

Pericyclic Reactions of the Enolate Ions of 2,6,6-Trimethylcyclohepta-2,4-dienone and 1,4,4-Trimethylbicyclo[5.1.0]oct-5-en-2-one †

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The rate at which the enolate ions of 2,6,6-trimethylcyclohepta-2,4-dienone (III), and 1,4,4-trimethylbicyclo[5.1.0]oct-5-en-2-one (XII) undergo pericyclic reactions has been investigated by studying the n.m.r. spectra of the anions, and by methylation. In the case of (XII), Cope rearrangement of the enolate ion produces an isolable isomeric ketone. The thermal rearrangement of three 3-alkylcar-4-en-2-ones has been studied. Dehydration of 1,4,4-trimethylbicyclo[5.1.0]oct-5-en-2-ol (XX), and its 2-methyl homologue (XXII), using phosphorus pentoxide-benzene or polyphosphoric acid, involves extensive, but stereospecific, structural changes producing di- and tri-methylisopropylbenzenes respectively.

THE formation of bicyclic products from the enolate ion (I) of eucarvone (III), *e.g.* during alkylation, is generally considered to proceed *via* the bicyclic enolate ion (II),¹ involving a hexatriene-cyclohexadiene disrotatory electrocycloisomerisation. However, Corey *et al.*^{1c} concluded from their results that anion (II) was probably much less stable than anion (I). In order to examine further the equilibrium between (I) and (II) we have recorded the n.m.r. spectrum of the anion formed from eucarvone (III). In contrast to the conclusion of Corey *et al.*, we find that anion (II) is slightly more stable than anion (I).

A solution of the enolate ion was generated by treating eucarvone ² with sodium hydride in dioxan, followed by removal of the insoluble material. We interpret the n.m.r. spectrum ‡ at 28° as a time-averaged spectrum of the anions (I) and (II): δ 5.82 (d, 3-H), 5.17 (t, 4-H), 3.15 (t, 5-H), 2.45 (d, 7-H) ($J_{3,4}$ 5.5, $J_{4,5}$ 6.6, and $J_{5,7}$ 7.4 Hz), 1.81 (s, 2-Me), and 0.95 (s, 6-Me₂) [numbering as for (I)]. From the chemical shifts of 5-H in the averaged spectrum, and using the chemical shift of 5-H in eucarvone itself (δ 5.95), and of 6-H in 3-methylcar-4-en-2-one ^{1a} (δ 1.69) as approximate values for the shifts of 5-H in (I) and 6-H in (II) respectively, we calculate that the equilibrium mixture of (I) and (II) contains $66 \pm 2\%$ of (II).

The n.m.r. spectrum of the enolate ions in dioxan at 100° showed no change from the spectrum at 28°. In order to observe the spectrum at lower temperatures, the anions were generated in tetrahydrofuran (THF) in a similar manner. This enabled us to observe the doublet and triplet at lower field, but the remainder was partially obscured by the THF absorption. The signals broadened with decreasing temperature, until at -70° the triplet had become a broad singlet and a new broad singlet of intensity one third that of the original triplet had appeared midway between the original doublet and triplet absorptions. At -90°, the doublet had also become a broad singlet. We were unable to observe a well resolved spectrum of (I) plus (II).

Methylation of the enolate ion of eucarvone was reported by Corey and Burke ² to produce a single product,

† Preliminary communication, A. J. Bellamy and W. Crilly, *Tetrahedron Letters*, 1973, 1893.

‡ The chemical shifts reported here were obtained using dioxan (δ 3.55) as an internal reference, and differ from those given in the preliminary communication; the latter were obtained using external benzene or tetramethylsilane as reference.

3-methylcar-4-en-2-one (IV), but recent investigations ^{1a,3} have shown that a product derived from the monocyclic enolate ion (I), 2,6,6,7-tetramethylcyclohepta-2,4-dienone (V) is usually formed as well. Under certain conditions two further products are formed, *viz.* 1,3-dimethylcar-4-en-2-one (VI) and probably 2-methoxy-3-methylcar-4-ene (<3%). Product (VI) can be formed from (IV) or (V), but the predominant route to (VI) is probably *via* (V). We have studied the variation in the amounts of the alkylated products (IV)–(VI) formed from eucarvone under a variety of conditions (see Table and Experimental section). Under conditions where little or no (VI)

Methylation of anions derived from eucarvone

Reactants (mmol)	Type of experiment							
	A			B				
	Products (%)			Products (%)				
(III)	NaH	MeI	(IV)	(V)	(VI)	(IV)	(V)	(VI)
2	1	3	76		24	82		18
2	1	5	77	1	22	74	1	25
1	10	5	78	2	20	71	13	16
1	10	20	78	9	13	77	16	7

is formed, there appears to be no significant difference in the ratio (IV) : (V) when methyl iodide is added after the generation of the anion (type A experiment) compared with the ratio when methyl iodide is present during the generation of the anion (type B experiment).

This indicates that the rate of interconversion of the anions (I) and (II) is much faster than either is converted into methylated product, and the amount of (IV) formed, 74–82%, indicates that anion (II) is more reactive than anion (I) by a factor of about 2. When the methylation was performed at low temperature (see Experimental section) in THF, the amount of product (IV) was increased to 93%.

Alkylation of the anion of eucarvone with benzyl chloride ^{1a,2} and allyl bromide gave exclusively bicyclic products, (VII) and (VIII) respectively.

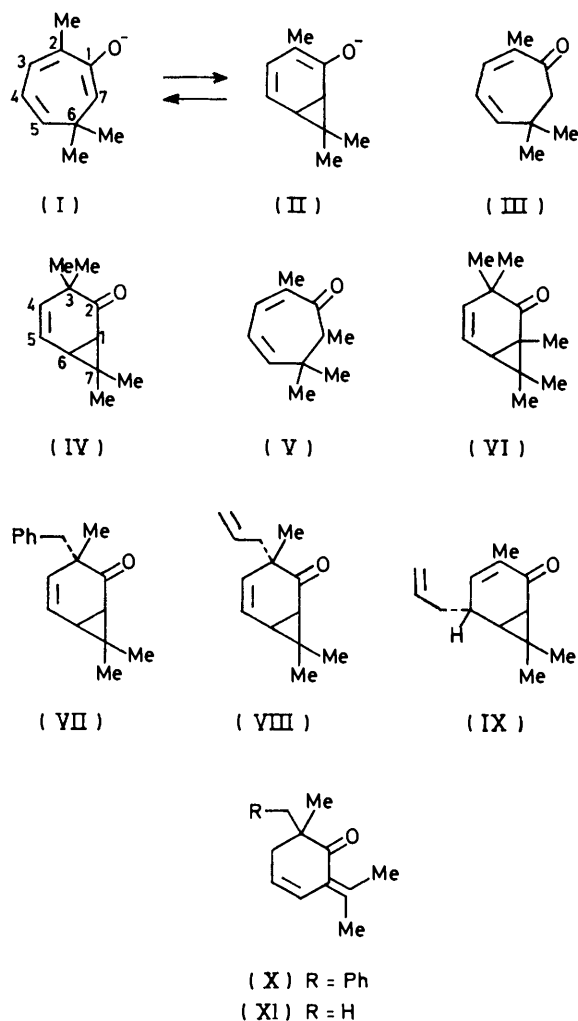
Thermal Rearrangements of 3-Alkylcar-4-en-2-ones.—At 150° in nonane, 3-(prop-2-enyl)car-4-en-2-one (VIII)

¹ (a) A. J. Bellamy and W. Crilly, *J.C.S. Perkin II*, 1972, 395; (b) A. J. Bellamy, *J. Chem. Soc. (B)*, 1969, 449; (c) E. J. Corey, H. J. Burke, and W. A. Remers, *J. Amer. Chem. Soc.*, 1956, **78**, 180.

² E. J. Corey and H. J. Burke, *J. Amer. Chem. Soc.*, 1956, **78**, 174.

³ A. J. Bellamy and G. H. Whitham, *Tetrahedron*, 1968, **24**, 247.

was quantitatively converted into 5-(prop-2-enyl)car-3-en-2-one (IX) by a Cope rearrangement. The product, in ether, was surprisingly stable when treated with methanolic potassium hydroxide, conditions which rapidly convert car-3-en-2-one into eucarvone.⁴ This stability is



presumably due to the hindered nature of the 5-H in (IX). However, when treated with 1M-ethanolic sodium ethoxide (single phase), the u.v. absorption of (IX) (λ_{max} 231 nm) steadily decreased, while an absorption maximum at 310 nm, characteristic of a cyclohepta-2,4-dienone, increased. The latter decreased in intensity after 25 min. (Eucarvone itself was not stable under these conditions.) Similar behaviour was observed with 5-propylcar-3-en-2-one; the latter was obtained by selective reduction of the propenyl double bond in (IX) using di-imide or catalytic hydrogenation.

The thermal behaviour of 3-benzylcar-4-en-2-one (VII) was investigated for comparison with that of (VIII). In this case the rearrangement was much slower even at

* Cf. car-2-ene isomerises to 3-isopropenyl-6-methylcyclohexene at 200° (G. Ohloff, *Tetrahedron Letters*, 1965, 3795).

⁴ W. D. P. Burns, M. S. Carson, W. Cocker, and P. V. R. Shannon, *J. Chem. Soc. (C)*, 1968, 3073.

190°, and the product was not 5-benzylcar-3-en-2-one as expected by analogy with (VIII), but probably 6-benzyl-2-isopropylidene-6-methylcyclohex-3-enone (X). 3-Methylcar-4-en-2-one (IV) behaved in a similar manner to (VII), the product being probably 6,6-dimethyl-2-isopropylidene-cyclohex-3-enone (XI). The thermal rearrangement of (VII) and (IV) therefore appears to be a 1,5-migration of hydrogen from the *endo*-methyl group at C(7) to C(4) with participation by the C(4)-C(5) double bond and the C(6)-C(7) cyclopropane bond to give a 6-alkyl-2-isopropenyl-6-methylcyclohex-3-enone, which isomerises, *via* enolisation of the carbonyl group, to give (X) or (XI) respectively.*

1,4,4-Trimethylbicyclo[5.1.0]oct-5-en-2-one (XII).—Homotropylidene was demonstrated by Doering and Roth^{5a} to undergo a reversible Cope rearrangement when in its *cisoid*-conformation.^{5b} The rate of isomerisation was considerably slower than that of bullvalene because homotropylidene exists predominantly in the unreactive *transoid*-conformation.

Since the enolate ion (XIII) of 1,4,4-trimethylbicyclo[5.1.0]oct-5-en-2-one⁶ (XII) has a similar structure to homotropylidene, it seemed reasonable to expect (XIII) to undergo a similar Cope rearrangement. In this case, the structure of the rearranged ion would be different from (XIII), *viz.* (XIV).

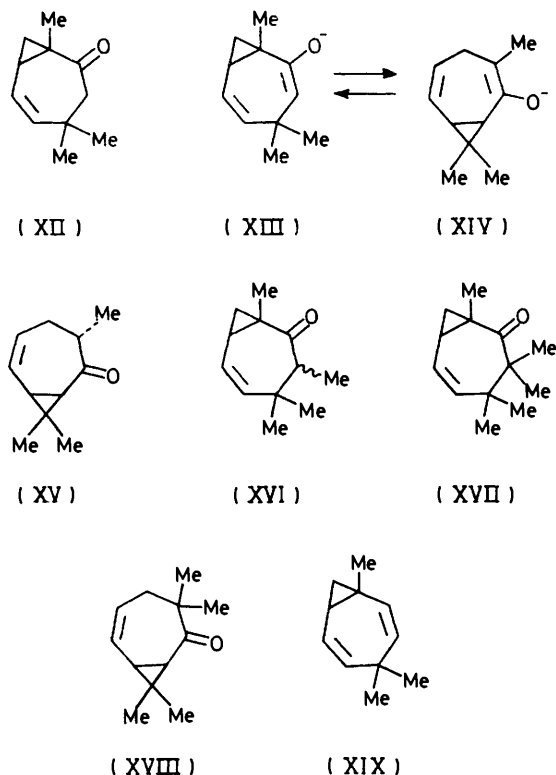
The anion of (XII) was generated in the same manner as for eucarvone (III) and the resulting solution in dioxan was heated at 100° during 20 h before quenching the anion in ethereal acetic acid. The product was a mixture of ketones (XII) and (XV) in the ratio of 3 : 2. The ketones were isolated by reduction of the mixture to the corresponding alcohols, separation of the latter, and oxidation of these back to the ketones. The new ketone (XV) had similar spectral properties to (XII) except that the n.m.r. spectrum was more complex due to a considerable amount of long range coupling. Base catalysed deuterium exchange of the ketone (XV), while removing the absorption of 1- and 3-H from the n.m.r. spectrum, complicated the spectrum by producing two ketones epimeric at C(3).

Hydrogenation of ketone (XII) is reported⁶ to give 2,2,6,6-tetramethylcycloheptanone and 3,3,8-trimethylcyclo-octanone in the ratio 3 : 1. Hydrogenation of ketone (XV) under similar conditions gave 3,8,8-trimethylbicyclo[5.1.0]octan-2-one when the reaction was stopped after the uptake of 1 mol. equiv. of hydrogen, and a further reduced product possessing three exchangeable hydrogen atoms if the hydrogenation was allowed to proceed further. Reductive cleavage of either C(1)-C(7) or C(1)-C(8) would give products with the observed characteristics. Treatment of the saturated ketone 3,8,8-trimethylbicyclo[5.1.0]octan-2-one, with lithium in ammonia gave two products (ratio 7 : 3), both resulting

⁵ (a) W. von E. Doering and W. R. Roth, *Angew. Chem. Internat. Edn.*, 1963, 2, 115; *Tetrahedron*, 1963, 19, 715; (b) L. Birladeanu, D. L. Harris, and S. Winstein, *J. Amer. Chem. Soc.*, 1970, 92, 6387.

⁶ E. J. Corey and M. Chaykovsky, *J. Amer. Chem. Soc.*, 1965, 87, 1353.

from cleavage of a cyclopropane bond adjacent to the carbonyl group,⁷ since they both contained three exchangeable hydrogen atoms. It is not possible, however, to deduce the complete structures of these two products



on the basis of the available evidence, owing to the possibility of epimerisation of the methyl group adjacent to the carbonyl group.

The n.m.r. spectrum of the anions (XIII) and (XIV) in diphenyl ether was recorded between 100 and 200°. At 100° the spectrum showed separate absorptions for the two ions, in the ratio of 4 : 5, and even at 200° only slight broadening of the spectrum was observed. Thus interconversion of the two ions by Cope rearrangement is considerably more difficult than for homotropyliidene itself. This is presumably due to the former possessing a more crowded *cisoid*-conformation^{5b} because of the *gem*-dimethyl group at C(4) in (XIII) and at C(8) in (XIV). The slowness of the Cope rearrangement in anion (XIII) is reflected in the lack of structural change when ketone (XII) is subjected to base catalysed deuterium exchange. By contrast, similar treatment of bullvalone results in all ten hydrogen atoms being replaced by deuterium; the enolate ion of bullvalone is fixed in a *cisoid*-conformation facilitating rapid Cope rearrangement, the latter allowing all hydrogen atoms in turn to reside α to the carbonyl group.⁸

The products of methylation of the anion of (XII) were also consistent with a slow interconversion of anions (XIII) and (XIV). When methyl iodide was present

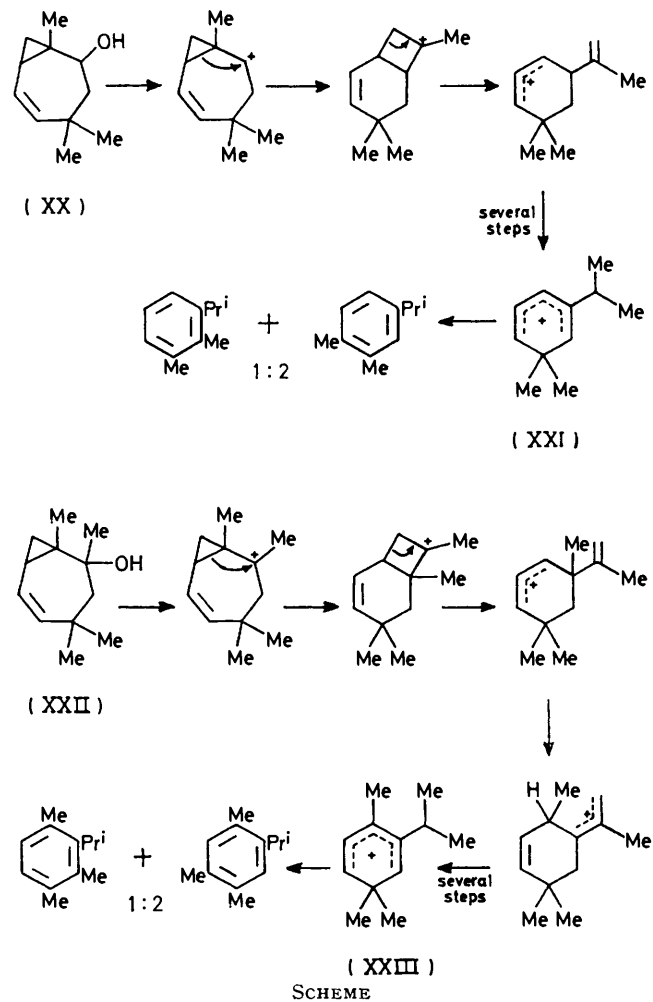
⁷ T. Norin, *Acta Chem. Scand.*, 1965, **19**, 1289.

⁸ W. von E. Doering, *Tetrahedron*, 1967, **23**, 3943.

during the generation of the anion, only products derived from anion (XIII) were obtained, *viz.* (XVI) (*cis* and *trans*) and (XVII). When methyl iodide was added to the equilibrated anion, one further major product was obtained derived from anion (XIV), *viz.* (XVIII).

Systems related to Ketone (XII).—Having observed Cope rearrangement in the anion (XIII), we hoped to observe similar behaviour in the related homotropyliidene, (XIX). Our attempts to synthesise (XIX) involved dehydration of the alcohol (XX) derived from ketone (XII). The alcohol used was a mixture of both epimers (9 : 1).

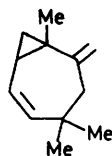
Dehydration using phosphorus pentoxide in benzene, or polyphosphoric acid, gave a mixture of two hydrocarbons (2 : 1) which were shown to be 1,2,4-isopropyl-dimethylbenzene and 1-isopropyl-2,3-dimethylbenzene respectively (see Experimental section). Dehydration of the tertiary alcohol (XXII), also derived from ketone (XII), under the same conditions, again gave two hydrocarbons (2 : 1) which were shown to be 1-isopropyl-2,4,5-trimethylbenzene and a 1,2,3,4-isopropyltrimethylbenzene respectively (see Experimental section). Since the



pairs of hydrocarbons formed from the two alcohols (XX) and (XXII) are structurally similar, and since they are formed in the same ratios, we suggest they are formed

from closely related intermediates, *viz.* (XXI) and (XXIII), in which the steric and electronic factors controlling the direction of methyl migration are virtually identical. A probable route for the formation of these intermediates from the parent alcohols is shown in the Scheme.

Dehydration of the tertiary alcohol (XXIII) was also attempted thermally. Doering⁸ used this method for the preparation of methylbullvalene. Three major hydrocarbon products were formed, only one of which, 1,4,4-trimethyl-2-methylenebicyclo[5.1.0]oct-5-ene (XXIV) (52%) was isolated and characterised. The other products did not exhibit temperature dependent n.m.r. spectra. Other methods to dehydrate alcohols (XX) and



(XXIV)

(XXII) were even less satisfactory (see Experimental section).

EXPERIMENTAL

All new compounds were purified by preparative g.l.c., and their purity was >95%. Elemental analyses were not obtained because further purification was precluded by the limited amounts of material available: in all cases the compounds were fully characterised spectroscopically.

N.m.r. Spectrum of the Anion of Eucarvone.—Eucarvone² (6.6 mmol) in dry dioxan (2 ml) was added under nitrogen to a stirred suspension of sodium hydride (40 mmol) in dioxan, and the mixture was refluxed for 2 h. After cooling to 20°, the mixture was centrifuged and the resultant solution was transferred to an n.m.r. tube containing an external benzene lock. Chemical shifts and coupling constants were determined using the computer program LAOCOON with magnetic equivalence where appropriate: δ (obs) 5.821 (d, 3-H), 5.166 (t, 4-H), 3.152 (t, 5-H), and 2.449 (d, 7-H) ($J_{3,4}$ 5.2, $J_{4,5}$ 7.0, and $J_{5,7}$ 7.5 Hz); δ (calc.) 5.8184 (3-H), 5.16831 (4-H), 3.15195 (5-H), and 2.45008 (7-H) ($J_{3,4}$ 5.501, $J_{4,5}$ 6.557, and $J_{5,7}$ 7.377 Hz); std. deviation for δ (calc.), 0.0012 p.p.m.; std. deviation for J (calc.), 0.168 Hz.

Methylation of Eucarvone.^{1a,2,3}—Eucarvone (1–2 mmol) and sodium hydride (1–10 mmol) in dioxan (3 ml) were refluxed under nitrogen for 2 h. After cooling to 20°, methyl iodide (3–20 mmol) was added and stirring was continued for 1.5 h. The mixture was poured into ether containing an excess of acetic acid and the product was isolated and analysed (Type A experiment).

Alternatively, the methyl iodide was added to the stirred suspension of sodium hydride before the eucarvone, the mixture in this case being refluxed for 3.5 h (Type B experiment). G.l.c. analysis indicated that 80–90% of the methyl iodide remained in the liquid phase during refluxing.

The product mixture consisted mainly of 3-methylcar-4-en-2-one (~75%), with smaller and variable amounts of 2,6,6,7-tetramethylcyclohepta-2,4-dienone (V), 1,3-dimethylcar-4-en-2-one (VI), and probably 2-methoxy-3-methylcar-4-ene. The products were separated by preparative g.l.c. (15% Carbowax 20M, 120°). The physical proper-

ties of 3-methylcar-4-en-2-one and 2,6,6,7-tetramethylcyclohepta-2,4-dienone have been reported.^{10,3} 1,3-Dimethylcar-4-en-2-one had ν_{\max} (film) 1695 and 1016 cm^{-1} , M^+ 178, δ (CCl_4) 5.72 (2 d, $J_{4,5}$ 10, $J_{5,6}$ 3.6 Hz, 5-H), 5.48 (d, $J_{4,5}$ 10 Hz, 4-H), 1.66 (m, $J_{5,6}$ 3.6 Hz, 6-H), and 1.29, 1.20, 1.10, 1.04, and 0.83 (5 s, 1-Me, 3-Me₂, and 7-Me₂). The product which is thought to be 2-methoxy-3-methylcar-4-ene had ν_{\max} (film) 1140 and 1014 cm^{-1} , M^+ 180, δ (CCl_4) 5.49 (m, 4- and 5-H), 3.47 (m, 2-H), 3.20 (s, OMe), 1.0–2.0 (m, 1- and 6-H), and 1.13, 1.07, 0.99, and 0.92 (4 s, 3- and 7-Me₂).

A solution of the anion of eucarvone [from eucarvone (3 mmol) and sodium hydride (3 mmol)] in tetrahydrofuran (THF) (5 ml) was cooled to -116° and methyl iodide (17 mmol) was added. After keeping at -116° for 3 h, the solution was allowed to warm slowly to 20°. The reaction was then quenched and the product was isolated as a mixture of 3-methylcar-4-en-2-one (93%), 2,6,6,7-tetramethylcyclohepta-2,4-dienone (6%), and 1,3-dimethylcar-4-en-2-one (1%).

Preparation of 3-(Prop-2-enyl)car-4-en-2-one (VIII).—Allyl bromide (0.132 mol) was added with stirring under nitrogen to a solution of the anion of eucarvone [from eucarvone (0.066 mol) and sodium hydride (0.132 mol)] in dioxan (50 ml) at 20°, and stirring was continued during 2 h. The excess of sodium hydride was destroyed by careful addition of glacial acetic acid, the mixture was poured into brine (250 ml), and the product was extracted and distilled, b.p. 60° at 0.3 mmHg, ν_{\max} (film) 1687 and 1014 cm^{-1} , M^+ 190, δ (CCl_4) 5.81 (m, $J_{4,5}$ 10, $J_{5,6}$ 3.5, $J_{1,5}$ 1 Hz, 5-H), 5.53 (m, $J_{1',2'}$ 8, $J_{2',3'}$ 6.5 Hz, 2'-H), 5.38 (d, $J_{4,5}$ 10 Hz, 4-H), 5.00 (d, J_{gem} 0.7 Hz, 3'-H *trans*), 4.86 (d, further split, J_{gem} 0.7, $J_{2',3'}$ 6.5 Hz, 3'-H *cis*), 2.12 (2 q further split, $J_{1',2'}$ 8 Hz, 1'-H₂), 1.59 (2 d, $J_{1,6}$ 7, $J_{5,6}$ 3.5 Hz, 6-H), 1.53 (2 d, $J_{1,6}$ 7, $J_{1,5}$ 1 Hz, 1-H), and 1.22, 1.00, and 0.94 (3 s, 3-Me and 7-Me₂).

Thermal Rearrangement of 3-(Prop-2-enyl)car-4-en-2-one (VIII).—The ketone (10 mmol) in dry nonane (b.p. 149°) was refluxed until ν_{\max} (nonane) 1690 cm^{-1} had been replaced by ν_{\max} (nonane) 1655 cm^{-1} (~2.5 h). [The rearrangement was also carried out in boiling decalin (b.p. 190°) during 15 min, and by flow pyrolysis at 380°, but these methods gave a less pure product.] A quantitative yield of 5-(prop-2-enyl)car-3-en-2-one (IX) was obtained, ν_{\max} (film) 1655 and 1016 cm^{-1} , λ_{\max} (EtOH) 231 nm ($\log \epsilon$ 4.02), M^+ 190, δ (CCl_4) 6.20br (m, $J_{4,5}$ 2, $J_{4,\text{Me}}$ 1 Hz, further coupled to 6-H, 4-H), 5.74 (m, 2'-H), 5.02br (d, J_{gem} 2 Hz, 3'-H₂), 2.43 (m, $J_{5,6}$ 2, $J_{1,5}$ 1.5, $J_{5,\text{Me}}$ 1.5 Hz, 5-H), 2.29 (m, 1'-H₂), 1.67 (t, $J_{5,\text{Me}}$ 1.5, $J_{4,\text{Me}}$ 1 Hz, 3-Me), 1.52 (2, d, $J_{1,5}$ 1.5, $J_{1,6}$ 7.5 Hz, 1-H), 1.18br (2, d, $J_{1,6}$ 7.5, $J_{5,6}$ 2 Hz, 6-H), and 1.17 and 1.03 (2 s, 7-Me₂). Car-3-en-2-one has ν_{\max} 1695 cm^{-1} , λ_{\max} (EtOH) 227 nm, δ 6.25 (4-H), 1.7 (3-Me), 1.48 (1- and 6-H), and 1.22 and 1.09 (7-Me₂).⁴

Methanolic potassium hydroxide (40%; 0.5 ml) was added to the product (60 mg) in ether (10 ml) at 0°, and the mixture was stirred for 1 h. After neutralisation with dilute hydrochloric acid, the isolated product (40 mg; b.p. 60° at 0.1 mmHg) was unchanged 5-propenylcar-3-en-2-one.

The u.v. spectrum of 5-propenylcar-3-en-2-one in methanolic sodium ethoxide (0.2 mg in 10 ml) was recorded at intervals for 1 h. The maximum at 231 nm decreased steadily, while a maximum at 310 nm increased during the first 25 min, and then decreased steadily.

Preparation of 5-Propylcar-3-en-2-one.—Acetic acid (5 mmol) was added under nitrogen to a stirred mixture of 5-(prop-2-enyl)car-3-en-2-one (0.25 mmol) and potassium azodicarboxylate (0.5 mmol) in ether (4 ml). When the

reaction ceased (36 h; as determined by g.l.c.), the solid was filtered off and the product was isolated by distillation, b.p. 45° at 0.05 mmHg, g.l.c. analysis indicated only one product, ν_{\max} (film) 1660 cm^{-1} , M^+ 192, δ (CCl_4) 6.20 (m, $J_{4,5}$ 1.5, $J_{4,\text{Me}}$ 1.5 Hz, further coupled to 6-H, 4-H), 2.40br (s, 5-H), 1.68 (t, $J_{4,\text{Me}}$ 1.5, $J_{5,\text{Me}}$ 1.5 Hz, 3-Me), 1.25—1.50 (m, $J_{1,5}$ 1.5, $J_{1,6}$ 7.5 Hz, 1-H, 1'-H₂, and 2'-H₂), 1.19 (s, 7-Me), 1.17br (d, $J_{1,6}$ 7.5 Hz, 6-H), 1.05 (s, 7-Me), and 0.97br (t, $J_{2',\text{Me}}$ 6 Hz, 3'-H₃). Hydrogenation over platinum in methanol gave the same product.

Thermal Rearrangement of 3-Benzylcar-4-en-2-one (VII).—A solution of 3-benzylcar-4-en-2-one^{1a,2} in decalin (1 : 10) was refluxed under nitrogen during 72 h. The rearrangement was monitored by g.l.c. The product, 6-benzyl-2-isopropylidene-6-methylcyclohex-3-enone (X), b.p. 110—115° at 0.05 mmHg, was pure by g.l.c., λ_{\max} (EtOH) 282 nm (ϵ 6130), ν_{\max} (film) 1690 and 1630 cm^{-1} , M^+ 240.151407 ($\text{C}_{17}\text{H}_{20}\text{O}$), δ (CCl_4) 7.14 (m, Ph), 6.55 (2 t, $J_{4,5}$ 10, $J_{3,5}$ 1.75 and 1.25 Hz, 5-H), 5.66 (2 t, $J_{4,5}$ 10, $J_{3,4}$ 4.5 and 4.25 Hz, 4-H), 2.80 (m, J_{gem} 14 Hz, PhCH_2), 2.23br (m, $J_{3,4}$ 4.5 and 4.25, $J_{3,5}$ 1.75 and 1.25 Hz, 3-H₂), 2.10br (s, vinylic Me), 1.94br (s, vinylic Me), and 1.03 (s, 2-Me).

The product was reduced to an alcohol with lithium hydridotri-*t*-butoxyaluminate in ether. The alcohol (two epimers) had λ_{\max} (EtOH) 242 nm ($\log \epsilon \sim 5.24$), ν_{\max} (film) 3500 and 1607 cm^{-1} , M^+ 242, δ (CCl_4) 7.15 (m, Ph), 6.30br (t, $J_{4,5}$ 12.5 Hz, 5-H), 5.60br (m, $J_{4,5}$ 12.5 Hz, 4-H) 3.97br (s, OH), 2.1—3.0 (4 d, J_{gem} 12.5 Hz, PhCH_2), 1.5—2.4 (several m, 3-H₂), 1.85br (s, vinylic Me), 1.78 and 1.75 (2 s, vinylic Me), 1.10 (m, 1-H), 0.96 and 0.52 (2 s, 3-Me, ratio 1.3 : 1).

Thermal Rearrangement of 3-Methylcar-4-en-2-one (IV).—The rearrangement was carried out as for the benzyl derivative, and the product was purified by preparative g.l.c. (15% Carbowax 20M, 140°) to give 2-isopropylidene-6,6-dimethylcyclohex-3-enone (XI), b.p. 82° at 10 mmHg, λ_{\max} (EtOH) 276 nm, ν_{\max} (film) 1690 and 1630 cm^{-1} , M^+ 164, δ (CCl_4) 6.43 (2 t, $J_{4,5}$ 10, $J_{3,5}$ 1.5 Hz, 5-H), 5.58 (2 t, $J_{4,5}$ 10, $J_{3,4}$ 4 Hz, 4-H), 2.24br (d, $J_{3,4}$ 4, $J_{3,5}$ 1.5 Hz, 3-H₂), 2.03 (s, vinylic Me), 1.87 (vinylic Me), and 1.05 (s, 2-Me₂).

Preparation of 1,4,4-Trimethylbicyclo[5.1.0]oct-5-en-2-one (XII).—Trimethyloxosulphonium iodide was prepared by treating dimethyl sulphoxide (96 g) with methyl iodide (180 ml) at 20° during 14 days. The yellow solid which crystallised out was filtered off, washed with chloroform, and dried (P_2O_5).

Dimethyl sulphoxide (375 ml) was added dropwise under nitrogen to a stirred mixture of sodium hydride (7.56 g, 0.315 mol) and trimethyloxosulphonium iodide (69.3 g, 0.315 mol). When the evolution of hydrogen had subsided, eucarvone² (45.0 g, 0.3 mol) was added with cooling. The mixture was stirred at 20° for 2 h and then at 50° for 1 h. Water (1200 ml) was added, and the product was isolated with ether (2 \times 500 ml). Distillation gave pure 1,4,4-trimethylbicyclo[5.1.0]oct-5-en-2-one (39 g, 80%), b.p. 98° at 12 mmHg, ν_{\max} (film) 1670 cm^{-1} , δ (CCl_4) 5.66 (2 d, $J_{5,6}$ 12, $J_{6,7}$ 5.5 Hz, 6-H), 5.33 (2 d, $J_{5,6}$ 12, $J_{3,5}$ 2 Hz, 5-H), 2.66br (d, J_{gem} 12 Hz, further coupled to Me at δ 0.90, 3-H), 1.98 (2 d, J_{gem} 12, $J_{3,5}$ 2 Hz, 3-H), 1.70—1.20 (m, 7-H and 8-H₂), and 1.18, 1.02, and 0.90 (3 \times Me), M^+ 164 [lit.,⁶ b.p. 89—90° at 10 mmHg, ν_{\max} 1690 cm^{-1} , δ 5.86—5.22 (2H, m), 2.87, 2.67 (1H), 2.08—1.30 (4H, m), and 1.18, 1.02, and 0.90 (3s, 3 Me)].

The ketone (164 mg) was treated with a solution of sodium methoxide in [²H]methanol [3.0 ml; from sodium (30 mg)],

and the mixture was refluxed during 20 h. The product was isolated by pouring into D₂O and extracting with pentane, and had M^+ 166, and the n.m.r. spectrum showed the absence of absorptions at δ 2.66 and 1.98 (3-H₂), with a simplified doublet at δ 5.33.

Isomerisation of 1,4,4-Trimethylbicyclo[5.1.0]oct-5-en-2-one (XII).—The ketone (10 g, 0.061 mol) in dioxan (50 ml) was added under nitrogen to a stirred suspension of sodium hydride (15 g, 0.625 mol) in boiling dioxan (200 ml), and the mixture was refluxed with stirring for a further 20 h. The cooled mixture was then poured into ether (1500 ml) containing acetic acid (40 ml). The isolated material was a mixture of two ketones in the ratio 3 : 2, the major one being the starting ketone (g.l.c.).

The ketone mixture (15 g, 0.09 mol) was reduced to the corresponding alcohols with lithium hydridotri-*t*-butoxyaluminate (0.38 mol) in THF (100 ml) (20 h at 20°). The product was a mixture of two alcohols (3 : 2), which were separated by chromatography on alumina using light petroleum-ether mixtures as eluant.

The major alcohol (5.17 g) (eluted second) in ether was oxidised with 6N-chromic acid to give 1,4,4-trimethylbicyclo[5.1.0]oct-5-en-2-one (XII), whereas the minor alcohol (4.76 g), after similar oxidation, gave 3,8,8-trimethylbicyclo[5.1.0]oct-5-en-2-one (XV), b.p. 98° at 11 mmHg, ν_{\max} 1710 and 1005 cm^{-1} , M^+ 164. The n.m.r. spectrum of the latter ketone was rather complex, and was analysed by spectrum simulation using the computer program LAOCOON with magnetic equivalence where appropriate. The analysed spectrum was assigned as follows: δ 5.738br (d, $J_{4,6}$ 1.31 and 0.88, $J_{5,6}$ 11.57, $J_{6,7}$ 3.8 Hz, and further coupled to Me at δ 1.23, 6-H), 5.561 (2 q, $J_{4,5}$ 2.88 and 5.33, $J_{5,6}$ 11.57, $J_{5,7}$ 0.64 Hz, 5-H), 2.901 (m, $J_{3,\text{Me}}$ 6.63, $J_{3,4}$ 10.71 and 4.29 Hz, 3-H), 2.359 (m, J_{gem} 1.72, $J_{3,4}$ 4.29, $J_{4,5}$ 5.33, $J_{4,6}$ 0.88, $J_{4,7}$ 1.56 Hz, 4-H *cis* to cyclopropane), 1.803 (m, J_{gem} 17.2, $J_{3,4}$ 10.71, $J_{4,5}$ 2.88, $J_{4,6}$ 1.31, $J_{4,7}$ 1.53 Hz, 4-H *trans* to cyclopropane), 1.62 (d, $J_{1,7}$ 8.78 Hz, 1-H), 1.35 (m, $J_{1,7}$ 8.78, $J_{4,7}$ 1.56 and 1.53, $J_{5,7}$ 0.64, $J_{6,7}$ 3.08 Hz, 7-H), 1.23 (s, 8-*endo*-Me, weakly coupled to 6-H), 0.982 (d, $J_{3,\text{Me}}$ 6.63 Hz, 3-Me), and 0.85 (s, 8-*exo*-Me).

After base catalysed ²H exchange of (XV) in [²H₁]methanol, the signals due to 3- and 1-H were absent (δ 2.90 and 1.62 respectively), but the remainder of the spectrum was more complex due to epimerisation at C(3); M^+ 166.

Hydrogenation of 3,8,8-Trimethylbicyclo[5.1.0]oct-5-en-2-one (XV).—The ketone (1 mmol) in methanol (2.0 ml) was hydrogenated at atmospheric pressure over 10% Pd-C (20 mg) during 7 days; 1.4 mmol of hydrogen was absorbed. The isolated product was a mixture of two components (3 : 2; g.l.c.), ν_{\max} (film) 1695 cm^{-1} , and gave parent ions at *m/e* 166 and 168.

When the hydrogenation was discontinued after the absorption of 1.0 mmol of hydrogen, the product was a single component, the major component in the previous experiment, *viz.* 3,8,8-trimethylbicyclo[5.1.0]octan-2-one, ν_{\max} (film) 1698s and 1010w cm^{-1} , M^+ 166, δ (CCl_4) (*inter alia*) 2.60br (m, 3-H), 1.14 and 1.07 (2 s, 8-Me₂), and 0.98 (d, $J_{3,\text{Me}}$ 6.6 Hz, 3-Me). After base-catalysed ²H exchange in [²H₁]methanol, M^+ was 168.

Base-catalysed ²H exchange of the mixture obtained from hydrogenation for 7 days gave a two component mixture (3 : 2) with M^+ 168 and 171.

Lithium-Liquid Ammonia Reduction of 3,8,8-Trimethylbicyclo[5.1.0]octan-2-one (XV).—The saturated ketone (0.15 g) was reduced with lithium (0.04 g) in liquid ammonia (25

ml) during 2 h. The initial product (four components) in ether was oxidised with 6*N*-chromic acid to give a two component mixture (7 : 3), ν_{\max} (film) 1695 cm^{-1} . Both components had M^+ 168. After base-catalysed ^2H exchange, both components had M^+ 171.

N.m.r. Spectrum of the Anion of 1,4,4-Trimethylbicyclo[5.1.0]oct-5-en-2-one.—The ketone (0.01 mol) was added to a stirred suspension of sodium hydride (0.1 mol) in diphenyl ether at 100° under nitrogen. After 6 h, the cooled mixture was centrifuged and the supernatant liquid was transferred to an n.m.r. tube. The n.m.r. spectrum (100°; 200/350 silicon oil as external lock) showed, *inter alia*, δ 6.26 (d, 5-H), 6.04br (t, 6-H) and 4.88 (s, 3-H) for the anion of 1,4,4-trimethylbicyclo[5.1.0]oct-5-en-2-one, and 6.42br (m, 5-H), 6.04br (t, 6-H), 3.82br (d, J_{gem} 16 Hz, 4-H *trans* to cyclopropane), and 2.64 (2 d, J_{gem} 16, $J_{4,5}$ 7 Hz, 4-H *cis* to cyclopropane) for the anion of 3,8,8-trimethylbicyclo[5.1.0]oct-5-en-2-one. The ratio of the two anions was *ca.* 4 : 5 (by integration of the 5-H and 4-H₂ absorptions respectively). The n.m.r. spectrum at 200° showed only slight broadening of the spectrum at 100°.

Methylation of 1,4,4-Trimethylbicyclo[5.1.0]oct-5-en-2-one.

—(a) *Methyl iodide present during the generation of the anion.* The ketone (0.012 mol) and methyl iodide (0.02 mol) were added to sodium hydride (0.06 mol) in dioxan (12 ml) and the mixture was refluxed with stirring under nitrogen during 12 h. The cooled mixture was poured into ether containing acetic acid and the product was isolated as a mixture of three components which were separated by preparative g.l.c. (15% Carbowax at 125°; 7 ft \times $\frac{1}{4}$ in): *trans*-1,3,4,4-tetramethylbicyclo[5.1.0]oct-5-en-2-one (XVI) (47%), ν_{\max} (film) 1700 and 1660 cm^{-1} , M^+ 178, δ (CCl₄) 5.56 (2 d, $J_{5,6}$ 12, $J_{6,7}$ 3.5 Hz, 6-H), 5.05 (2 d, $J_{5,6}$ 12, $J_{5,7}$ 1 Hz, 5-H), 3.08 (q, $J_{3,\text{Me}}$ 7 Hz, further coupled to 4-Me at δ 0.84, 3-H), 1.25 (s, Me), 1.20 (m, $J_{6,7}$ 3.5, $J_{5,7}$ 1 Hz, 7-H), 1.05 (s, Me), 1.00 (d, $J_{3,\text{Me}}$ 7 Hz, 3-Me), 0.84 (s, 4-Me), and 0.84 (m, 8-H₂); *cis*-1,3,4,4-tetramethylbicyclo[5.1.0]oct-5-en-2-one (XVI) (43%) ν_{\max} (film) 1670 cm^{-1} , M^+ 178, δ (CCl₄) 5.60br (2 d, $J_{5,6}$ 12.5, $J_{6,7}$ 5.5 Hz, 6-H), 5.27 (d, $J_{5,6}$ 12.5 Hz, 5-H), 2.66 (q, $J_{3,\text{Me}}$ 7 Hz, 3-H), 1.50—1.00 (m, 7-H and 8-H₂), 1.15 (s, Me), 0.92 (s, Me), 0.89 (d, $J_{3,\text{Me}}$ 7 Hz, 3-Me), and 0.68 (s, Me); and 1,3,3,4,4-pentamethylbicyclo[5.1.0]oct-5-en-2-one (XVII) (10%), M^+ 192, δ (CCl₄) 5.66 (2 d, $J_{5,6}$ 12, $J_{6,7}$ 4.5 Hz, 6-H), 5.04 (d, $J_{5,6}$ 12 Hz, 5-H), 0.84 (2 d, $J_{6,7}$ 4.5 Hz, 7-H), 0.58 (m, 8-H₂), and 1.37, 1.26, 1.02, 1.01, and 0.81 (5 s, 5 \times Me).

Treatment of the *trans*-monomethylated product with potassium *t*-butoxide in *t*-butyl alcohol produced a mixture of the *trans*- and the *cis*-isomer (11 : 9).

(b) *Methyl iodide added to the generated anion.* The equilibrated anion was generated using sodium hydride in dioxan, and was then treated at 20° with methyl iodide (same quantities as in the previous experiment) for 30 min. The product mixture contained the same three products as in (a) (33.2, 7.4, and 0.5% respectively), together with unchanged starting ketone (2.7%), 3,3,8,8-tetramethylbicyclo[5.1.0]oct-5-en-2-one (XVIII) (53.8%), M^+ 178, δ (CCl₄) 5.70 (m, 5- and 6-H), 2.56br (d, J_{gem} 13.5 Hz, 4-H), 1.84br (d, 4-H), 1.60 (d, $J_{1,7}$ 9 Hz, 1-H), 1.40br (d, $J_{1,7}$ 9 Hz, further coupled to 5- and 6-H, 7-H), 1.20 (s, Me₂), and 1.00 and 0.84 (2 s, 2 \times Me), and 2-methoxy-1,4,4-trimethylbicyclo[5.1.0]oct-5-ene (24%), M^+ 180, δ (CCl₄) 5.36 (2 d, $J_{5,6}$ 11, $J_{6,7}$ 2.5 Hz, 6-H), 4.90 (2 t, $J_{5,6}$ 11, $J_{3,5}$ 1.5, $J_{5,7}$ 1.5 Hz, 5-H), 3.22 (s, OMe), 2.74 (2 d, $J_{2,3}$ 1.5 and 9 Hz, 2-H), 2.05 (2 d, J_{gem} 13.5, $J_{2,3}$ 9 Hz, 3-H), 1.40 (2 t, J_{gem} 13.5, $J_{2,3}$ 1.5, $J_{3,5}$ 1.5 Hz, 3-H), 1.00 (s, Me), 0.96 (s, Me₂), 0.74 (m, J_{gem} 2.5, $J_{5,7}$ 1.5, $J_{6,7}$ 2.5,

$J_{7,8\text{-trans}}$ 4.5 Hz, 7- and 8-H), and 0.23 (m, J_{gem} 2.5, $J_{7,8\text{-trans}}$ 4.5 Hz, 8-H).

Dehydration of 1,4,4-Trimethylbicyclo[5.1.0]oct-5-en-2-ol.—The alcohol, m.p. 38—45°, was prepared by lithium aluminium hydride reduction in ether of the corresponding ketone (XII). G.l.c. analysis of the acetate derivative showed that both epimers were present (9 : 1).

(a) *With phosphorus pentaoxide in benzene.* The alcohol (0.9 mmol) in benzene (2 ml) was added dropwise to phosphorus pentaoxide (0.6 g) and the mixture was refluxed during 4 h. Ice was added and the mixture was shaken until homogeneous, basified with 0.88 ammonia solution, and then extracted. G.l.c. analysis of the product indicated a two component mixture (2 : 1). The components were isolated by chromatography on 10% silver nitrate-silica gel (pentane eluant). The major component, eluted first, was a 1,2,4-isopropylidimethylbenzene, λ_{\max} (hexane) 274 (ϵ 433), 266 (437), and 263 nm (352), ν_{\max} (film) 2920s, 1605w, 1500m, 1450m, 1387m, 1360w, 1330w, 1260w, 1170w, 1120w, 1070w, 1060w, 1020w, 1000w, 890m, 820s, and 710m cm^{-1} [*cf.* 1,2,4-trimethylbenzene, λ_{\max} (hexane) 276 (ϵ 613), 267 (604), and 263 nm (473), ν_{\max} (film) 2920s, 1615w, 1513s, 1460s, 1390m, 1265m, 1218w, 1160w, 1130w, 1110m, 1030m, 890m, 820s, and 712w cm^{-1}], M^+ 148, δ (CCl₄) 6.84 (m, 3 \times ArH), 2.78 (m, $J_{\text{H,Me}}$ 7 Hz, Me₂CH), 2.20 (2 s, 2 \times ArMe), and 1.20 (d, $J_{\text{H,Me}}$ 7 Hz, Me₂CH).

The minor component was 1-isopropyl-2,3-dimethylbenzene, λ_{\max} (hexane) 270 (ϵ 237), 265 (280), 262 (279), and 258 nm (266), ν_{\max} (film) 2980s, 1595w, 1480s, 1396w, 1376m, 1350w, 1268w, 1180w, 1120m, 1050m, 1035w, 1009w, 795s, and 720s cm^{-1} [*cf.* 1,2,3-trimethylbenzene, λ_{\max} (hexane) 270 (ϵ 178), 265 (215), 262 (222), and 257 nm (198), ν_{\max} (film) 2930s, 1590w, 1483m, 1450s, 1390m, 1168w, 1110m, 1080w, 1020w, 1000w, 775s, and 719s cm^{-1}], M^+ 148, δ (CCl₄) 6.91 (m, 3 \times ArH), 3.14 (m, $J_{\text{H,Me}}$ 7 Hz, Me₂CH), 2.21 (s, ArMe), 2.17 (s, ArMe), and 1.16 (d, $J_{\text{H,Me}}$ 7 Hz, Me₂CH).

(b) *With polyphosphoric acid.* The alcohol (0.3 mmol) in polyphosphoric acid (6 g) at 20° during 10 h gave the same products, in the same ratio as in (a).

(c) *With phosphoryl chloride-pyridine.* At least 17 products were detected which were not investigated further. A similar mixture was obtained with thionyl chloride-pyridine.

(d) *By pyrolysis of the corresponding acetate.* The alcohol was acetylated using acetic anhydride-pyridine to give a mixture of two epimers (9 : 1). The mixture of acetates was pyrolysed at temperatures up to 460° in a Pyrex tube (150 \times 15 mm) packed with glass beads with a nitrogen flow rate of 0.67 ml s^{-1} . The products were collected in a trap at -80°. G.l.c. analysis showed a large number of minor products, with the major component being the starting acetates.

Dehydration of 1,2,4,4-Tetramethylbicyclo[5.1.0]oct-5-en-2-ol.—The alcohol was prepared (90%) by treating 1,4,4-trimethylbicyclo[5.1.0]oct-5-en-2-one (XII) with an excess of methylmagnesium iodide in ether, b.p. 40° at 0.05 mmHg, δ (CCl₄-D₂O) 5.60 (2 d, $J_{5,6}$ 12, $J_{6,7}$ 6.5 Hz, 6-H), 5.05 (2 d, $J_{5,6}$ 12, $J_{3,5}$ 1 Hz, 5-H), 1.65 (m, 3-H₂), 1.30, 1.23, 1.15, and 0.98 (4 s, 4 \times Me), 1.09 (m, 7-H), 0.86 (m, 8-H), and 0.64br (t, 8-H).

(a) *Thermally.* The alcohol was dehydrated by injection onto a preparative g.l.c. column (20% S.E. 30, 20 ft), with an injection block temperature of 200°. The products were collected in a trap at -80°. Analysis by g.l.c.-mass spectrometry (Apiezon L at 130°) showed the product to be

a mixture of three components, in order of elution: unidentified (27%), M^+ 162, unidentified (21%), M^+ 162, and 1,4,4-trimethyl-2-methylenebicyclo[5.1.0]oct-5-ene (XXIV) (52%), M^+ 162. The latter was separated from the other two components by preparative g.l.c. (S.E. 30, 100°), ν_{\max} (CCl₄) 1650, 1630, and 1025 cm⁻¹, δ (CCl₄) 5.64 (2 d, $J_{6,7}$ 4.5, $J_{5,6}$ 12 Hz, 6-H), 4.96 (d, J_{gem} 2 Hz, :CHH), 4.92br (d, $J_{5,6}$ 12 Hz, further coupled to 3-H, 5-H), 4.65br (s, J_{gem} 2 Hz, further coupled to 3-H, :CHH), 2.14br (q, coupled to 5-H and :CHH, 3-H₂), 1.19 (s, Me), 1.12 (m, $J_{6,7}$ 4.5 Hz, 7-H), 0.94 and 0.92 (2 s, Me₂), and 0.70 (m, 8-H₂). The two unidentified components from the dehydration were subjected to variable temperature n.m.r. studies in *p*-dichlorobenzene, 60–160°, but no change in the spectrum was observed.

(b) *With phosphorus pentoxide in benzene.* The alcohol (1 mmol) and phosphorus pentoxide (0.6 g) in benzene (2 ml) were refluxed during 4 h. The product was a mixture of two components (2 : 1), which were separated by preparative g.l.c. (15% Carbowax 20M, 120°, 7 ft × $\frac{1}{4}$ in). The major component was 1-isopropyl-2,4,5-trimethylbenzene,

ν_{\max} (film) 2950s, 1900w, 1740w, 1520m, 1460s, 1400w, 1390m, 1370m, 1350w, 1270m, 1200w, 1150m, 1110m, 1090w, 1030m, 1000m, and 885 s cm⁻¹, M^+ 162, δ (CCl₄) 6.83 (s, ArH), 6.74 (s, ArH), 3.02 (m, $J_{H,Me}$ 7 Hz, Me₂CH), 2.21, 2.17br, and 2.13 (3 s, 3 × ArMe), and 1.17 (d, $J_{H,Me}$ 7 Hz, Me₂CH). The minor component was a 1,2,3,4-isopropyl-trimethylbenzene, ν_{\max} (film) 2950s, 1490m, 1470m, 1390m, 1370w, 1340w, 1260w, 1020m, and 820s cm⁻¹, M^+ 162, δ (CCl₄) 6.84 (m, J_{ortho} 8 Hz, 2 × ArH), 3.13 (m, $J_{H,Me}$ 7 Hz, Me₂CH), 2.20 (s, 2 × ArMe), 2.16br (s, ArMe), and 1.17 (d, $J_{H,Me}$ 7 Hz, Me₂CH). Similar results were achieved using polyphosphoric acid.

(c) *With phosphoryl chloride-pyridine.* The same result as in (a) was achieved.

(d) *With thionyl chloride-pyridine.* The alcohol was recovered.

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