23. Stereochemistry of an Ene Reaction involving 1,7-Dienes; Bicyclo[3.3.1]nonanes from (3-Cyclohexenyl)diallylcarbinols

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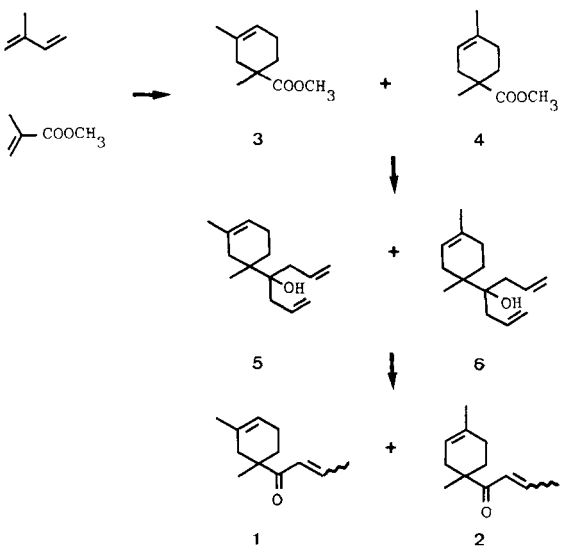
Summary

(3-Cyclohexenyl)diallylcarbinols undergo a thermal *retro*-ene reaction to give crotonylcyclohexenes at *ca.* 200°. A side-reaction is an ene reaction to give bicyclo[3.3.1]nonanes. These become the main products above 300°. The stereochemistry of 2-allyl-1,4,6-trimethylbicyclo[3.3.1]-6-nonen-2-ols and related compounds is discussed, and a case is described in which the allyl group is not freely rotating.

Introduction. – One route for the preparation of the useful perfume substances 1-(1,3-dimethyl-3-cyclohexenyl)-2-buten-1-one (**1**) and 1-(1,4-dimethyl-3-cyclohexenyl)-2-buten-1-one (**2**) involves the reaction of allylmagnesium chloride with the products **3**, **4**, of a *Diels-Alder* reaction between isoprene and methyl methacrylate [1] *(Scheme 1)*. The initial compounds formed are the diallyl compounds **5** and **6**, and

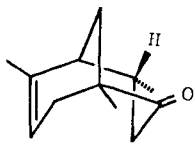
Scheme 1



these can be transformed either by pyrolysis or with *t*-BuOK in THF to **1** and **2**. The latter transformations of homoallylic alkoxide fragmentations have been described in various synthetic applications, particularly in the preparation of the damascones from cyclogeraniates [2].

During the transformation of **5** and **6** to **1** and **2**, a number of by-products are formed, one particularly undesirable structure (perfumistically) being the bicyclo-[3.3.1]nonenone **7**, presumably formed by an ene reaction. This paper deals with the elucidation of such ene reactions.

Results. – Differential thermal analysis of a mixture (3:7) of **5** and **6** indicated two reactions occurring at 220° and 250°. Heating the mixture of **5** and **6** in decalin at 220° for 75 h led to a 66% yield of a mixture of all isomers of **1** and **2**, together with a number of by-products. At 250° in decalin, a ketonic by-product, later identified as **7**, became a major impurity (the isomer with an exocyclic double bond, **8**, was visible in the NMR spectrum), while other impurities, **9**, **10**, **11**, and the products **12**[1]) resulting from a *retro*-aldol reaction, were also identified. The compounds **9**, **10** and **11** were formed by acid treatment of the diallyl compounds **5** and **6**, but their formation was suppressed by use of added base.



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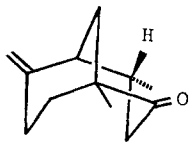

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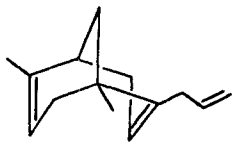

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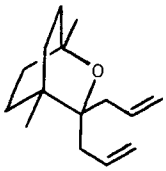

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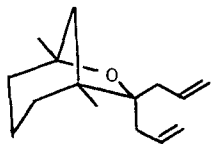

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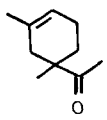
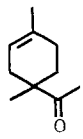


12a



12b

To simplify the analytical work, the diallyl compounds **5** and **6** were purified by careful distillation. This was followed by medium-pressure column chromatography, because a small amount of decomposition had occurred during the distillation with formation of **7**, **8** and **12**, and other minor impurities.

Heating the alcohol **5** in refluxing (195°) decalin containing 5% of quinoline led to a 70% yield of a mixture of the monocyclic ketones (*Z*)- and (*E*)-**1**,[2]) and the bicyclic ketone **13** in the proportion of 9:1 *(Scheme 2)*. At 300° in the same solvent (sealed

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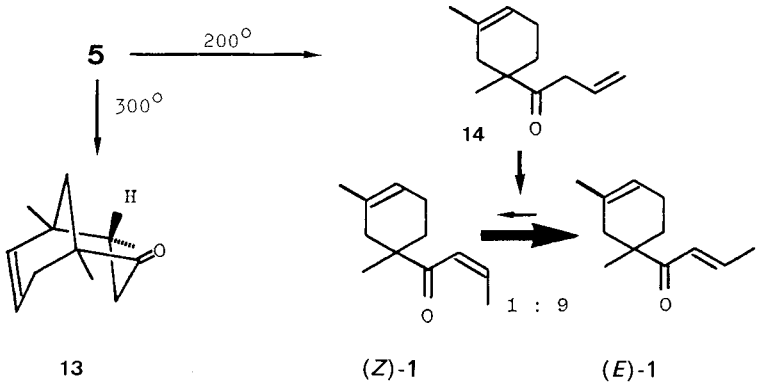
[1]) The ketone **12a** has been isolated from *Juniperus communis* oil [3].

[2]) The (*Z*)-isomers of **1** and **2** are generally accompanied by the corresponding nonconjugated (allyl) isomers, **14**, **15**, from which they are difficult to separate.

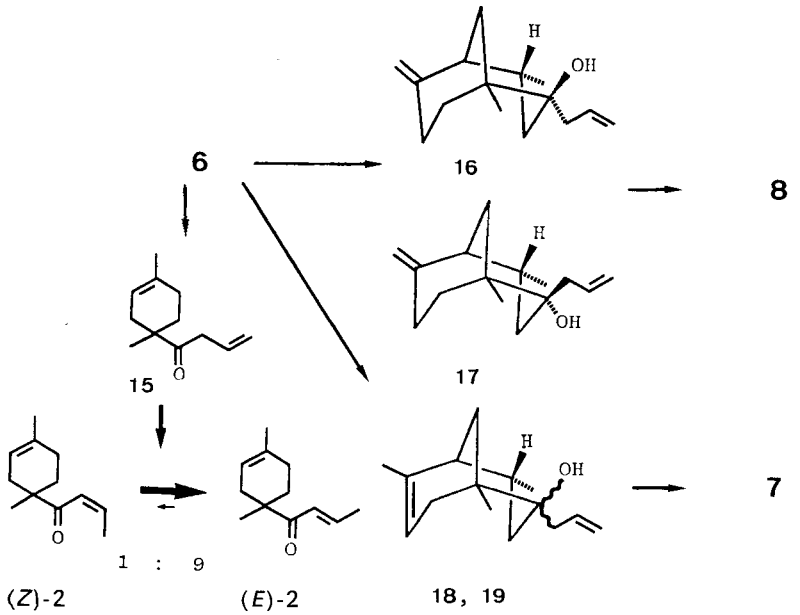
Scheme 2



tube), the only compound isolated (70% yield) was the bicyclic ketone, **13**. Heating the pure (*E*)-isomer ((*E*)-**1**) of the monocyclic ketone at 250° in the same solvent mixture for 20 h resulted only in isomerization (13%) to the (*Z*)-isomer ((*Z*)-**1**), and no formation of the bicyclic ketone, but at 300°, the bicyclic ketone was formed exclusively.

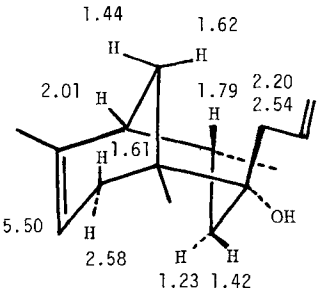
Heating the 1,4-dimethyldiallyl alcohol **6** in the same solvent mixture at reflux (195°) gave, in 67% yield, a mixture of the monocyclic ketones (*Z*)- and (*E*)-**2** and **15**, also containing a trace of the bicyclic ketone **7**, together with a heavier fraction (20%) consisting of two alcohols, **16** and **17** (9:1) *(Scheme 3)*. When the latter were heated to

Scheme 3



300°, they were converted entirely into the ketone **8**. At 300°, the diallyl alcohol **6** gave principally the bicyclic ketone **7** (55% isolated yield) in which traces of **8** could be detected by NMR spectroscopy. The monocyclic ketones **2** were also cyclized to **7** by heating in decalin/quinoline in a sealed tube at 300°.

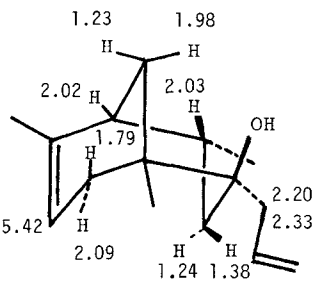
Although the alcohols **18** and **19** were not isolated from any of these experiments, they were prepared by treatment of the bicyclic ketone **7** with allylmagnesium chloride. By NMR spectroscopy, the major product thus formed was identified as having an *endo*-hydroxyl group (**18**), although the addition was not highly stereoselective (**18**/**19** *ca.* 3:1). Both **18** and **19** yielded the ketone **7** on heating in decalin above 200°.



CH_3: 0.85 (*d*), 0.92, 1.71

$-HC=CH_2$: 5.10, 5.13, 5.90

18



CH_3: 0.86 (*d*), 0.93, 1.71

$-HC=CH_2$: 5.11, 5.16, 5.91

19

Structure of the Products. – We have previously shown [4] how mass spectrometry can be used to distinguish between the 1,3-dimethylcyclohexenyl methyl ketone **12a** and its 1,4-dimethyl isomer **12b** using the fact that the acetyl group is lost more easily from the 1,3-dimethyl isomer **12a**. Similarly, the 1,3-dimethyl isomers **1** and **5** lose their side chains in the mass spectrometer more easily than the 1,4-dimethyl isomers **2** and **6**. Furthermore the 1,3-dimethyl isomers **3**, **5**, and **1** are always eluted from a *Carbowax* column slightly earlier than **4**, **6** and **2**, respectively. The NMR spectra of the (*Z*)-isomers of **1** and **2** always exhibit signals of varying amounts of the non-conjugated ketones **14** and **15** with which they are co-eluted from silica gel columns and most GC columns. In these monocyclic ketones, the $H_2C(2)$ group gives rise to a characteristic *AB*-set of signals, and the small but clear differences (at 360 MHz) in the signals of the quaternary CH_3 group also provide a means of distinguishing between the various isomers. Other facets of the structures of these compounds (*e.g.* the stereochemistry of the double bond in **1** and **2**) are straightforward (see *Exper. Part*).

The hydrocarbon **9** has a ^{1}H-NMR spectrum consistent with an allyl group and two trisubstituted double bonds, the vinyl H-atoms of which (at 5.34 and 5.52 ppm) were only very slightly coupled with adjacent protons. Three CH_3-groups (quaternary, on a methine and on an unsaturated C-atom) were present, and since the formula was $C_{15}H_{22}$ (MS), the compound was bicyclic. ^{13}C-NMR spectrometry confirmed the structure shown.

Compounds **10** and **11** had mass spectra somewhat similar to the starting materials **5** and **6**, but were much less polar. Both had two different CH_3-groups (NMR) and two

allyl groups, identical in the case of **10** but different in the case of **11**. The ^{1}H-NMR spectrum of **10** showed four groups of two protons each and a very simple ^{13}C-NMR spectrum having 2*q*, 4*t*, 1*d*, and 3*s*, entirely consistent with the structure containing a plane of symmetry. The spectra of **11** were more complex, particularly the ^{13}C-NMR spectrum which contained 2*q*, 8*t*, 2*d*, and 3*s*. In neither compound was there a double bond other than in the allyl groups, and in both cases the O-atoms were flanked by quaternary C-atoms.

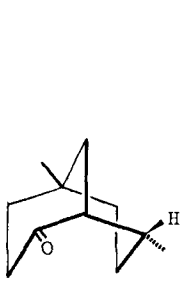
Although the gross structure of **7** was clear from the ^{1}H- and ^{13}C-NMR spectra, the stereochemistry could not be assigned with certainty. Thus the protons on the bridgehead were clearly distinguished (at 1.64 and 1.76 ppm, *dd*, J = 2.5 and 13; 3 and 13 Hz, respectively) as were those of the methylene group at C(8) (1.97 ppm, *m*), but the protons on C(3), C(4), C(5) all overlapped at around 2.2 ppm. The signals of the methylidene group of the bicyclic ketone **8** were clearly visible at 4.76 and 4.86 ppm, but the two ketones were not readily separable by GC. After the allyl-*Grignard* reaction on the ketone **7**, the stereochemistry of the two alcohols **18** and **19** was established from the 360 MHz ^{1}H-NMR spectra. The attributions are shown on the formulae, and were confirmed by double irradiation experiments. In both cases, the proton attributed to H_{endo}–C(3) had two large coupling constants (13 and 14 Hz in the case of **18**, and 12 and 14 Hz for **19**), the *gem*-coupling constant being in both cases 14 Hz. The H_{exo}–C(3) proton in both **18** and **19** had coupling constants of 14 and 4 Hz. Since biocyclo[3.3.1]nonanes are in the double chair conformation unless there is a large substituent at C(3) [5], this establishes the configuration of the CH_3–C(4) group as equatorial (*endo*). The configuration of the OH-group was clear from its influence on the axial H–C(4) when it was itself in the axial position; in this orientation it also influenced the *syn*-proton on the bridge, while when it was equatorial (as in **18**) the most marked effect was to shift the equatorial H–C(8) to lower field. An interesting confirmation of the structure of **18** was observed in that one of the protons of the allyl CH_2-group underwent a long-range coupling with H_{endo}–C(3) (2 Hz). Examination of models shows that rotation of the allyl group must be severely restricted, and one of the methylene protons is *anti*-periplanar with H_{endo}–C(3). This coupling is naturally absent from the NMR spectrum of **19**.

The compounds having a methylidene group were assigned stereochemistry in the same way as described for those with an endocyclic double bond. In addition, the ketone **8** was shown directly to have an equatorial CH_3-group at C(4) by the fact that H–C(4) is coupled in the *trans*-diaxial mode with H–C(3) (J = 12 Hz). Going from the alcohol **17** with an equatorial (*endo*) OH-group to **16**, with an axial OH-group, the signals for H–C(4) and the *syn*-proton of the bridge undergo a shift to lower field (from 1.70 to 1.97 ppm for H–C(4) and 1.74 to 2.10 for H_{syn}–C(9)). The overlapping signals around 2.2–2.3 did not permit a definite conclusion about the existence of a fixed position of the allyl group in **17** similar to that observed in **18**. The equatorial (*endo*) position of the C(4)–CH_3-group in the bicyclic ketone **13** was also confirmed by the coupling constant of H_{endo}–C(3) and H_{exo}–C(4), which was 12 Hz, the *gem*-coupling H_{endo}–C(3)–H_{exo}–C(3) being 16 Hz, and the only coupling visible for the C(3) protons was H_{exo}–C(3)–H_{endo}–C(4), which is 5 Hz.

It might also be noted that all the isomers of the bicyclic alcohols **16**, **17**, and **19** except one, **18**, have rather similar mass spectra (losing $C_3H_5^{\cdot}$, allyl as the principal

fragmentation). The exception, **18**, is the only one in which loss of a proton 1,3- to the OH-group can occur directly from an allylic position, and this is the only one to lose water to any extent in the mass spectrometer.

Discussion. – The only reported high-yielding ene reaction involving a 1,7-diene system is that of the enol of 2-methyl-5-(3-butenyl)cyclohexanone described by *Conia et al.* [6] (see also [7]). *Conia et al.* placed the CH_3-group formed *endo* to the bicyclic system (**20**) on grounds of the stereochemistry of the presumed transition state, although the evidence advanced was not conclusive. Judging by our present results, there is no doubt that the conformation of the intermediate so far as the stereochemistry of the methyl group is concerned is as *Conia et al.* supposed in every case. A more subtle stereochemical point concerns the stereochemistry of the allyl and hydroxyl groups in the alcohols **16** and **17**, for it is not easy to see why the conformation of the intermediate state should prefer **21** rather than **22**.



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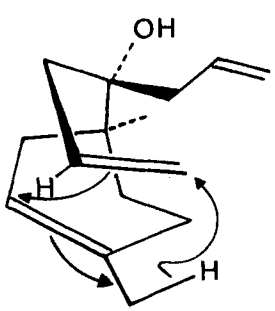

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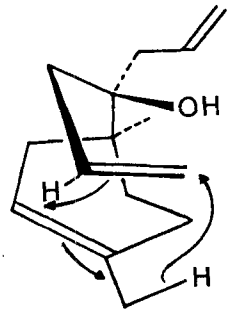

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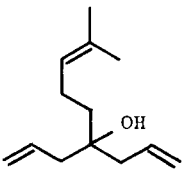
There are probably two routes to **7** and **13**, one from the ketones **1** and **2** occurring only at higher temperatures (> 300°) and one *via* the allyl compounds **18** and **19**, although we have never isolated the latter among the pyrolysis products of **5** and **6**. Further indirect evidence of their presence are the traces of the hydrocarbon **9** formed when conditions are acidic. It is, however, impossible to discuss the stereochemistry of their formation from **5** and **6**.

We thought that one reason why we were able to overcome the reluctance of 1,7-dienes to undergo ene reactions [7] was because the double allyl group enabled one double bond to be forced into the proximity of the methyl or methylene group from which a proton was to be transferred, and it might therefore be possible to extend the principle to a completely open-chain system. We accordingly synthesized the diallyl carbinol **23**, and subjected it to the same reaction conditions (decalin with a trace of quinoline at 300°) as those under which **5** and **6** gave reasonable yields of bycyclic compounds. The only compounds we could detect, however, were the *retro*-ene products **24** (the (*Z*)-component of which was mixed with **25**). Strangely, **24** has only been mentioned once before in the literature in 1935 [8], and the structure of the compound described was questioned the same year by *Ruzicka* [9]. The compound described earlier formed a semicarbazone with m.p. 163° [8] or 166° [9]. Our ketone **24** formed a semicarbazone in H_2O/MeOH (9 :1) with m.p. *ca.* 140–145° (crude), but we were unable

to recrystallize it satisfactorily (from either aqueous MeOH or AcOEt/hexane), so although absolute certainty is not possible, it seems unlikely that our ketone is the same as that described in 1935 [8].



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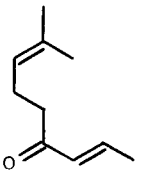

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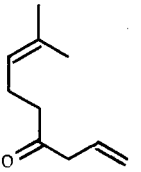

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We acknowledge valuable discussions with Dr. *R.L. Snowden*, and careful NMR measurements by Mr. *W. Thommen*.

Experimental Part

General. The IR spectrum was measured on a *Perkin-Elmer Infracord* spectrometer. NMR spectra were recorded in $CDCl_3$ on a *Bruker WH-360* instrument. Chemical shifts are given in ppm downfield from TMS (= 0 ppm), coupling constants J in Hz. Mass spectra were measured on a *Finnegan* quadrupole instrument coupled with a gas chromatograph. Results are quoted in m/z (% most important fragment), and generally the ten most important fragments are given. Column chromatography was carried out on *Merck H* (Type *60*) silica gel using a *Jobin-Yvon* medium pressure liquid chromatograph, and gas chromatography (GC) on a *Carlo-Erba* type *GT* chromatograph for preparative work, and a *Carlo-Erba* type *4200* for analytical work, in both cases using He as carrier gas.

4-(1,3-Dimethyl-3-cyclohexenyl)-1,6-heptadien-4-ol (**5**), *and 4-(1,4-Dimethyl-3-cyclohexenyl)-1,6-heptadien-4-ol* (**6**). In a 6-l flask were placed 57 g of Mg and 200 ml of dry Et_2O. The reaction was started with *ca.* 2 ml of MeI, then the following solution was added dropwise: 168 g of a mixture (*ca.* 3:1) of methyl 1,4-dimethyl-3-cyclohexenecarboxylate and methyl 1,3-dimethyl-3-cyclohexenecarboxylate (prepared by a *Diels-Alder* reaction [10] without added *Lewis* acid), 184 g of allyl chloride and 1 l of dry Et_2O. After heating at reflux for 2.5 h, the reaction was not complete, and a further 40 g of allyl chloride in 100 ml of Et_2O was added. After refluxing for a further 3 h, the mixture was allowed to cool and poured into 100 ml of 10% HCl and 1.5 kg of ice. The Et_2O layer was separated, and the aq. layer extracted with Et_2O. Washing ($NaHCO_3$, H_2O), drying and concentrating the Et_2O phases gave 210 g of material which was distilled rapidly to yield 9 g of the starting material, and 164 g of a mixture of **5** and **6** (b.p. 80–92°/0.1 Torr).

Careful distillation of this material on a *Fischer* 'Spaltrohr' column allowed separation of the two isomers. The 1,3-isomer was concentrated to the extent of *ca.* 70% in the head fraction, b.p. 117°/8 Torr, while the 1,4-isomer **6** was obtained nearly pure from the last fractions (b.p. 121/10 Torr). Four runs each of 15 g of material consisting of 75% of **5** + **6** (70:30) was chromatographed on silica gel in hexane/AcOEt (97:3), from which 20 g of the 1,3-isomer **5** was obtained in 92% purity. This was used for subsequent experiments, but for spectral determinations it was further purified by GC on *Carbowax*. ^{1}H-NMR: 0.92 (*s*, 3H); 1.65 (*s*, 3H); 1.46–1.50 (2H); 1.54 (*AB*, *d*, J = 17, 1H) and 2.21 (*d*, J = 17, 1H); 2.00 (br. *s*, 2H); 5.37 (br. *s*, 1H). The allyl groups have signals at 2.3–2.5 (4H), 5.07–5.16 (4H), and 5.89–6.03 (2H). MS: 202 (M^+, 1), 179 (15), 161 (14), 138 (8) (this fragment is characteristic of the 1,3-dimethyl isomer, and is absent from the 1,4-isomer), 137 (8), 119 (14), 110 (23), 109 (68), 95 (41), 69 (100), 67 (33), 41 (57). The 1,4-isomer **6** was purified in the same way. ^{1}H-NMR: 0.92 (*s*, 3H); 1.65 (*s*, 3H); 1.50–1.65 (2H); the *AB*-system is probably at 1.66 (overlapping prevented clarity) and 2.25 (*d*, J = 17, 1H); 5.31 (br. *s*, 1H); allyl signals as for **5**. MS: 202 (M^+, 1), 179 (14), 161 (17), 137 (10), 119 (10), 110 (18), 109 (68), 95 (30), 69 (100), 67 (29), 41 (52).

1-(1,3-Dimethyl-3-cyclohexenyl)-2-buten-1-one (**1**). A solution of 5 g of *t*-BuOK and 7 g of **5** in 70 ml of DMF was maintained at 50° for 2.5 h. After pouring the solution on to ice, the products were extracted into

Et_2O, which was washed H_2O, 10% HCl, $NaHCO_3$, H_2O, dried and concentrated. The residue was chromatographed on silica gel in hexane/Et_2O 19:1. The (*Z*)-isomer was eluted first: ^{1}H-NMR: 1.125 (*s*, 3H); 1.68 (long-range *J ca.* 1.5, 3H); 1.72 and 2.39 (*AB*-system, *J* = 18); 2.06 (*dd*, *J* = 7 and 2, 3H); 5.34 (br. *s*, 1H); 6.23 (*dq*, *J* = 11 and 7, 1H); 6.42 (*dq*, *J* = 11 and 2, 1H); the coupling of 11Hz between the last two signals supports the (*Z*)-configuration. MS: see *Table*. The NMR spectrum showed the presence of the non-conjugated isomer, *1-(1,3-dimethyl-3-cyclohexenyl)-3-buten-1-one* (**14**) also readily distinguishable by its MS (see *Table*). ^{1}H-NMR: 1.333 (*s*, 3H); one branch of the *AB*-system visible at 2.375 (H_{eq}-C(2)); allyl system at 3.28 (CH_2), 5.09 and 5.14 (*d*, H_2C=), and 5.94 (*m*, −CH=).

The (*E*)-isomer of **1** was eluted later, and was purified for spectral measurements by prep. GC. ^{1}H-NMR: 1.122 (*s*, 3H); 1.68 (3H); 1.73 and 2.36 (*AB*-system, *J* = 18); 1.88 (*dd*, *J* = 7 and 2, 3H); 5.34 (1H); 6.52 (*dq*, *J* = 15 and 2, 1H); 6.97 (*dq*, *J* = 15 and 7, 1H).

1-(1,4-Dimethyl-3-cyclohexenyl)-2-buten-1-one (**2**) was prepared as described above for the 1,3-dimethyl isomers, but using **6** instead of the isomer **5**. In this case, after the column chromatography, very careful prep. GC on *Carbowax* enabled the isolation of the (*Z*)-isomer in a practically pure state – its t_R is very slightly less than that of the non-conjugated isomer **15**. ^{1}H-NMR of (*Z*)-**2**: 1.112 (*s*, 3H); 1.63 (br. *s*, 3H); 1.97 and 2.45 (*AB*-system, *J* = 17); 2.06 (*dd*, *J* = 7 and 2, 3H); 5.35 (br. *s*, 1H); 6.23 (*dq*, *J* = 11 and 7, 1H); 6.42 (*dq*, *J* = 11 and 2, 1H). MS: see *Table*. Eluted just after (*Z*)-**2** on the *Carbowax* column, *1-(1,4-dimethyl-3-cyclohexenyl)-3-buten-1-one* (**15**) was obtained in 70% purity, the analytical sample still containing 30% of (*Z*)-**2**. ^{1}H-NMR of **15**: 1.122 (*s*, 3H); 1.63 (br. *s*, 3H); one branch of the *AB*-system is visible at 2.43; 5.34 (br. *s*, 1H); allyl signals at 3.27 (CH_2); 5.09 and 5.14 (*d*, H_2C=); 5.94 (*m*, −CH=). MS: see *Table*.

Table. *Mass Spectra* (selected fragments) *of Isomers of* **1** *and* **2** (% most abundant fragment)

m/z	(*Z*)-**1**	(*Z*)-**2**	(*E*)-**1**	(*E*)-**2**	**14**	**15**
178 (M^+)	1	20	3	26	1.5	2.5
163	3	37	7	57	0.6	1.5
137	1	0	2	1	7	30
109	100	100	100	88	100	100
93	12	26	24	31	7	8
81	10	30	11	30	9	14
69	47	91	57	100	10	14
67	29	75	32	72	32	43
55	11	27	13	29	9	12
43	11	25	15	29	14	20
41	28	67	34	68	22	30
39	13	32	17	34	10	13

The (*E*)-isomer of **2** was eluted later from the silica gel column. ^{1}H-NMR: 1.108 (*s*, 3H); 1.62 (br. *s*, 3H); 1.83 and 2.96 (*AB*-system, *J* = 17); 1.88 (*dd*, *J* = 7 and 2, 3H); 5.35 (br. *s*, 1H); 6.52 (*dq*, *J* = 15 and 2, 1H); 6.97 (*dq*, *J* = 15 and 7, 1H). MS: see *Table*.

Action of Acid on the Diallylcarbinols **5** and **6**. For this experiment, recovered diallylcarbinols from the pyrolysis experiment were used. They already contained (by GC) small amounts of the substances described below, and no new substances were detected after the experiment.

The crude carbinol mixture (143 g) was stirred at 90° with 1 g of *Filtrol* for 120 h. Filtration and distillation yielded 10 g of a light fraction (b.p. 36–51°/0.1 Torr) which was not further examined, then 70 g of a mixture having b.p. 51–60°/0.1 Torr. The latter was chromatographed in hexane/Et_2O (19:1), changing the proportions progressively to 9:1, 8:2, 7:3 and 6:4. The chromatogram was followed by TLC and GC, and all products were purified by prep. GC on *Carbowax* for analysis. After a trace of a mixture of 1,3- and 1,4-dimethyl-3-cyclohexenyl methyl ketone (**12**) ([4], identified spectrally by comparison with an authentic sample), *2-allyl-1,4,6-trimethylbicyclo[3.3.1]nona-2,6-diene* (**9**) was eluted.^{1}H-NMR: 0.82 (*d*, *J* = 7, 3H); 0.94 (*s*, 3H); 1.70 (*d*, *J* = 1, 3H); 2.72 (*m*, 2H, C=CCH_2CH=); 5.03 (*d*, *J* = 10, 1H) and 5.07 (*d*, *J* = 18) (C=CH_2); 5.34 (*s*, $w_{1/2}$ = 5, H–C(3)); 5.52 (*s*, $w_{1/2}$ = 10, H–C(7)); 5.97 (*m*, C*H*=CH_2). ^{13}C-NMR: 16.9, 23.0, and 23.0 (all *q*, CH_3); 22.9, 31.8, and 32.7 (*t*, CH_2); 39.1 and 53.5 (*d*, CH); 46.2 (*s*); 115.4 (*t*) and 122.0 (*d*) (−CH=CH_2); 128.6

and 137.0 (*d*), and 132.9 and 150.1 (*s*) (2 × −CH=C <). MS: 202 (M^+, 61), 187 (49), 161 (100), 159 (39), 145 (47), 119 (73), 109 (45), 105 (61), 91 (44), 41 (41). This was followed by two substances eluted close together (**10** and **11**). The first was *3,3-diallyl-1,4-dimethyl-2-oxabicyclo[2.2.2]octane* (**10**). ^{1}H-NMR: 0.84 and 1.07 (each *s*, 3H); 2.41 (narrow *m*, 4H, allyl CH_2); 5.02 (*d*, J = 10) and 5.05 (*d*, J = 16); 5.99 (*m*, 2H). ^{13}C-NMR: 22.8 and 27.3 (*q*, CH_3); 31.6, 32.8 and 40.9 (*t*, CH_2); 33.9, 69.2 and 79.5 (*s*); 136.3 (*d*) and 116.1 (*t*) ($CH=CH_2$). MS: 180 (17), 179 ($M-C_3H_5^+$, 77), 137 (28), 110 (17), 109 (100), 95 (25), 69 (48), 67 (25), 43 (43), 41 (43). The second was *7,7-diallyl-1,5-dimethyl-6-oxabicyclo[3.2.1]octane* (**11**). ^{1}H-NMR: 0.93 and 1.26 (each *s*, 3H); 2.26 and 2.54 (each *m*, 2H); distributed around 5.1 (*m*, 4H); 5.83 and 5.99 (each *m*, 1H, $CH_2CH=CH_2$). ^{13}C-NMR: 21.6 and 27.1 (*q*, CH_3); 20.4, 35.3, 37.4 (2), 40.9 and 50.9 (*t*, CH_2); 37.5, 79.2 and 86.1(*s*); 117.2 and 117.4 (*t*) and 134.9 and 135.4 (*d*). The two isomers of **1** and **2** were next eluted, followed closely by **7**, described in the next experiment.

1,4-endo,*6-Trimethylbicyclo[3.3.1]non-6-en-2-one* (**7**). A solution of 10 g of **6** in 30 ml of decalin, 0.5 g of quinoline and 0.1 g of hydroquinone was heated in a sealed tube at 300° for 16 h and then distilled. After removal of the decalin, there 5.5 g of material distilled with b.p. 100°/1 Torr, of which 73% (GC) was the ketone **7**. For analysis it was purified by GC on *Carbowax*. IR (neat): 1715 (C=O). ^{1}H-NMR: 1.01 (*d*, J = 7, 3H); 1.02 (*s*, 3H); 1.64 (*dd*, J = 2.2 and 12.5, 1H) and 1.77 (*dd*, J = 3 and 12.5) ($H_2C(9)$); coupling with H–C(5) and the large geminal coupling confirmed by double irradiation); 2.18 (*m*, 1H, H–C(4)); *ca.* 2.2 (4H); 5.56 (br. *s*, $w_{1/2}$ = 10, 1H, $C=CHCH_2$). ^{13}C-NMR: 21.2, 24.0, 25.2 (*q*); 37.3, 40.5, 44.6 (*t*); 39.9, 41.2 (*d*); 42.6 (*s*); 122.2 (*d*) and 134.7 (*s*) (C=CH); 214.3 (*s*) (C=O). MS: 178 (M^+, 42), 163 (28), 145 (27), 121 (35), 120 (44), 107 (42), 93 (100), 91 (59), 77 (35), 41 (41). Visible in the NMR spectrum were traces of the signals of the methylidene ketone **8**, which is eluted from a capillary GC column (*UCON*) just before **7**.

Heating ketone **2** (*E*)/(*Z*) 9:1) in decalin/quinoline at 300° for 18 h yielded the same product **7** exclusively.

2-Allyl-1,4-endo-*dimethyl-6-methylidenebicyclo[3.3.1]nonan-2-ols* (**16** and **17**). A solution of 15 g of **6**, 0.45 g of quinoline and 0.1 g of hydroquinone in 100 ml of decalin was heated at reflux in a current of N_2. The progress of the reaction was followed by capillary GC (*UCON* column). After 164 h, no more starting material was detectable, and the major products were the isomers of the ketone **2**, together with a little **7**. With t_R somewhat similar to those of the starting material were two new peaks (*ca.* 9:1 in order of t_R). Distillation yielded 8 g of the ketonic mixture (b.p. 114°/10 Torr) and 3 g of residue. This was purified by bulb-to-bulb distillation, then chromatographed on silica gel in hexane/Et_2O (9:1), following the separation by TLC. After elution of the ketonic material, 0.8 g of the major isomer was eluted (detected by capillary GC), which proved to be the 2-*endo*-allyl-2-*exo*-ol **16.** The (minor) 2-*exo*-allyl-2-*endo*-ol isomer **17** (0.1 g) was then eluted. These compounds were purified by GC on *Carbowax* for analysis.

16: ^{1}H-NMR (couplings by double resonance): 0.92 (*s*, 3H); 0.80 (*d*, J = 7, 3H) coupled with 1.97 (1H, H–C(4)), the latter in turn coupled with 1.39 (*dd*, J = 13 and 15) and 1.63 (*dd*, J = 5.5 and 15) which are therefore $H_2C(3)$; 1.21 (*dd*, J = 13 and 3) coupled with 2.10 (*ddd*, J = 13, 3, 3) ($H_2C(9)$); 1.76 (*m*) coupled (large J) with 1.32 and (J = 3) with H_{syn}-C(9), so these are $H_2C(8)$; 4.62 and 4.73 (each *t*, J = 3, 1H, $=CH_2$); allyl signals at 2.18 and 2.36 (CH_2), 5.93 (*m*), 5.12 and 5.17 ($-CH=CH_2$). MS: 220 (M^+, trace), 179 (100), 161 (18), 121 (24), 107 (27), 105 (22), 95 (22), 93 (20), 69 (95), 41 (38).

17: ^{1}H-NMR (couplings by double resonance): 0.88 (*s*, 3H); 0.81 (*d*, J = 7, 3H) coupled with 1.70 (*m*, 1H), coupled in turn with 1.38 (*dd*, J = 13 and 15, 1H) and 1.80 (*dd*, J = 5 and 15); 1.44 (*dd*, J = 14 and 3) coupled with 1.74 (*ddd*, J = 14, 3, 3); 4.61 and 4.73 (each *t*, J = 3, 1H); allyl at 2.28, 2.52, 5.92, 5.10 and 5.17. MS: 202 (M^+, 2) 179 (100), 161 (27), 121 (26), 107 (39), 105 (25), 95 (22), 93 (24), 69 (67), 41 (46).

1,4-endo-*Dimethyl-6-methylidenebicyclo[3.3.1]nonan-2-one* (**8**). A solution of 0.3 g of 2-*endo*-allyl-1,4-*endo*-dimethyl-6-methylidenebicyclo[3.3.1]nonan-2-ol (**16**), 10 mg of quinoline and 5 mg of hydroquinone in 20 ml of decalin was heated for 17 h at 300°. GC showed the compound to be entirely converted into the title product, which was purified by bulb-to-bulb distillation and prep. GC (*Carbowax*), whereupon it crystallized, m.p. 31–32°. ^{1}H-NMR: 1.04 (*s*, 3H); 0.93 (*d*, J = 7, 3H); 1.48 (*ddd*, J = 13, 13, 7.5, H_{exo}-C(8)); 1.76 (*dd*, J = 13 and 3.5, 1H) and 1.86 (*ddd*, J = 13, 2, 2, 1H) ($H_2C(9)$); 2.04 (*dd*, J = 17 and 12) and 2.60 (*dd*, J = 17 and 6.5) ($H_2C(3)$, the proton with the 2 large coupling constants being *endo*); 4.76 and 4.87 (each *t*, J = 2.5, 1H, $=CH_2$). MS: 178 (M^+, 38), 121 (38), 108 (45), 107 (90), 94 (38), 93 (100), 91 (44), 79 (80), 69 (68), 41 (57).

Under the same conditions, the *exo*-allyl isomer **17** gave the same ketone (shown by an identical t_R on the *UCON* GC capillary column).

2-Allyl-1,4-endo,*6-trimethylbicyclo[3.3.1]non-6-en-2-ols* (**18** and **19**). A *Grignard* reagent was prepared from 3.75 g of allyl bromide and 0.75 g of Mg in 50 ml of dry THF at r.t. A solution of 1.7 g of **7** in 15 ml THF was added slowly at 10–15°. The mixture was heated at reflux for 1 h then poured on to ice and NH_4Cl. The products were extracted with Et_2O and after washing, drying and concentrating the solution a residue, 2 g, was

obtained. This was distilled (bulb-to-bulb), and GC (*Carbowax*) then showed two new compounds (1:3), the minor compound having the shorter t_R. Chromatography on silica gel in hexane/Et_2O (17:3) yielded 2 main fractions. The first (0.6 g) was a 1:1 mixture of the minor isomer **19** and unchanged starting material, from which **19** was separated by prep. GC. The next fraction (0.5 g) was practically pure *exo*-allyl-*endo*-hydroxy-compound **18**. The ^{1}H-NMR spectra are described in the theoretical part. MS of the major isomer **18**: 202 (M-18$^+$, 55), 187 (30), 179 (56), 161 (42), 119 (48), 107 (51), 105 (38), 93 (40), 91 (52), 69 (100), 41 (65). MS of the minor isomer **19**: 220 (M^+, 2), 202 (2), 179 (100), 161 (11), 111 (23), 109 (17), 107 (18), 95 (20), 93 (18), 91 (22), 69 (70), 41 (25).

1,4-endo,*5-Trimethylbicyclo[3.3.1]non-6-en-2-one* (**13**). A solution of 5 g of **5**, 0.25 g of quinoline and 50 mg of hydroquinone in 20 ml of decalin was heated at 300° in a sealed tube for 16 h, then cooled and directly chromatographed on silica gel in hexane/Et_2O (19:1). The decalin was eluted first, followed by 2.5 g of the title material which was practically pure. For analysis it was purified by bulb-to-bulb distillation and GC on *Carbowax*. ^{1}H-NMR: 0.85 (*d*, J = 7, 3H); 1.06 and 1.08 (each *s*, 3H); 1.53 and 1.58 (*AB* system, J = 15, $H_2C(9)$); 1.77 (*m*, 1H, H–C(4)); 1.97 (*q*, J = 3, $H_2C(6)$); 5.82 (*ddd*, J = 10, 3, 3, H–C(7)). MS: 178 (M^+, 40), 163 (10), 145 (5), 108 (39), 107 (62), 93 (100), 91 (40), 77 (28), 41 (32).

The pure (*E*)-isomer of **1** (0.1 g) was heated with one drop of quinoline and a crystal of hydroquinone in 1 ml of decalin in a sealed tube at 250° for 20 h. The only change observed was isomerization of 13% of the material to the (*Z*)-isomer (measured by GC, structure confirmed by NMR). When the experiment was repeated at 300°, the only product detected was compound **13** (*ca.* 95%).

4-Allyl-8-methyl-1,7-nonadien-4-ol (**23**). To 8.5 g of Mg in dry THF was added 1 g of allyl bromide. When the reaction had started, 42 g of allyl bromide and 25 g of ethyl 5-methyl-4-hexenoate (prepared by esterification of 5-methyl-4-hexenoic acid [11]) in 450 ml of dry THF were added dropwise over 2.5 h. After refluxing for 1 h more, the mixture was cooled and poured on to ice and 35 g of NH_4Cl. The product was extracted into pentane, which was washed to neutrality, and dried. The residue after evaporation (25 g) was distilled, b.p. 112–114°/10 Torr. ^{1}H-NMR: 1.48 (*m*, 2H); 1.61 and 1.68 (each *s*, 3H); 2.05 (*m*, 2H); 2.25 (*d*, J = 7, 4H); 5.13 (*m*, 5H); 5.85 (*m*, 2H). MS: 167 (M – 18$^+$, 1.5), 153 (11), 135 (32), 111 (13), 107 (13), 93 (12), 83 (16), 69 (100), 55 (16), 41 (48).

Thermolysis of **23**. A solution of 1 g of **23**, 50 mg of quinoline and 20 mg of hydroquinone in 10 ml of decalin was heated at various temperatures in a sealed tube. Above 300°, the molecule began to fragment into a complex mixture of smaller components, but after 2.5 h at 300°, the reaction mixture exhibited (GC) two new peaks (18% and 50%), together with 27% of unchanged starting material. Prolonged heating did not reveal any new components with t_R anticipated for products of an ene reaction. Preparative GC enabled purification of the substances for analysis. The minor peak, with a shorter t_R on *Carbowax*, was a nearly 1:1 mixture of *(2Z)-8-methyl-2,7-nonadien-4-one* ((*Z*)-**24**) and *8-methyl-1,7-nonadien-4-one* (**25**). ^{1}H-NMR: A. Signals attributed to (*Z*)-**24**: 1.61 and 1.67 (each *s*); 2.11 (*d*, J = 7); 2.27 (*q*); 2.47 (*t*?); 5.09 (*t*, J = 6); 6.16 (*m*). B. Signals attributed to **25**: the signals at 2.27 and 2.47 are at *ca.* 0.01 ppm higher field, and the allyl signals are at 3.17 (*d*, J = 7), 5.14, 5.18 and 5.93. GC/MS coupling gave the MS of (*Z*)-**24**: 152 (M^+, 8), 137 (8), 134 (4), 109 (18), 84 (19), 69 (100), 67 (9), 55 (12), 41 (30), 39 (15), and the MS of **25**: 152 (M^+, 4), 137 (3), 111 (35), 83 (14), 69 (100), 67 (7), 55 (15), 41 (39), 39 (15). The major peak was *(2E)-8-methyl-2,7-nonadien-4-one* ((*E*)-**24**); ^{1}H-NMR: 1.61 and 1.67 (each *s*, 3H); 1.89 (*dd*, J = 7 and 2, 3H); 2.28 (*q*, J = 6, 2H); 2.54 (*t*, J = 6); 5.08 (*t*, J = 6, 1H); 6.12 (*dq*, J = 15 and 2, 1H); 6.83 (*dq*, J = 17 and 7, 1H). MS: 152 (M^+, 8), 137 (10), 134 (4), 109 (13), 84 (25), 69 (100), 67 (13), 55 (15), 41 (63), 39 (33).

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