·4323, $\nu_{max.}$ 1720 and 1660 cm.$^{-1}$, τ 4·65 (m, CH:CH), 7·4—7·8 (4H, m), 7·96 (Me), and 8·39 (d, J 5, Me) [Found: C, 75·25; H, 11·15%; M (mass spectrum), 112. Calc. for $C_7H_{12}O$: C, 74·95; H, 10·8%; M, 112]. G.l.c. analysis (5% silver nitrate in ethylene glycol; 25°) showed that the *cis*-olefin (eluted second) was contaminated with 6% of the *trans*-olefin (eluted first) (lit.,[4] n_D^{20} 1·432).

Hydrogenation of hept-5-yn-2-one, over Lindlar catalyst[33] in ethanol, and according to the method of Crombie *et al.*,[4] gave (70%) the same *cis*-ketone, containing not more than 2% of the corresponding *trans*-olefin.

cis-*Oct*-5-*en*-2-*one* (7b).—Hydrolysis of *cis*-6-(2-methyl-1,3-dioxolan-2-yl)hex-3-ene (from a Wittig synthesis) gave (82%) the ketone, b.p. 54—57°/10 mm., n_D^{23} 1·4339, $\nu_{max.}$ 1723 and 1660 cm.$^{-1}$, τ 4·74 (m, CH:CH), 7·4—8·18 (6H), 7·96 (Me), and 9·04 (t, J 8, Me), [Found: M (mass spectrum), 126. Calc. for $C_8H_{14}O$: M, 126]. G.l.c. analysis (5% silver nitrate in ethylene glycol; 25°) showed that the *cis*-olefin (eluted second) was contaminated with 6% of the *trans*-olefin (eluted first) (lit.,[34] n_D^{20} 1·4323).

Hydrogenation of oct-5-yn-2-one, over Lindlar catalyst[33] in ethanol, gave (85%) the same *cis*-ketone, containing not more than 2% of the corresponding *trans*-olefin.

trans-5-(2-*Methyl*-1,3-*dioxolan*-2-*yl*)*pent*-2-*ene* (19a).—*trans*-Hept-5-en-2-one was obtained (51%) from *trans*-but-2-enyl chloride, according to the method of Crombie *et al.*,[20] and had b.p. 152°, $n_D^{17·5}$ 1·4322, $\nu_{max.}$ 1720 and 970 cm.$^{-1}$, τ 4·62 (m, HC:CH), 7·5—7·9 (4H, m), 7·96 (Me), and 8·37 (m, :CH·CH_3) (lit.,[20] n_D^{20} 1·4285). Treatment with ethylene glycol in benzene containing toluene-*p*-sulphonic acid then gave (75%) the ethylene acetal, b.p. 79—84°/18 mm., n_D^{24} 1·4377—1·4410, τ 4·65 (m, HC:CH), 6·17 (2 × $CH_2{\cdot}O$), 7·7—8·5 (7H, m), and 8·77 (Me) (lit.,[32] n_D^{19} 1·4430). G.l.c. analysis (5% saturated silver nitrate in ethylene glycol 25°) showed one peak only.

trans-6-(2-*Methyl*-1,3-*dioxolan*-2-*yl*)*hex*-3-*ene* (19b).—6-(2-Methyl-1,3-dioxolan-2-yl)hex-3-yne (2·5 g.) in ether (20 ml.) was added to a stirred solution of sodium (1·35 g.) in liquid ammonia (250 ml.) under nitrogen. The mixture was stirred for 3 hr., and then ammonium chloride (5 g.) was added, followed by ether (100 ml.). The ether solution was decanted, and then distilled to give the *olefin* (1·9 g., 75%), b.p. 82—83°/10 mm., n_D^{23} 1·4439, $\nu_{max.}$ 1058, 970, 945, and 860 cm.$^{-1}$, τ 4·63 (m, HC:CH), 6·16 (2 × $CH_2{\cdot}O$), 7·7—8·59 (6H, m), 8·77 (Me), and 9·04 (t, J 7·3, Me) [Found: C, 70·6; H, 10·6%; M (mass spectrum), 170. $C_{10}H_{18}O_2$ requires C, 70·5; H, 10·7%; M, 170]. G.l.c. analysis (5% saturated silver nitrate in ethylene glycol; 25°) showed one peak only.

Methyl trans-*Penta*-2,4-*dienoate* (11).—A mixture of 3-methoxycarbonylprop-2-enylidenetriphenylphosphorane[7] (47 g.) and dry paraformaldehyde (30 g.) in benzene (300 ml.) was boiled for 24 hr., cooled, and filtered. The filtrate was evaporated to dryness and the residue was then treated with light petroleum (b.p. 60—80°). The triphenylphosphine oxide which was precipitated was filtered off and the filtrate was evaporated. Distillation gave the diene (3·1 g., 21%), b.p. 43—45°/12 mm., n_D^{20} 1·4821, $\nu_{max.}$ 1728, 1648, 1603, 1014, 967, 930, and 870 cm.$^{-1}$, τ 2·76 (dd, J 10·5 and

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[34] S. H. Harper and R. J. D. Smith, *J. Chem. Soc.*, 1955, 1512.

15·5, HC:C*H*·CH:), 3·52 (ddd, *J* 9·5, 10·5, and 16·5, :HC·C*H*:CH_2), 4·16 (d, *J* 15·5, *H*C:CH), 4·41 (dd, *J* 2 and 16·5, HC:C*H*H), 4·55 (dd, *J* 2 and 9·5, HC:CH*H*) and 6·31 (Me) (lit.,[35] b.p. 50—51°/18 mm., n_D^{23} 1·4822). The *maleic anhydride adduct* had m.p. 105—110°, τ 3·82 (m, HC:CH), 6·27 (OMe), 6·41 (3H, m), and 7·43 (2H, m) (Found: C, 57·6; H, 4·85. $C_{10}H_{10}O_5$ requires C, 57·1; H, 4·8%).

trans-*Octa*-5,7-*dien*-2-*one* (13).—The ketone was prepared from methyl *trans*-penta-2,4-dienoate as previously described.[6] Reduction of methyl *trans*-penta-2,4-dienoate with lithium aluminium hydride gave (55%) *trans*-penta-2,4-dien-1-ol, b.p. 56°/14 mm., n_D^{20} 1·4810, $\lambda_{max.}$ 224 mμ, $\nu_{max.}$ 3360, 1660, 1605, 1089, 1007, 970, 952, and 905 cm.$^{-1}$, τ 3·35—4·48 (m, HC:CH·CH:), 4·63—5·05 (m, :CH_2), 5·92 (d, *J* 5, CH_2·OH), *ca.* 5·92 (OH; disappears on treatment with deuterium oxide) (lit.,[6] b.p. 66—68°/26 mm., n_D^{20} 1·4838). Chlorination of this alcohol, with phosphorus trichloride in pyridine, gave (90%) *trans*-1-chloropenta-2,4-diene,[6] which yielded the *trans*-diene ketone, b.p. 80—84°/15 mm., n_D^{19} 1·4750, $\nu_{max.}$ 1720, 1650, 1603, 1005, 950, and 900 cm.$^{-1}$, τ 3·44—5·05 (5H, m, olefinic), 7·42—7·85 (4H, m), and 7·93 (Me) (lit.,[6] b.p. 75—78°/12 mm., n_D^{20} 1·4768). G.l.c. analysis (10% XF-1150; 150°) showed one peak only.

6-(2-*Methyl*-1,3-*dioxolan*-2-*yl*)*hexa*-2,3-*diene* (23).—Bromoform (103·5 g.) was added, during 1·5 hr., to a stirred and cooled (−10°) mixture of *trans*-5-(2-methyl-1,3-dioxolan-2-yl)pent-2-ene (63·5 g.) and potassium t-butoxide [from potassium (16 g.)] in pentane (70 ml.) under nitrogen. The mixture was stirred at 25° for 15 hr., and was then poured into water (200 ml.) and extracted with light petroleum (b.p. 60—80°). The combined extracts were washed (H_2O), dried, and evaporated. Distillation gave 1,1-dibromo-2-methyl-3-[2-(2-methyl-1,3-dioxolan-2-yl)-ethyl]cyclopropane (30 g., 22%), b.p. 98—105°/0·2 mm., n_D^{19} 1·5082—1·5088, $\nu_{max.}$ 1062, 946, and 862 cm.$^{-1}$, τ 6·13 (2 × CH_2·O), 8·0—8·6 (4H, m), 8·74 (Me), and 8·6—9·1 (5H, m). The dibromocyclopropane (66 g.) in ether (50 ml.) was added to a stirred mixture of magnesium (24·5 g.) and ether (100 ml.) at a rate such as to maintain gentle reflux. The mixture was boiled for 3 hr., then cooled and diluted with water and extracted with ether. The extracts were washed (H_2O), dried, and evaporated. Distillation gave the *allene* (21·2 g., 63%), b.p. 93—100°/16 mm., n_D^{19} 1·4655—1·4659. An analytical sample purified by preparative g.l.c. (30% XF-1150; 115°) had b.p. 110° (bath)/16 mm., n_D^{20} 1·4725, $\nu_{max.}$ 1970, 1063, 947, and 870 cm.$^{-1}$, τ 5·01 (m, 2 × :CH), 6·17 (2 × CH_2·O), 7·69—8·54 (4H, m), 8·36 (dd, *J* 5 and 5, :CH·C*H*$_3$), and 8·77 (Me) [Found: C, 71·3; H, 9·5%; *M* (mass spectrum), 168. $C_{10}H_{16}O_2$ requires C, 71·4; H, 9·6%; *M*, 168].

Octa-5,6-*dien*-2-*one* (7; R = :CH·CH_3).—Hydrolysis of 6-(2-methyl-1,3-dioxolan-2-yl)hexa-2,3-diene gave (88%) the *ketone*, b.p. 65—70°/16 mm., n_D^{19} 1·4548—1·4560. An analytical sample purified by preparative g.l.c. (30% Carbowax 20M; 115°) had b.p. 80° (bath)/16 mm., n_D^{20} 1·4662, $\nu_{max.}$ 1970 and 1715 cm.$^{-1}$, τ 5·0 (m, 2 × :CH), 7·41—8·12 (4H, m), 7·96 (Me), and 8·4 (dd, *J* 5 and 5, :CH·C*H*$_3$) [Found: C, 77·0; H, 10·0%; *M* (mass spectrum), 124. $C_8H_{12}O$ requires C, 77·4; H, 9·7%; *M*, 124].

Carboxylations with Magnesium Methyl Carbonate (MMC): General Procedure.—Solutions of MMC in dimethylformamide were prepared according to the method of Finkbeiner and Stiles.[14]

The methyl ketone (*ca.* 11 g.) was added to a solution of MMC (*ca.* 45 g.) in dimethylformamide (*ca.* 230 ml.), and the mixture was then heated to boiling under a fast stream of nitrogen; solvent which distilled off was continually replaced by the dropwise addition of dimethylformamide. After 0·5 hr. the mixture became viscous, and heating was then stopped. The solvent was evaporated off at 80° *in vacuo* and the residue was added to ice–water (200 ml.) and then acidified, at 0—5°, with 2N-hydrochloric acid. The mixture was then extracted, at 0°, with ether (6 × 50 ml.). The extracts were combined, washed (H_2O), and then evaporated at 0° *in vacuo*. Titration of the residue with N-potassium hydroxide (phenolphthalein) gave an essentially quantitative yield (by titration) of an aqueous solution of the potassium salt of the corresponding β-keto-acid. These solutions were used directly in the next stage.

Methyl esters of the β-keto-acids were prepared by treating the free acids, at 0°, with ethereal solutions of diazomethane, followed by isolation of the neutral product.

Potassium cis-2-*Oxo*-*octa*-5,7-*diene*-1-*carboxylate* (8c; R^1 = K). In accord with the general procedure, *cis*-octa-5,7-diene-2-one (10·9 g.) was heated with MMC (45 g.) in dimethylformamide (227 ml.), and the potassium salt of the β-keto-acid was isolated. The methyl ester had b.p. 76—86°/0·2 mm., n_D^{25} 1·4797, $\nu_{max.}$ 1755, 1725, 1655, 1635, 1597, 1002, 970, 910, and 795 cm.$^{-1}$, τ as in Table 1 and 6·33 (Me), 6·66 (CO·CH_2), and 7·23—7·73 (4H); the n.m.r. spectrum further indicated the presence (17%) of the *enol*-form [τ 5·08 (*H*C:CHOH)] of the ester (Found: C, 66·0; H, 7·9. Calc. for $C_{10}H_{14}O_3$: C, 65·9; H, 7·7%).

Potassium cis-2-*Oxo*-*hept*-5-*ene*-1-*carboxylate*. (8a; R^1 = K). In accord with the general procedure, *cis*-hept-5-en-2-one (10·6 g.) was heated with MMC (49·6 g.) in dimethyl formamide (250 ml.), and the potassium salt of the β-keto-acid was isolated. The methyl ester had b.p. 64—70°/0·3 mm., n_D^{25} 1·4549, $\nu_{max.}$ 1748, 1720, and 1630 cm.$^{-1}$, τ 4·65 (m, HC:CH), 6·33 (OMe), 6·68 (CO·CH_2), and 7·1—8·02 (4H, m); the n.m.r. spectrum further indicated the presence (10%) of the *enol*-form [τ 5·10 (*H*C:CHOH)] of the ester [Found: *M* (mass spectrum), 170. Calc. for $C_9H_{14}O_3$: *M*, 170]. The *copper chelate* had m.p. 98° (Found: C, 54·0; H, 6·5. $C_{18}H_{26}CuO_6$ requires C, 53·8; H, 6·5%).

Potassium cis-2-*Oxo*-*oct*-5-*ene*-1-*carboxylate* (8b; R^1 = K). In accord with the general procedure, *cis*-oct-5-en-2-one (11 g.) was heated with MMC (45·6 g.) in dimethylformamide (230 ml.), and the potassium salt of the β-keto-acid was isolated. The methyl ester had b.p. 84—85°/0·15 mm., n_D^{25} 1·4519, $\nu_{max.}$ 1749, 1720, and 1640 cm.$^{-1}$, τ 4·72 (m, HC:CH), 6·32 (OMe), 6·69 (CO·CH_2), 7·3—8·19 (6H, m), and 9·05 (t, *J* 8, Me); the n.m.r. spectrum further indicated the presence (14%) of the *enol*-form [τ 5·10 (*H*C:CHOH)] of the ester [Found: C, 65·7; H, 9·1; *M* (mass spectrum), 184. Calc. for $C_{10}H_{16}O_3$: C, 65·2; H, 8·75%; *M*, 184] (lit.,[34] n_D^{20} 1·4448).

Potassium-2-*Oxo*-*octa*-5,6-*diene*-1-*carboxylate* (8; R^1 = K, R = :CH·CH_3). In accord with the general procedure, octa-5,6-dien-2-one (10·8 g.) was heated with MMC (45 g.) in dimethylformamide (230 ml.), and the potassium salt of the β-keto-acid was isolated. The methyl ester had b.p. 70—80°/0·15 mm., $n_D^{21.5}$ 1·4659, $\nu_{max.}$ 1968, 1750, 1720, and 1638 cm.$^{-1}$, τ 4·99 (m, 2 × :CH), 6·39 (OMe), 6·58 (CO·CH_2), 7·21—8·03 (4H, m), and 8·42 (dd, *J* 4·5 and 5, :CH·C*H*$_3$).

Synthesis of the 3-*Hydroxyalkene*-2,5-*diones: General Procedure.*—An aqueous solution of the potassium salt of the

[35] H. O. House and T. H. Cronin, *J. Org. Chem.*, 1965, **30**, 1061.

β-keto-acid, and one of aqueous pyruvaldehyde (1·8—2 mol.; *ca.* 40% solution) were each adjusted to pH 8·2 (pH meter) and then mixed. The pH of the mixture was checked to be 8·2, and the solution was then kept under nitrogen at 25° for 48 hr. It was extracted with ether, and the combined extracts were washed (H_2O) and dried. Distillation gave the appropriate hydroxy-dione. Freshly prepared pyruvaldehyde was always used; experiments with commercial aqueous pyruvaldehyde gave lower yields of less pure products.

(±)-cis-3-*Hydroxyundeca*-8,10-*diene*-2,5-*dione* (9c). The potassium salt of the β-keto-acid [from *cis*-octa-5,7-dien-2-one (10·9 g.)] was treated with aqueous pyruvaldehyde [28·2 ml.; containing pyruvaldehyde (11·8 g.)]; the *hydroxy-diene-dione*, isolated (68%) as described, had b.p. 100—112°/0·35 mm., n_D^{24} 1·4956, $\lambda_{max.}$ 228 mμ (ε 18,600), $\nu_{max.}$ 3460, 1715, 1645, 1593, 1098, 1003, 970, 910, and 790 cm.$^{-1}$, τ as in Table 1 and 5·75 (dd, *J* 5 and 6, C*H*OH), 6·1 (OH), 7·22 (m, CO·CHH), 7·53 (4H, m), and 7·8 (Ac) (Found: C, 67·0; H, 7·9. $C_{11}H_{16}O_3$ requires C, 67·3; H, 8·2%).

(±)-cis-3-*Hydroxydec*-8-*ene*-2,5-*dione* (9a). The potassium salt of the β-keto-acid [from *cis*-hept-5-ene-2-one (10·6 g.)] was treated with aqueous pyruvaldehyde [33 ml.; containing pyruvaldehyde (13·6 g.)], and the hydroxy-dione, isolated (55%) as described, had b.p. 103—105°/0·4 mm., n_D^{22} 1·4702—1·4712, $\nu_{max.}$ 3470, 1718, and 1100 cm.$^{-1}$, τ 4·68 (m, HC:CH), 5·8 (dd, *J* 5 and 6, C*H*OH), 6·32 (OH), 7·26 (m, CO·CHH), 7·34—7·94 (4H, m), 7·81 (Ac), and 8·4 (d, *J* 5, :CH·CH_3) [Found: C, 65·0; H, 8·8%; *M* (mass spectrum), 184. Calc. for $C_{10}H_{16}O_3$: C, 65·2; H, 8·8%; *M*, 184 (lit.,[4] n_D^{20} 1·465—1·472).

(±)-cis-3-*Hydroxyundec*-8-*ene*-2,5-*dione* (9b). The potassium salt of the β-keto-acid [from *cis*-oct-5-en-2-one (11 g.)] was treated with aqueous pyruvaldehyde [30 ml.; containing pyruvaldehyde (12·6 g.)]; the hydroxy-dione, isolated (54%) as described, had b.p. 110—112°/0·3 mm., n_D^{24} 1·4680, $\nu_{max.}$ 3460, 1715, and 1095 cm.$^{-1}$, τ 4·73 (m, HC:CH), 5·78 (dd, *J* 5 and 6, C*H*OH), 6·32 (OH), 7·23 (m, CO·CHH), 7·32—8·23 (6H, m), 7·81 (Ac), and 9·04 (t, *J* 8, Me) [Found: C, 66·3; H, 9·5%; *M* (mass spectrum), 198. Calc. for $C_{11}H_{18}O_3$: C, 66·6; H, 9·2%; *M*, 198] (lit.,[4] n_D^{20} 1·461—1·463).

3-*Hydroxyundeca*-8,9-*diene*-2,5-*dione* (*Diastereoisomeric Mixture*) (9; R = :CH·CH_3). The potassium salt of the β-keto-acid [from (±)-octa-5,6-diene-2-one (10·8 g.)] was treated with aqueous pyruvaldehyde (32 ml.; containing pyruvaldehyde (12·6 g.)], and the hydroxy-dione, isolated (45%) as described, had b.p. 113—150°/0·3 mm., n_D^{21} 1·4877—1·4980. A sample purified by preparative g.l.c. (30% QF-1; 120°) had b.p. 140°/0·1 mm., n_D^{25} 1·4950, $\nu_{max.}$ 3450, 1970, 1720, and 1100 cm.$^{-1}$, τ 4·97 (m, 2 × :CH), 5·77 (dd, *J* 5 and 6, C*H*OH), 6·37 (OH), 7·23 (m, CO·CHH), 7·3—8·1 (4H, m), 7·8 (Ac), and 8·38 (dd, *J* 4·5 and 5, :CH·CH_3) [Found: C, 67·1; H, 8·3%; *M* (mass spectrum), 196. Calc. for $C_{11}H_{16}O_3$: C, 67·3; H, 8·2%; *M*, 196].

Synthesis of the Rethrolones: General Procedure.—The hydroxy-dione was shaken at 25° with 0·1N-aqueous sodium hydroxide containing ethanol and hydroquinone (100 mg.) under nitrogen for 3 hr. The mixture was acidified with concentrated hydrochloric acid and then extracted with ether (5 × 50 ml.). The ether extracts were washed with sodium hydrogen carbonate solution, then with water, and dried. Distillation gave the rethrolone, which was immediately sealed under vacuum; small samples were sometimes purified by preparative g.l.c.[36] (30% QF-1; glass column; 140°).

(±)-cis-4-*Hydroxy*-3-*methyl*-2-(*penta*-2,4-*dienyl*)*cyclopent*-2-*en*-1-*one* [(±)-cis-*pyrethrolone*] (1c). (±)-*cis*-3-Hydroxyundeca-8,10-dien-2,5-dione (11·7 g.) was cyclised in 0·1N-sodium hydroxide (360 ml.) containing ethanol (36 ml.), and the product was isolated as described. The rethrolone (8·1 g., 76%) had b.p. 110—130°/0·4 mm., n_D^{24} 1·5300. A sample purified by g.l.c. had b.p. 140° (bath)/0·1 mm., n_D^{25} 1·5440, $\lambda_{max.}$ 225·5 mμ (ε 29,500) [Elliott[21] gives n_D^{20} 1·5475, $\lambda_{max.}$ 225 mμ (ε 33,500) for natural (+)-pyrethrolone], $\nu_{max.}$ 3430, 1703, 1650, 1590, 1092, 1055, 1010, 960, 908, and 795 cm.$^{-1}$, τ ($CDCl_3$) as in Tables 1 and 2 [Found: *M* (mass spectrum), 178. Calc. for $C_{11}H_{14}O_2$: 178]. The semicarbazone had m.p. 200—201° (lit.,[3] 205—206° for the naturally derived racemic pyrethrolone). The 2,4-dinitrophenylhydrazone, prepared in methanol solution, and purified by chromatography in benzene–petroleum (b.p. 60—80°) (3 : 2) on Alumina I, had m.p. 192—193° (from benzene) (Found: C, 57·9; H, 4·9. Calc. for $C_{18}H_{20}N_4O_5$: C, 58·1; H, 5·4%).

(±)-cis-4-*Hydroxy*-3-*methyl*-2-(*but*-2-*enyl*)*cyclopent*-2-*en*-1-*one* [(±)-cis-*cinerolone*] (1a). (±)-*cis*-3-Hydroxydec-8-en-2,5-dione (5·7 g.) was cyclised in 0·1N-sodium hydroxide (190 ml.) containing ethanol (19 ml.) and the product was isolated as described. Distillation gave the rethrolone (3·2 g., 63%), b.p. 114—125°/0·25 mm., n_D^{23} 1·5138. A sample purified by g.l.c. had b.p. 140° (bath)/0·15 mm., n_D^{25} 1·5159, $\lambda_{max.}$ 230 mμ (ε 11,500), $\nu_{max.}$ 3425, 1703, 1650, 1090, 1053, and 1012 cm.$^{-1}$, τ ($CDCl_3$) as in Table 2 and 4·6 (m, HC:CH–), 8·31 (d, *J* 6, :CH·CH_3) [Found: C, 72·5; H, 8·7%; *M* (mass spectrum), 166. Calc. for $C_{10}H_{14}O_2$: C, 72·3; H, 8·5%; *M*, 166] (lit.,[4] n_D^{20} 1·5130). The semicarbazone had m.p. 196—197° [lit.,[2] m.p. 196—198° for the naturally derived racemic cinerolone semicarbazone, and m.p. 197—199° for the semicarbazone from synthetic (±)-*cis*-cinerolone].

(±)-cis-4-*Hydroxy*-3-*methyl*-2-(*pent*-2-*enyl*)*cyclopent*-2-*en*-1-*one* [(±)-cis-*jasmololone*] (1b). (±)-*cis*-3-Hydroxyundec-8-en-2,5-dione (9 g.) was cyclised in 0·1N-sodium hydroxide (280 ml.) containing ethanol (28 ml.) and the product was isolated as described. Distillation gave the rethrolone (5·44 g., 66%), b.p. 123—129°/0·4 mm., n_D^{24} 1·5117. A sample purified by g.l.c. had b.p. 140° (bath)/0·05 mm., n_D^{24} 1·5100, $\lambda_{max.}$ 230 mμ (ε 11,200), $\nu_{max.}$ 3400, 1700, 1645, 1090, 1050, and 1010 cm.$^{-1}$, τ ($CDCl_3$) as in Table 2 and 4·72 (m, HC:CH), 7·85 (m, :CH·CH_2·CH_3), and 9·04 (t, *J* 7·3, CH_2·CH_3) [Found: C, 73·3; H, 9·3%; *M* (mass spectrum), 180. Calc. for $C_{11}H_{16}O_2$: C, 73·3; H, 9·0%; *M*, 180] (lit.,[4] n_D^{20} 1·506—1·508). The semicarbazone had m.p. 195—196°.

4-*Hydroxy*-3-*methyl*-2-(*pent*-2,3-*dienyl*)*cyclopent*-2-*en*-1-*one* [*Allenolone* (*Diastereoisomeric Mixture*)](24). 3-Hydroxyundeca-8,9-dien-2,5-dione (8·6 g.) was cyclised in 0·1N-sodium hydroxide (210 ml.) containing ethanol (21 ml.), and the product was isolated as described. Distillation gave allenolone (3·75 g., 61%), b.p. 133—152°/0·5 mm. A sample purified by g.l.c. had b.p. 140° (bath)/0·1 mm., n_D^{26} 1·5288, $\lambda_{max.}$ 229 mμ (ε 9100), $\nu_{max.}$ 3405, 1968, 1698, 1653, 1095, 1055, and 1015 cm.$^{-1}$, τ ($CDCl_3$) as in Table 2 and 4·94 (m, 2 × :CH), and 8·40 (dd, *J* 6 and 5, :CH·CH_3) [Found: C, 74·0; H, 7·7%; *M* (mass spectrum), 178. Calc. for $C_{11}H_{14}O_2$: C, 74·1; H, 7·9%; *M*, 178].

Synthesis of the Rethrins: General Procedure.—The acid

[36] P. J. Godin and T. A. King, unpublished work.

chloride of (+)-*trans*-chrysanthemic acid was obtained as described previously.[2] (+)-*trans*-Pyrethroyl chloride was obtained from the hydrolysis of pyrethrum extract by a modification (due to Elliott and Janes [37]) of the earlier procedure.[38]

The rethrolone (0·004 mole) in benzene (15 ml.) and pyridine (2 ml.) was treated with the acid chloride (1·5 equiv.) in benzene (10 ml.), and the mixture was left at 25° for 12 hr. It was washed with sodium hydrogen carbonate solution, dilute hydrochloric acid, and water, and the benzene solution was then dried. Evaporation of the solvent followed by chromatography of the residue in benzene–light petroleum (b.p. 60—80°) on Alumina (Woelm neutral, grade I; 50 g.) [t.l.c. control; silica gel; benzene–ethyl acetate (4 : 1)] gave pure (>95%) pyrethrins (by n.m.r.). Cinerin I, jasmolin I, and the rethrin from allenolone and *trans*-chrysanthemoyl chloride could also be purified by preparative g.l.c. (30% QF-1; 5 ft. × 3/8 in. glass columns; 200°) without appreciable decomposition (*cf.* ref. 23).

(±)-*Penta*-cis-2′-*dienylrethronyl*-(+)-trans-*chrysanthemate* [(±)-*pyrethrin I*] (3e). The ester, prepared and purified as described, had n_D^{25} 1·5179, $\lambda_{max.}$ 224 mμ, $\nu_{max.}$ 1723, 1712, 1660, 1595, 995, and 905 cm.$^{-1}$ (i.r. spectrum closely similar to that of the natural material [1]); for τ values in this and the following cases see ref. 22.

(±)-*But*-cis-2′-*enylrethronyl*-(+)-trans-*chrysanthemate* [(±)-*cinerin I*] (3a). The ester, prepared as described above and purified by g.l.c., had n_D^{24} 1·5068, $\nu_{max.}$ 1725, 1715, and 1660 cm.$^{-1}$ (i.r. spectrum closely similar to that of the natural material [1]).

(±)-*Pent*-cis-2′-*enylrethronyl*-(+)-trans-*chrysanthemate* [(±)-*jasmolin I*] (3c). The ester, prepared as described above and purified by g.l.c., had n_D^{25} 1·5039, $\nu_{max.}$ 1723, 1715, and 1660 cm.$^{-1}$ [i.r. spectrum closely similar to that of synthetic (±)- and natural (+)-cinerin I].

Penta-2′,3′-*dienylrethronyl*-(+)-trans-*chrysanthemate* (*Allene-rethrin I*; *Diastereoisomeric Mixture*) (3; R = :CH·CH_3, R^1 = Me). The ester, prepared as described above and purified by g.l.c., had n_D^{25} 1·5128, $\nu_{max.}$ 1963, 1723, 1715, and 1660 cm.$^{-1}$; the n.m.r. spectrum was closely similar to the combined spectra of allenolone (see text) and methyl (±)-*trans*-chrysanthemate (2a; ester); *cf.* ref. 22.

(±)-*Penta*-cis-2′-*dienylrethronyl*-(+)-trans-*pyrethrate* [(±)-*pyrethrin II*] (3f). The ester, prepared and purified as described, had $n_D^{23·5}$ 1·5190, $\lambda_{max.}$ 227·5 mμ, $\nu_{max.}$ 1720, 1712, 1660, 995, and 910 cm.$^{-1}$, (i.r. spectrum closely similar to that of the natural material [1]).

(±)-*But*-cis-2′-*enylrethronyl*-(+)-trans-*pyrethrate* [(±)-*cinerin II*] (3b). The ester, prepared and purified as described, had $n_D^{22·5}$ 1·5135, $\lambda_{max.}$ 233·5 mμ, $\nu_{max.}$ 1720, 1712, and 1648 cm.$^{-1}$ (i.r. spectrum closely similar to that of the natural material [1]).

(±)-*Pent*-cis-2′-*enylrethronyl*-(+)-trans-*pyrethrate* [(±)-*jasmolin II*] (3d). The ester, prepared and purified as described, had n_D^{25} 1·5119, $\lambda_{max.}$ 232 mμ, $\nu_{max.}$ 1722, 1713, and 1650 cm.$^{-1}$ [i.r. spectrum closely similar to that of synthetic (±)- and natural (+)-cinerin II].

Penta-2′,3′-*dienylrethronyl*-(+)-trans-*pyrethrate* (*Allene-rethrin II*; *Diastereoisomeric Mixture*) (3; R = :CH·CH_3; R^1 = CO_2Me). The ester, prepared and purified as described, had $n_D^{21·5}$ 1·5238, $\lambda_{max.}$ 232 mμ, $\nu_{max.}$ 1963, 1716, and 1653 cm.$^{-1}$, n.m.r. spectrum closely similar to the combined spectra of allenolone (see text) and methyl (+)-*trans*-pyrethrate (2b; ester); *cf.* ref. 22.

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[38] F. B. LaForge, W. F. Gersdorff, N. Green, and M. S. Schechter, *J. Org. Chem.*, 1952, **17**, 381.