the solution cooled to 10°. A yellow powder precipitated (1.2 g) which was suspended in hot ethanol and filtered when cold to give 0.9 g of II, a white powder, m.p. 229–234°.

^{1}H-NMR. (in $CDCl_3$): C_6H_{11} at 0.9–2.35 ppm (*m*, 11.1 H), CH_3 at 3.11 (*s*, 11.9 H); ^{31}P-73.5 ppm (in $CHCl_3$).

IR. (in KBr) bands for: CH_3CH_2 at 2800, 2970; C=N at 1630, 1560; C–N at 1105; P–N at 773 [cm^{-1}].

$C_{12}H_{23}N_4PS_2$ (318.4)	Calc.	C 45.26	H 7.28	N 17.59	P 9.72	S 20.13%
	Found	C 45.31	H 7.21	N 17.46	P 9.60	S 20.04%

Mol. weight: 318 (mass spectroscopically)

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255. Controlled Allylic Transformations *via* the *Meisenheimer* Rearrangement

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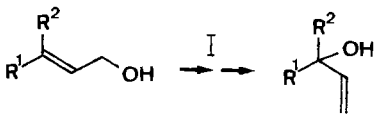
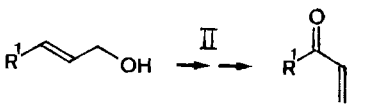
(31. VIII. 73)

Summary. Described are synthetic sequences which effect allylic transformations I and II. Sequence I involves (1) conversion of a primary allyl alcohol into the corresponding N, N-dimethylamine oxide, (2) [2,3]-rearrangement to give an N, N-dimethylhydroxylamine and (3a) reduction to give the 'rearranged' secondary or tertiary allyl alcohol [*e.g.* **36** → **35** → **37** → **40**]. Sequence II involves the same steps (1) and (2), followed by (3b) N-methylation of a secondary N, N-dimethylhydroxylamine and (4) *Hofmann* elimination to give a vinyl ketone [*e.g.* **11** → **12** → **13** → **14** → **15**].

Introduction. – In one approach to the problem of converting the ionones into the isomeric damascones[1]), we have found synthetic sequences which are based on the *Meisenheimer* rearrangement and which effect allylic transformations of the general





R^2 = H, R^3

[1]) For a discussion of this problem, see ref. [1] [2].

types I and II. Only a few sequences were carried out but these methods should be general. Sequence I gave the pure 'rearranged' allyl alcohol in six steps (isolation of three intermediates) in *ca.* 60% overall yield. This is a useful synthetic equivalent of an S_N2' reaction (leading to the thermodynamically less stable isomer). Sequence II gave the desired vinyl ketone in *ca.* 60% overall yield in five steps (isolation of the same three intermediates).

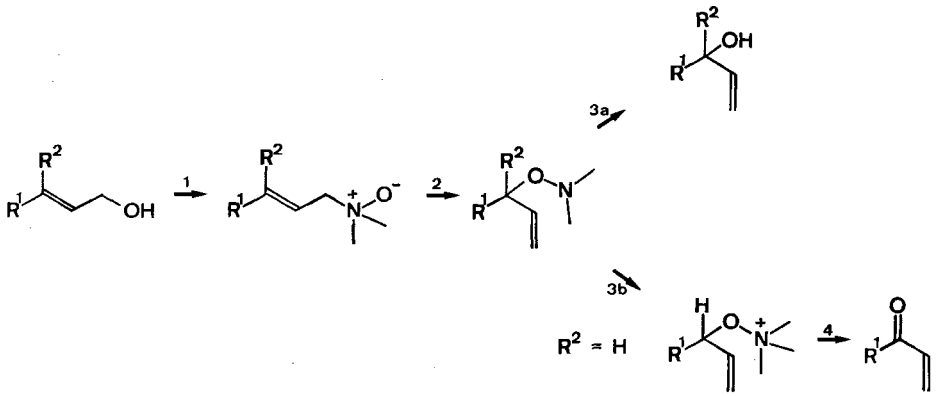
Until recently, only one related synthetic method, a sequence based on the *Wharton* reaction[2]), was known. While the present work was in progress, at least four groups have provided new solutions. The method of *Büchi et al.* [2] was devised specifically for the purpose of converting ionones into damascones and is based on a novel oxidative cyclisation of the oximes of conjugated ketones to give isoxazoles.

The other new methods [5–7] use essentially the same general approach as we do. This involves, sequentially, (1) modification of the allylic functionality by substitution reactions (without allylic rearrangement) to give a reactive intermediate which can then (2) undergo an intramolecular allylic rearrangement and (3) modification of the rearranged species. The substitution reactions can be carried out without rearrangement. The intramolecular rearrangement is used to introduce a functionalized oxygen atom, the rearrangement equilibrium favouring the desired isomer, or being amenable to control.

The simplest way of effecting the required intramolecular allylic rearrangement is to make use of a suitable [2,3]-sigmatropic process. The method of *Evans* [5] and of *Grieco* [6] is based on the allyl sulfenate/allyl sulfoxide rearrangement and the method of *Sharpless* [7] is based on analogous [2,3]-shifts from selenium to oxygen.

In the present work, we have made use of the thermal rearrangement of amine oxides to give hydroxylamines, discovered 54 years ago by *Meisenheimer* [8]. Both [1,2]- and [2,3]-*Meisenheimer* rearrangements are known and their mechanisms have been investigated repeatedly [9–14]. This work indicates that the hydroxylamines are

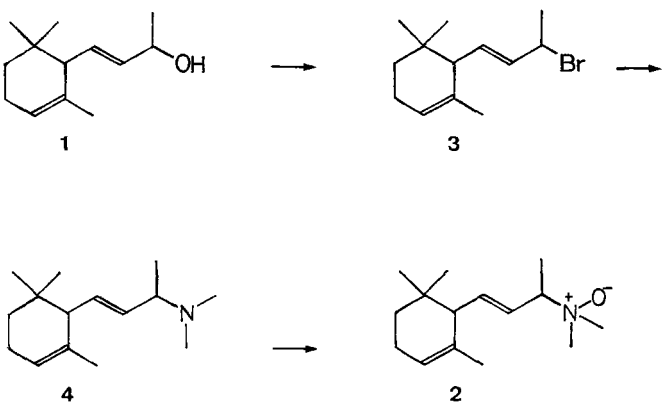
Scheme 1



[2]) Hydrazinolysis of epoxydihydro-α-ionone and of its γ-isomer gives only small amounts of *Wharton* products. The main reactions are novel cyclisations [3] [4]. For leading references on the *Wharton* reactions, see ref. [3].

the stable isomers. Methods for cleaving the weak N–O bond in these [8] [15], as well as in the derived hydroxylammonium salts [16–18] are available. Reductive cleavage of the hydroxylamines should thus give the corresponding alcohols [Sequence I: Scheme **1**, steps (1), (2), (3a)] and N-alkylation followed by *Hofmann*-like elimination should give the desired conjugated carbonyl compounds [Sequence II: Scheme **1**, steps (1), (2), (3b), (4)], without a separate oxidation step. If this scheme is extended to systems in which *Cope* elimination is structurally feasible, then this process may compete with the [2,3]-rearrangement. Little was known about this possibility [19]; this competition does in fact occur and limits the scope of our methods to that given in Scheme **1** (primary allyl alcohols as starting materials).

Results. *α-Ionols → α-damascone.* The α-ionols (**1**) were converted into the corresponding N,N-dimethylamine oxides **2** by routine steps: bromination (**1** → **3**), reaction of the bromides **3**[3]) with dimethylamine (**3** → **4**) and oxidation of the N-ionyl-N,N-dimethylamines (**4**)[3]) by hydrogen peroxide (**4** → **2**) and these steps could be modified in a number of ways. The substitution reactions **1** → **3** and **3** → **4** occurred without allylic rearrangement, probably because the other allylic position is shielded by the substituted cyclohexene ring. In each step, mixtures of diastereoisomers, with *trans*-geometry, were obtained.

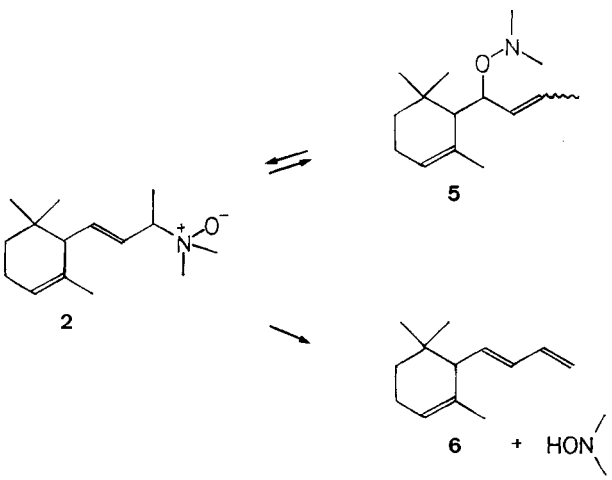


1 **3** **4** **2**

The thermolysis of the non-volatile, salt-like amine oxides **2** (as the crude microcrystalline solid or suspended in paraffin) was combined with continuous distillation of the volatile products: it was carried out *in vacuo* (0.05 Torr) and the products were condensed in a cooled trap (this experimental procedure is the one used for carrying out *Cope* and *Hofmann* elimination reactions [20]). This operation brought about concurrent [2,3]-rearrangement of **2** to give the O-damascyl-N,N-dimethylhydroxylamines (**5**)[3]) and elimination in **2** to give triene **6**[3]) and N,N-dimethylhydroxylamine. The most favourable ratio of rearrangement/elimination was obtained on working at as low a temperature as possible[4]). At best a 45:55 mixture of the hydrox-

[3]) Identification is based on spectral (analytical) data (see experimental section).

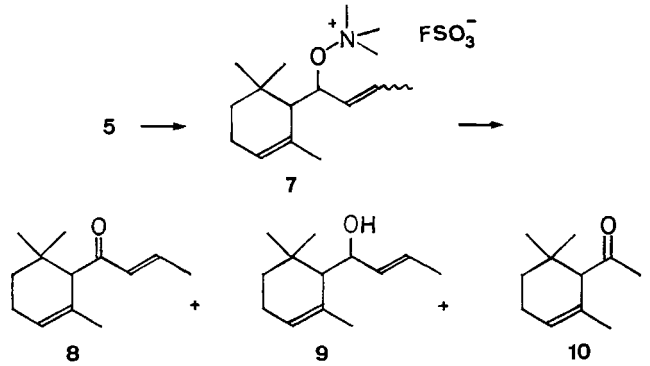
[4]) At first *ca.* 35°, towards the end of the reaction up to 100°; the diastereoisomers **2** seem to have significantly different reactivities (see experimental section).



ylamines **5** and the triene **6** could be isolated, in a combined yield of 94% (based on amines **4**).

The NMR.-spectrum of the mixture (**5**) indicates the gross structure **5**; we have not investigated the stereochemistry of the various isomers which are present[5]). The mixture **5** was stable at room temperature but at higher temperatures further rearrangements (which were not investigated, *v. infra*), and finally elimination to give the triene **6**, occurred[6]).

Compounds **5** and **6** could be separated by distillation but it was easier to remove **6** after N-methylation of **5** in the mixture. N-alkylation was not achieved with the usual alkylating agents, but methyl fluorosulfonate [21] in ether (5°, 30 min) reacted cleanly and rapidly. The triene **6** was separated from the crude oily hydroxylammonium fluorosulfonates **7** and these, without purification, were transferred into a stirred two-phase system consisting of aqueous 4N sodium hydroxide and hexane (80°, 18h).



[5]) The diastereoisomers with *trans*-geometry are probably the main components (see experimental section).

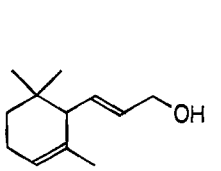
[6]) This thermolysis was carried out in the injection port of a gas chromatograph and also gave a small amount of the amines **4**. Thermolysis in solution or in the gas phase may take a different course.

Work-up furnished α-damascone (**8**) [22] in 55% yield (based on **5**). Side products were the α-damascols (**9**) [3] (9% yield) and ketone **10** (13% yield). Ketone **10** is formed from α-damascone (**8**) under the reaction conditions, by retro-aldol type cleavage [23].

This sequence, which involves the transformation of a secondary allylic amine oxide, *via* the corresponding secondary hydroxylamine, into the corresponding ketone, is unsatisfactory and was not further elaborated: the substitution reactions which are used to prepare the required amine may be difficult to carry out without allylic rearrangement in other, less hindered systems, and elimination competes with the intramolecular rearrangement.

Discussion. Reactions of the amine oxides **2**: the [2,3]-rearrangements and elimination reactions of diastereoisomers **2** are best viewed as concerted processes, each involving a number of diastereoisomeric aromatic (isoxazole-like) transition states. The [2,3]-rearrangements are reversible: this explains, *inter alia* (*v. infra*), the fact that triene **6** is obtained when the hydroxylamines **5** are heated (**5** ⇌ **2** → **6**). In the procedure used for the thermolysis of **2**, the hydroxylamines **5** are produced under non-equilibrium conditions. The position of the equilibrium between these species is not known[7]); the hydroxylamines **5** seem to be stable at room temperature.

Reactions of hydroxylammonium salts **7**: the reaction leading to formation of α-damascone (**8**) under mild conditions is clearly of the *Hofmann* type [17], but facilitated by the weakness of the N–O bond which is being broken and by the strength of the C=O bond which is formed. It is not clear how the α-damascols (**9**) arise: this could involve S_N2 type substitution at carbon, with cleavage of the C–O bond, or S_N2 type substitution at the charged nitrogen atom, with cleavage of the N–O bond. We favour the latter mechanism on the grounds of bond energies (the N–O bond is *ca.* 30 kcal/mol weaker than the C–O bond); to the best of our knowledge there is no analogy in the literature[8]). Use of a hindered base in a non-aqueous solvent should supress this substitution reaction.



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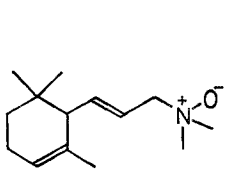

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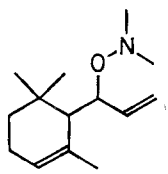

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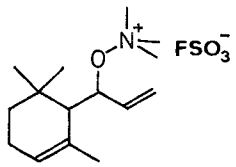

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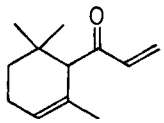

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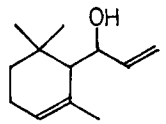

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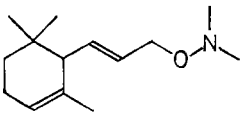
[7]) These must be different for pure **2** ⇌ **5** and for systems involving solutions of **2** or of **5** or of both [9] [10].

[8]) '– in general, alkylhydroxylamines are not well-known compounds' [24].

Further Results. A primary allyl amine oxide, in which direct elimination is excluded, can be efficiently converted into the corresponding ketone, *via* the secondary hydroxylamine. Two complete sequences (II) were carried out. Starting with the α-ionol-derived primary allyl alcohol **11** [25], amine oxide **12** was readily obtained as before. In other (less hindered) cases, making the required amines and amine oxides (by analogous reactions, or with various modifications) should pose no problems since primary allylic isomers are thermodynamically favoured over secondary (and tertiary) isomers.

Thermolysis of the crude amine oxide **12** combined with distillation (80°, 0.05 Torr) as described, furnished a mixture of the diastereoisomeric hydroxylamines **13**[3]) in 97% yield. Treatment of these with methyl fluorosulfonate (ether, 5°, 2 h) gave the fluorosulfonates **14**, whose reaction with aqeous base (2N NaOH, H_2O/hexane, 65°, 20 h) as described, furnished a 9:1 mixture of vinyl ketone **15**[3]) and of the alcohols **16**[3]) in 79% combined yield (based on **13**). Use of the hindered base lithium diisopropylamide (dimethoxyethane) in the elimination reaction gave better results, but this procedure is more difficult to control. The elimination step could be modified further[9]).

On standing for *ca.* one week at room temperature, the mixture of diastereoisomeric hydroxylamines **13** (initially as a liquid) underwent complete rearrangement to give the crystalline amine oxide **12**[3]). In the system **12** ⇌ **13** (no solvent), crystalline **12** is thus thermodynamically favoured. At higher temperatures however, this system (**12** ⇌ **13**) undergoes further rearrangements[10]): on heating the secondary hydroxylamines **13** in benzene solution (80°, 6 h), a mixture of the primary hydroxylamines **17**[3]) and **18**[3]) was obtained[11]).



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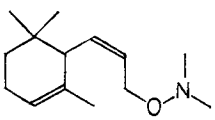

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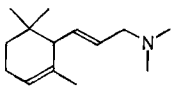
Methylation of this mixture and *Hofmann*-like elimination afforded the corresponding *trans*-aldehyde **20** (a single isomer), a known [25] compound.

Discussion. Very likely, these novel rearrangements are mechanistically related to the [1,2]-*Meisenheimer* rearrangements. These occur by homolytic cleavage of the C–N bond, to give radical pairs which then recombine to form a C–O bond [13–14]. Clearly the system **12** ⇌ **13** can also react by homolytic dissociation to give two radical pairs **21** and **22**, with *cis*- and *trans*-geometry of the allyl radical, which then recom-

[9]) We neglected to try tertiary amines as bases. These would probably have been the best choice.

[10]) The analogous reactions were not observed in system **2** ⇌ **5**; instead elimination (**2** → **6**) occurs.

[11]) A small amount of the amine **19** was also formed.



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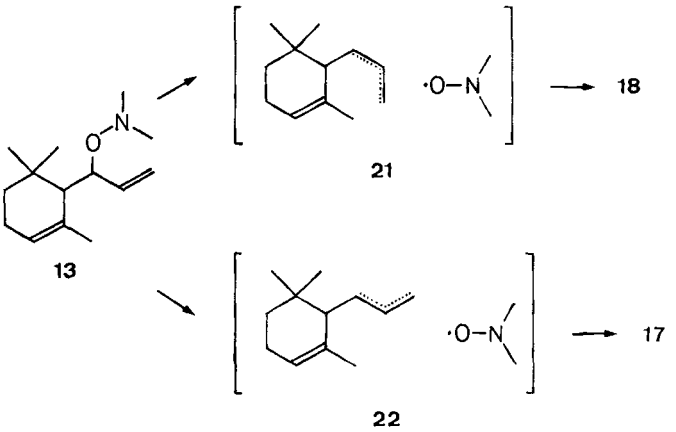
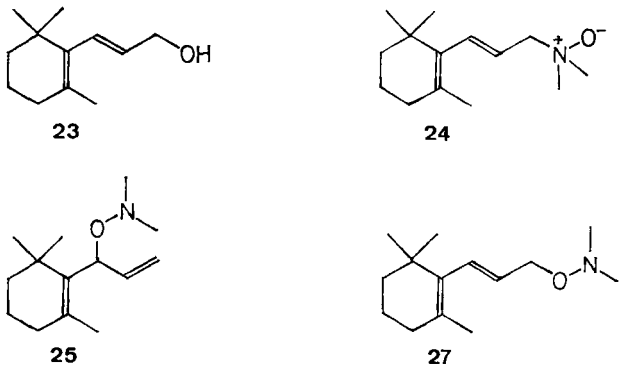
bine to give the stable C–O bonded primary isomers **17** and **18**. These processes have a higher activation barrier than the [2,3]-rearrangements. Similar dual pathways ([2,3]-rearrangement and dissociation/recombination) operate in most related (isoelectronic) systems.



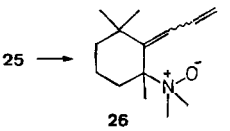
Further Results. In the same way, the conjugated β-ionol-derived allyl alcohol **23** [26] was converted into the corresponding amine oxide **24**, which underwent re-



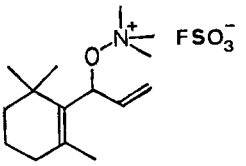
arrangement to give the diallyl hydroxylamine **25**[3]. On further heating, **25** was smoothly transformed[12] into the single primary *trans*-isomer **27**[3].

The hydroxylammonium salt **28** derived from **25**, on reaction with aqueous base, gave a mixture of compounds **23**, **30**[3]), **31**[3]) and **32**[3]), and none of the desired divinyl ketone **29**. Clearly, under these conditions the diallyl hydroxylammonium salt **28** undergoes solvolysis of the S_N1–E 1 type, by heterolysis of the C–O bond. The alde-

[12]) Interestingly, elimination through formation of amine oxide **26** did not occur.



hyde **31**, a known compound [26–27], must be derived from **34** (**28** → **34** → **31**). Treatment of **28** with lithium diisopropylamide (dimethoxyethane), gave ketone **29**[3]) as the main product, but in low yield[9]). The primary hydroxylammonium salt **34** could also be obtained from the corresponding hydroxylamine **27**, and on treatment with base, gave aldehyde **31**.



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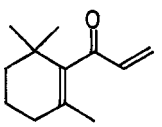

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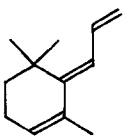

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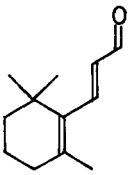

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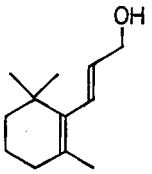

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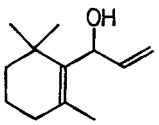

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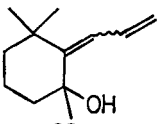

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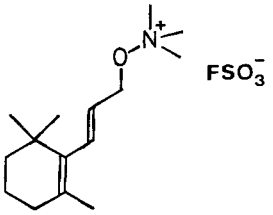

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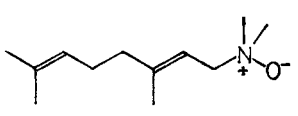
To complete the series, the rearrangement of a primary amine oxide to give a tertiary hydroxylamine was studied. This was done in the geranyl, neryl, linalyl systems. N-geranyl-N,N-dimethylamine oxide (**35**) was obtained from geraniol (**36**) as before. On heating, it cleanly rearranged to give the linalyl hydroxylamine **37**. Thermolysis in solution (benzene, 120°) converted **37** into a mixture of the geranyl and neryl hydroxylamines **38**[3]) and **39**[3]).



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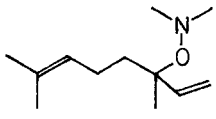

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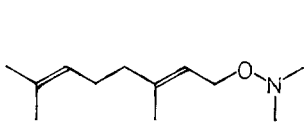

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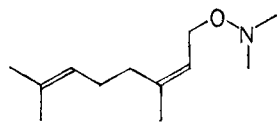

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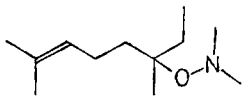
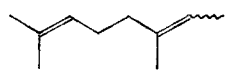
Sequence I was completed only in this system: reductive cleavage of the N–O bond in linalyl hydroxylamine **37** with zinc in acetic acid (35°, 24 h) gave very pure linalool (**40**) in 86% yield. This method can certainly be applied to other tertiary allylic N,N-dimethylhydroxylamines, as well as to secondary ones. Catalytic hydrogenation (*Raney* nickel, methanol) only gave **41** and reduction with sodium in ammonia/*t*-butyl alcohol gave a mixture of dienes **42**.

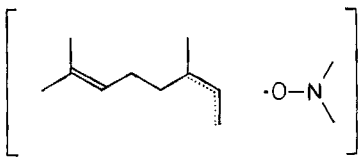


41

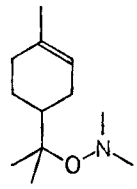


42

The rearrangement of O-linalyl-N,N-dimethylhydroxylamine (**37**) in benzene solution (120°) to give the neryl hydroxylamine **39** probably involves formation of a solvent caged radical pair **43**. This allyl radical-dimethylnitroxide radical pair then collapses very rapidly; the allyl radical does not undergo any intramolecular reac-



43



44

tions such as addition to the double bond at the end of the chain and this is not unexpected. Interestingly, cyclisation – in a second radical pair **43'** or perhaps of the free neryl radical –, did occur to some extent when **37** was passed through a heated quartz tube (300°, 12 Torr, N_2). This gas phase thermolysis led to the formation of more than twenty products and a major one was identified as N,N-dimethyl-O-α-terpinyl hydroxylamine (**44**)[3] (see experimental section).

Discussion. The series of transformations **35** → **37**, **37** → **38** + **39**, **37** → **44** can serve to illustrate the spectrum of reactions of the allyl amine oxide – allyl hydroxylamine system. These reactions have successively higher activation barriers and correspond to different degrees of association of the allyl radical – dimethylnitroxide radical 'fragments'. Rearrangement **35** → **37** may be the concerted process, rearrangements **37** → **38** + **39** involve caged radical pairs and cyclisation **37** → **44** involves a loose pair or a free radical.

These reactions proceed by concerted interchange of C–N and C–O bonds and by homolysis of C–N or C–O bonds and recombination to give C–O bonds. N-methylation of the various hydroxylamines gives hydroxylammonium salts which react by

heterolysis, – of the N–O bond in the *Hofmann*-like eliminations **7** → **8**, **14** → **15** and of the C–O bond in the solvolysis of **28**.

I thank Dr. *G. Ohloff*, research director of *Firmenich SA*, for his support and encouragement, *A. de Chambrier* for technical assistance and *W. Thommen* for measuring the 90 MHz NMR. spectra.

Experimental Section[13])

1. *Ionyl bromides* (**3**). A solution of 10.0 g of a mixture of the *trans*-α-ionols (**1**) (51 mmol) in 40 ml of pentane was added dropwise (10 min) to a stirred suspension of 2.3 ml of PBr_3 in pentane, at −40°. The resulting mixture was stirred for 10 min at −40°, and for another 30 min at room temperature. The pentane solution was decanted from the inorganic, oily phase, washed (H_2O, $NaHCO_3$ sol.), and dried ($MgSO_4$). The pentane was then removed on a rotary evaporator and the remaining crude **3** was used without further purification. Yield 10.7 g (42 mmol, 81%). – *NMR. of the mixture* **3** (60 MHz): 5.15–6.0 (3H, *m*); 4.7–4.9 (1H, *m*); 1.73 (3H, *d* (J = 6.5 Hz)); 1.54 (3H, *m*); 0.88, 0.82 (6H, *s* (broad)).

2. *N-Ionyl-N,N-dimethylamines* (**4**). To a stirred solution of 10 g of dimethylamine in 35 ml of methanol were added dropwise (15 min) 10.7 g of **3** (42 mmol) in 15 ml of methanol, at −70°. The resulting mixture was left for 2 h at 5° and then for 24 h at 25°. The methanol and excess dimethylamine were distilled off on a rotary evaporator and the residue was taken up in dilute aqueous acid. This solution was extracted with ether and then made alkaline and again extracted with ether. The usual work-up of the latter extract and distillation (b.p. 116–118°/12 Torr) gave 7.54 g of a mixture of diastereoisomers **4** (34 mmol, 82%) of good purity (GC., 5 m, 180°, one peak). *Spectral data of the mixture* **4**: NMR. (60 MHz): 5.3–5.5 (3H, *m*); 2.5–2.9 (1H, *m*); 2.14 (6H, *s*); 1.58 (3H, *m*); 1.08 (3H, *d* (J = 6.5 Hz)); 0.87, 0.81 (6H, *s* (broad)). – MS. 221 (M^+, weak), 207 (16), 206 (100), 176 (16), 150 (39), 105 (14), 98 (17), 84 (29), 72 (45), 41 (13).

3. *Preparation and thermolysis of N-ionyl-N,N-dimethylamine oxides* (**2**). A solution of 7.54 g of **4** (34 mmol) in 26 ml of methanol was treated with 13 ml of 30% aqueous H_2O_2, at 5°, and the homogenous mixture was left at 0° for 60 h. Excess H_2O_2 was then decomposed by stirring for 4.5 h with *ca.* 20 mg of PtO_2 powder. The methanol and water were distilled off on a rotary evaporator (25–35°/12–0.05 Torr). The crude amine oxide **2** remained as a microcrystalline solid. The flask containing the crude **2** was attached to a liquid N_2-cooled trap by a short U-tube and heated *in vacuo* (0.05 Torr); the volatile products of the thermolysis, **5**, **6** and N,N-dimethylhydroxylamine, were collected in the trap. The contents of the trap were periodically taken up in pentane, washed (H_2O), dried ($MgSO_4$), concentrated (rotary evaporator) and analyzed by NMR. After 34 h of thermolysis/distillation at 35°, 5.23 g of a *ca.* 1:1 mixture of **5** and **6** were collected (4.75, 0.36 and 0.12 g after 10 h, 7 h and 7 h). Some **2** then still remained and was subjected to thermolysis/distillation as before, but heated to *ca.* 100° during 40 min. This afforded another 1.25 g of a *ca.* 1:3 mixture of **5** and **6**. According to NMR.-analysis the combined distillates, 6.50 g, consisted of a *ca.* 45:55 mixture of **5** and **6**, namely 3.40 g of **5** (14.5 mmol, 42% yield based on **4**) and 3.10 g of **6** (17.5 mmol, 52%). Combined yield of **5** and **6** 94%, based on **4**.

Hydroxylamines **5** were not stable on being subjected to GC. (5 m, oven at 180°, injector block at 210°): they reacted to give the triene **6**, along with a small amount of the amines **4**. The mixture of **5** and **6** could be redistilled but separation by distillation was tedious. The composition of the mixture **5** changed on redistillation (b.p. of the mixture of **5** and **6** 85–100°/12 Torr). Two diastereoisomers with *cis*-geometry, and two diastereoisomers with *trans*-geometry of structure **5** could be present. These apparently interconvert to some extent during distillation (broad gem-dimethyl signals, two $(CH_3)_2N$-signals, of changing ratios)[5]).

[13]) NMR. spectra: *Varian* A 60 and *Hitachi Perkin-Elmer* R-20 B, in CCl_4 solution, and *Bruker* HF X 90, in $DCCl_3$ solution, δ-scale (ppm); some uncharacteristic signals in the NMR. spectra are omitted. IR. spectra: *Perkin-Elmer* 125 (films), max. in cm^{-1}. Mass spectra: *Atlas* CH_4, inlet temperature *ca.* 150°; *ca.* 70 eV; M^+ and up to ten fragment ions are given as *m/e* (down to 10%), in % of the most abundant ion (100%). Gas chromatography (GC.): *F & M* 500 and *Carlo Erba* GT, glass columns with 5 mm inner diameter, 15% Carbowax 20 M15 on chromosorb (acid washed, mesh 60/80).

Repeated short-path distillation at 0.05 Torr (bath 60°) gave a sample of diastereoisomers **5**, free of **6**.

5: $C_{15}H_{27}NO$ (237.4) Calc. C 75.89 H 11.47 N 5.90% Found C 75.67 H 11.37 N 6.16%

Spectral data of the mixture of O-α-damascyl-N, N-dimethylhydroxylamines (**5**): NMR. (60 MHz): 5.20–5.65 (3H, *m*); 3.95–4.35 (1H, *m*); 2.38, 2.39 (6H, *s* (broad)); 1.6–1.8 (6H, *m*); 0.96, 0.87 (6H, *s* (broad)). – IR.: 2940, 2900, 2840 s, 1660 w, 1460, 1430 m, 1370, 1350, 1300, 1190, 1125 w, 980 m, 955 s, 930, 915 m, 825 w.

Spectral data of the triene **6**: [made by thermolysis (GC.) of **5**, see also section 4]: NMR. (60 MHz): 4.70–6.60 (6H, *m* (complex)); 1.7–2.3 (3H, *m*); 1.57 (3H, *s* (broad, further fine structure)); 0.89, 0.82 ppm (6H, *s*). – IR.: 3090, 3040, 3005 m, 2960, 2920, 2860 s, 1795 w, 1640, 1600, 1470, 1450, 1430, 1380, 1375 m, 1360 s, 1340, 1300, 1215, 1125, 1075 w, 1000 s, 960 w, 950 m, 895 s, 870 w, 825, 805, 735 m. – MS.: 176 (M^+, 13), 120 (100), 119 (12), 107 (15), 106 (13), 105 (98), 92 (33), 91 (34), 79 (22), 77 (17), 41 (24).

4. *Methylation of* **5** *and* Hofmann *elimination.* A stirred solution of 6.50 g of a mixture of **5** and **6** (14.5 mmol of **5** in 3.10 g of **6**) in 30 ml of ether was treated with 3.0 ml of methyl fluorosulfonate, at 5°. Almost immediately, an oily precipitate formed. This mixture was stirred at 5° for 30 min and the ether was then removed on a rotary evaporator. The remaining mixture (two liquid phases, the upper layer pentane-soluble) was repeatedly decanted with pentane. To the remaining mixture of the crude salts **7** and of excess methyl fluorosulfonate (a viscous oil, one phase), were added 25 ml of 4 N aqueous NaOH and 10 ml of hexane, and this two-phase system was stirred at 75–80° for 18 h. The hexane layer was then separated and the aqueous phase was extracted with ether. The usual work-up and distillation gave two fractions: I, b.p. 80–85°/12 Torr, 527 mg; II, b.p. 98–110°/12 Torr, 1.78 g. According to GC. (2.3 m, 160°, peaks in the order **6**, **10**, **8**, **9**, the mixture **9** gave one peak), fraction I consisted of a 45:55 mixture of **6** and **10** (1,75 mmol of **10**, 13% yield based on **5**) and of a trace of **8**. Fraction II consisted of a 85:15 mixture of **8** and **9** (8.0 mmol of α-damascone (**8**), 55% yield based on **5**, 1.25 mmol of the α-damascols (**9**), 9% yield), a minor unknown component and of traces of **6** and **10**. 77% of the starting material **5** are accounted for as **8**+**9**+**10**.

Compounds **8**, **9** (**9** as a mixture of diastereoisomers) and **10** were isolated by GC. (1.6 m, 140°, 125°). α-Damascone (**8**) [22] and the mixture of α-damascols (**9**) [3] were identified by their spectra.

Spectral data of ketone **10**: NMR. (60 MHz): 5.55 (1H, '*s*' (broad)); 2.63 (1H, *s* (broad)); 2.08 (3H, *s*); 1.57 (3H, '*s*'); 0.90, 0.88 (6H, *s*). – IR: 3030 w, 2960, 2910, 2870, 2840, 1700 s, 1670, 1470 m, 1450 s, 1385 m, 1360, 1350 s, 1310 m, 1270, 1255, 1225 w, 1200 m, 1150 s, 1140 m, 1080, 1000, 970, 910, 860, 830, 800, 740, 610, 580 w. – MS.: 166 (M^+, 29), 124 (11), 123 (100), 109 (14), 95 (14), 81 (70), 67 (15), 55 (12), 43 (64).

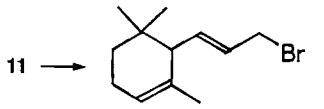
5. α-*Cyclocitrylidene ethanol* (**11**) (see ref. [25]). a) α-*Cyclocitrylidene acetic acid* (**45**), *butyl* α-*cyclocitrylidene acetate* (**46**). Procedures in the literature [28] [29] were modified as follows: to a solution of 150 g (3.75 mmol) of NaOH in 350 ml of water were added 400 g of crushed ice; this mixture was stirred and cooled (ice/water) and during 90 min, 130 g of chlorine (1.8 mol) were introduced. Then another 21 g of NaOH (0.54 mol) in 50 ml of water and 100 g of α-ionone (0.52 mol) were added and the resulting mixture was stirred at 36° for 20 h. The reaction flask then contained a white foamy solid and two liquid phases. This mixture was acidified with 15% aqueous H_2SO_4 and extracted first with dichloromethane and then with ether. The combined extracts were dried ($MgSO_4$) and concentrated. The crude acid **45** so obtained (100 g), was dissolved in a mixture of 67 g of *n*-butanol and 100 ml of toluene. After addition of 1.25 g of *p*-toluene sulfonic acid hydrate, the mixture was heated to reflux and water was removed by codistillation. When no more water separated (6 h), 90 ml of solvent were distilled out and the remaining solution was poured into water. Extraction with pentane, the usual work-up and distillation (b.p. 85–89°/0.05 Torr) gave 100 g of **46** (0.40 mol, 77%) of good purity (GC., 2.3 m, 200°).

Spectral data of **46**: NMR: (60 MHz): 6.67 (1H, *q*, J_1 = 15, J_2 = 9.5 Hz); 5.70 (1H, *d*, J_1 = 15 Hz); 5.47 (1H, '*s*' (further fine structure)); 4.08 (2H, '*t*', J = 6Hz); 2.27 (1H, *d* (broad), J_2 = 9.5 Hz); 1.58 (3H, '*s*' (further fine structure)); 0.93, 0.88 (6H, *s*); 0.95 (3H, '*t*'). – IR.: 3015 w, 2960, 2920, 2870, 1720, 1640 s, 1450, 1380, 1360, 1330, 1300 m, 1270, 1240 s, 1220 m,

1195, 1160, 1135 s, 1090, 1060, 1020 w, 985 m, 960, 870, 830, 815 w. – MS.: 250 (M^+, 9) 194 (42), 138 (38), 93 (100), 92 (26), 91 (22), 90 (16), 77 (15), 57 (16), 55 (12), 41 (26).

b) *Alcohol* **11**. To 2.50 g of $LiAlH_4$ (66 mmol) in 70 ml of ether were added dropwise, with stirring, 20.0 g of **46** (80 mmol) and the resulting mixture was stirred at reflux for 28 h. Then 2.5 ml of 5% aqueous KOH solution, followed by 4 ml of saturated aqueous NaCl solution were added dropwise with stirring. A white solid precipitate formed and was separated from the ether solution by filtration through a glass filter. The precipitate was washed with ether. Work-up of the ether solutions and distillation (b.p. 121–122°/12 Torr) gave 11.6 g of **11** (64 mmol, 80%) of good purity (GC., 2.3 m, 200°). *Spectral data of* **11**: NMR. (60 MHz): 5.1–6.0 (3H, *m*); 4.01 (2H, *d*, J = 4.5 Hz); 1.75–2.20 (3H, *m*); 1.59 (3H, '*s*' (further fine structure)); 0.90, 0.82 (6H, *s*). – IR.: 3300 s, 3030 m, 2960, 2910, 2860 s, 1660 w, 1470 m, 1450, 1430, 1380 s, 1370 m, 1360 s, 1340, 1300, 1220, 1165, 1140, 1130 w, 1085, 1070, 1030 m, 1000, 970 s, 930 w, 820 m. – MS.: 180 (M^+, 5), 124 (100), 109 (29), 96 (43), 95 (36), 93 (82), 91 (46), 81 (73), 68 (46), 55 (41), 41 (49).

6. *Bromide* **47**. Step **11** → **47** was carried out as described for step **1** → **3** [section 1]. Yield of crude **47** (used without further purification) 85%. – *NMR.* (60 MHz): 5.5–5.9 (2H, *m*); 5.40



47

(1H, '*s*' (further fine structure, broad)); 3.89 (2H, *d* (broad), J = 6.5 Hz); 1.80–2.30 (3H, *m*); 1.59 (3H, '*s*' (further fine structure)); 0.90, 0.84 (6H, *s*).

7. *Amine* **19**. Amine **19** was made from bromide **47** as described for step **3** → **4** [section 2]. B.p. 120–124°/12 Torr; yield 86%. *Spectral data of* **19**: NMR. (60 MHz): 5.25–5.50 (3H, *m*); 2.81 (2H, *d* (broad), J = 5.0 Hz)); 2.12 (6H, *s*); 1.58 (3H, '*s*' (further fine structure)); 0.98, 0.92 (6H, *s*). – IR.: 3030 w, 2960, 2910, 2860, 2820, 2780 s, 1660 w, 1450 s, 1380, 1370 m, 1360 s, 1340, 1320, 1300 s, 1260 m, 1230, 1210 w, 1170 m, 1150, 1130, 1090, 1070 w, 1040, 1015 m, 970 s, 845, 820 m. – MS.: 207 (M^+, 18), 162 (46), 147 (26), 136 (26), 107 (21), 91 (25), 84 (78), 79 (53), 71 (61), 58 (100), 42 (20), 41 (23).

8. *Preparation and thermolysis of* **12**. The oxidation of 7.30 g of the amine **19** (35 mmol) to give the amine oxide **12** was carried out like the analogous step **4** → **2** [section 3]. 580 mg of unreacted **19** were recovered. The crude powdery amine oxide **12** was mixed with 10 g of paraffin und subjected to thermolysis/distillation at 0.05 Torr, as described [section 3]. This afforded 6.93 g of **13** (31 mmol, 97% yield based on amine **19** used) (1.14 g after 8 h at 40–45°, 4.83 and 0.96 g after 9 and 8 h at 75–80°). The NMR. spectrum of this material was identical with that of a redistilled sample (b.p. 98–100°/12 Torr).

13: $C_{14}H_{25}N$ (223.4) Calc. C 75.28 H 11.28 N 6.27% Found C 74.57 H 11.29 N 6.47%

Spectral data of the mixture **13**: NMR. (60 MHz): 4.8–6.0 (4H, *m*); 4.24 (1H, *d* (broad, further fine structure), J = 8.0 Hz); 2.48 (6H, *s*); 1.71 (3H, '*s*' (further fine structure); 1.00, 0.88 (6H, *s*). – IR.: 3080, 3030 w, 2960, 2910, 2860 s, 1635 w, 1465, 1440, 1430, 1420, 1380 m, 1360, 1330, 1260, 1205, 1200, 1135 w, 1080, 1020, 1010 m, 985 s, 960 m, 920 s, 890, 860 w, 830 m, 800, 760 w.

When a freshly distilled sample of the mixture **13** was left at 0° overnight, crystals of **12** had formed. Reaction of **13** back to **12** was more rapid at room temperature and complete conversion occurred in *ca.* 1 week. Crystals of **12** so obtained were dissolved in deuterium oxide (clear solution): *NMR. of* **12** (60 MHz, D_2O, relative to sodium 2,2-dimethyl-2-silapentan-5-sulfonate as standard): 5.75 (2H, *m*); 5.41 (1H, '*s*' (broad)); 3.85 (2H, *m*); 3.11 (6H, *s*); 1.51 (3H, *s* (broad)); 0.90, 0.85 (6H, *s*). In the next step [section 9] freshly distilled **13** was used.

9. *Methylation of* **13** *and* Hofmann *elimination*. 500 mg of **13** (2.24 mmol) in 5 ml of ether were treated with 0.26 ml of methyl fluorosulfonate at 5°, with stirring. An oily precipitate formed immediately. After stirring this mixture at 5° for 2 h, the ether was removed on a rotary evaporator (25°/12 Torr), 3 ml of aqueous 2N NaOH and 5 ml of hexane were added to the crude

oily fluorosulfonate **14** so obtained and this two-phase mixture was stirred at 65° for 20 h. The hexane layer was then separated and the aqueous layer was extracted with ether. Work-up and distillation (b.p. 92–96°/12 Torr) afforded 314 mg of a *ca.* 10:1 mixture of **15** and **16** (1.61 mmol of **15**, 0.16 mmol of **16**, combined yield 79%) (GC., 2.3 m, 150°, peaks in the order **15**, **16**, the mixture **16** gave one peak). These compounds (**16** as a mixture) were separated by GC.

Spectral data of ketone **15**: NMR. (90 MHz): 6.62 (1H, $d \times d$, $J_1 = 10$, $J_2 = 17.5$ Hz); 6.24 (1H, $d \times d$, $J_3 = 2$, $J_2 = 17.5$ Hz (further fine structure)); 5.72 (1H, $d \times d$, $J_1 = 10$, $J_3 = 2$ Hz (further fine structure)); 5.67 (1H, *'s'* (broad)); 3.00 (1H, *s* (broad)); 2.12 (4H, *m*); 1.58 (3H, *'s'* (further fine structure)); 0.98, 0.87 (6H, *s*). – IR.: 3100, 3020 w, 2960, 2920, 2870, 1690, 1670, 1610 s, 1470, 1450 m, 1395 s, 1365 m, 1345, 1320, 1250, 1220, 1200, 1170 w, 1145 m, 1130, 1115 w, 1085 m, 1070, 1025 w, 990, 965, 950 m, 900, 885, 870, 830 w. – MS.: 178 (M^+, 24), 124 (10), 123 (100), 122 (12), 121 (11), 95 (13), 81 (69), 67 (13), 55 (40), 43 (16), 41 (22).

Spectral data of the mixture **16**: NMR. (60 MHz): 4.85–6.50 (4H, complex *m*); 4.32 (1H, $d \times d$ (broad, further fine structure), $J_1 = 7$, $J_2 = 3$ Hz); 1.74 (3H, *'s'* (further fine structure)); 1.00, 0.87 (6H, *s*). – IR. (CCl_4): 3620, 3500 m, 3080, 3020 w, 2960, 2920, 2870, 2840 s, 1690, 1640, 1610 w, 1470, 1385, 1380, 1360 m, 1345, 1330, 1310, 1235, 1140, 1110, 1080 w, 1025 m, 990 s, 960 m, 925, 915 s, 860 w, 830 m. – MS.: 124 (29), 123 (100), 109 (28), 95 (13), 81 (70), 67 (15), 57 (18), 55 (19), 43 (18), 41 (21).

10. *Thermolysis of* **13**. A solution of 1.00 g of **13** in 5 ml of benzene was heated to reflux for 6 h (no exclusion of air). The solvent was then removed on a rotary evaporator and the residue was distilled (b.p. 110–112°/12 Torr). The distillate consisted of a mixture of **17** and **18**, and of a small amount of the amine **19** (NMR.-analysis). This mixture was taken up in pentane, washed with dilute mineral acid and with water, dried, concentrated and redistilled (b.p. 110–112°/12 Torr) to afford 527 mg of a mixture of **17** and **18** (combined yield 53%).

17+**18**: $C_{14}H_{25}N$ (223.4) Calc. C 75.28 H 11.28 N 6.27% Found C 74.90 H 11.18 N 6.68

Spectral data of the mixture **17**+**18**: NMR. (60 MHz): 5.25–5.60 (3H, *m*); 3.95–4.30 (2H, *m*); 2.49, 2.47 (6H, *s*); 1.58 (3H, *'s'* (further fine structure)); 1.03, 0.88 (one isomer), 0.88, 0.82 (the other isomer) (together 6H, *s*). – IR.: 3030 m, 2960, 2920, 2860 s, 2820 m, 2760, 1660 w, 1470, 1440, 1380, 1375 m, 1360 s, 1210 m, 1140, 1130 w, 1085, 1075 m, 1030, 970 s, 820 m.

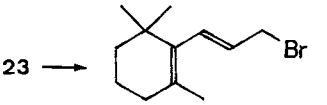
11. *Methylation of the mixture of* **17** *and* **18** *and* Hofmann *elimination*. 491 mg of a mixture of **17** and **18** (together 2.20 mmol) in 5 ml of ether were treated with 0.26 ml of methyl fluorosulfonate, at 5°, and the mixture was stirred at 5° for 2 h. The ether was then removed on a rotary evaporator and the oily residue was dissolved in 5 ml of glyme. This solution was added to a stirred solution of 5.0 mmol of lithium diisopropylamide in glyme/hexane at –30°, made by treating 515 mg of diisopropylamine (5.05 mmol) in 5 ml of glyme with 2.9 ml of 1.75 N butyllithium/hexane (5.05 mmol). This mixture was left at –30° for 10 min and was then poured into excess 2% aqueous H_2SO_4. Work-up and distillation (b.p. 108°/12 Torr) gave 202 mg of a mixture which consisted of *ca.* 70% of **20**, *ca.* 15% of **11** and *ca.* 15% of **31** (combined yield 52%) (GC., 2.3 m, 160°, peaks in the order **20**, **11**, **31**). These compounds were isolated by GC. For the spectral data of **11**, see section 5b, of **31**, see section 18. **31** is probably formed by base-catalyzed isomerization of **20** and **11** by hydrolysis during work-up.

Spectral data of α-cyclocitrylidene acetaldehyde (**20**) (see also ref. [25]): NMR. (60 MHz): 9.46 (1H, *d*, $J_1 = 7.5$ Hz); 6.61 (1H, $d \times d$, $J_2 = 9.5$, $J_3 = 15.0$ Hz); 5.97 (1H, $d \times d$, $J_1 = 7.5$, $J_3 = 15.0$ Hz); 5.50 (1H, *'d'* (broad, further fine structure)); 2.41 (1H, *d* (broad), $J_2 = 9.5$ Hz); 1.85–2.25 (2H, *m*); 1.58 (3H, *m*); 0.95, 0.88 (6H, *s*). – IR.: 3030 w, 2960, 2920, 2860 s, 2800, 2730 m, 1680 s, 1625, 1470, 1445, 1380, 1360 m, 1345, 1290, 1230, 1210, 1180 w, 1140, 1120 s, 1080, 1075, 1010 m, 980 s, 960, 930, 880 w, 820 m, 790, 735 w, 630 s. – MS.: 178 (M^+, 25), 122 (100), 107 (100), 95 (31), 93 (76), 91 (29), 79 (53), 77 (31), 55 (16), 44 (20), 41 (38).

12. *β-Cyclocitrylidene ethanol* (**23**) (see ref. [26]). a) *β-Cyclocitrylidene acetic acid* (**48**) was prepared according to ref. [26] [29] and esterified to give *ethyl β-cyclocitrylidene acetate* (**49**)[14]. b) *Alcohol* **23** was prepared by reduction of ethyl ester **49**, as described [section 5b] for step **46** → **11**. B.p. 121–122°/12 Torr; yield 83%.

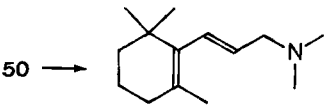
[14]) Carried out by Dr. *J. Becker* of this laboratory. We thank Dr. *Becker* for donating a sample of the ester **49**.

Spectral data of **23** (see ref. [26]): NMR. (60 MHz): 6.06 (1H, *d* (broad), J_1 = 16 Hz); 5.47 (1H, $d \times t$, J_1 = 16, J_2 = 5.0 Hz); 4.11 (2H, *d* (further fine structure), J_2 = 5.0 Hz); 1.65 (3H, *s*); 0.97 (6H, *s*). – IR.: 3320, 2930, 2860, 2820 s, 1640 w, 1450 s, 1380, 1370 m, 1360 s, 1205, 1200 m, 1170, 1135 w, 1090, 1005, 965 s. – MS.: 180 (M^+, 69), 165 (97), 147 (95), 123 (68), 121 (72), 105 (84), 93 (79), 91 (80), 81 (75), 55 (77), 41 (100).



50

13. *Bromide* **50** was prepared from alcohol **23**, as described [section 1] for step **1** → **3**. Yield 87%. *NMR. of* **50** (60 MHz): 6.59 (1H, *d* (broad), J_1 = 16 Hz); 5.60 (1H, $d \times t$, J_1 = 16, J_2 = 7.5 Hz); 1.68 (3H, '*s*' (further fine structure)); 0.91 (6H, *s*).



51

14. *Amine* **51** was prepared from bromide **50**, as described [section 2] for step **3** → **4**, except that tetrahydrofuran was used as solvent. B.p. 110–111°/12 Torr. Yield 78%.

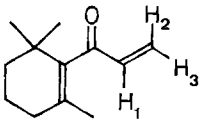
Spectral data of **51**: NMR. (60 MHz): 5.85 (1H, *d* (broad), J_1 = 16 Hz); 5.36 (1H, $d \times t$, J_1 = 16, J_2 = 6 Hz); 2.88 (2H, *d* (broad), J_2 = 6Hz); 2.14 (6H, *s*); 1.64 (3H, '*s*' (broad)); 0.96 (6H, *s*). – IR.: 2960, 2920, 2860, 2810, 2770, 1450 s, 1380, 1370 m, 1360 s, 1260, 1230 m, 1200 w, 1170 m, 1145, 1090 w, 1040 m, 1020, 970 s, 855, 810 w. – MS.: 192 (M^+, 59), 192 (80), 162 (35), 147 (64), 107 (26), 93 (29), 91 (29), 71 (82), 69 (30), 58 (100), 41 (33).

15. *Preparation and thermolysis of* **24**. The oxidation of 2.91 g of **51** (14.0 mmol) to give the amine oxide **24** was carried out like the analogous steps **4** → **2** and **19** → **12** [sections 3 and 8]. 127 mg of unreacted **51** were recovered. The crude amine oxide **24** was mixed with 10 g of paraffin and subjected to thermolysis/distillation at 55–60° as described [sections 3 and 8]. This afforded 2.67 g of **25** (13.0 mmol, 93% yield based on amine **51** used) (1.92, 0.52 and 0.23 g after 5 h, 7 h and 7 h). *NMR. of hydroxylamine* **25** (60 MHz): 6.08 (1H, $d \times d \times d$, J_1 = 5.5, J_2 = 10, J_3 = 17 Hz); 4.85–5.30 (2H, *m*); 4.65 (1H, *d* (broad, further fine structure)); 2.50 (6H, *s*); 1.63 (3H, *s*); 1.11, 0.93 (6H, *s*).

When the thermolysis/distillation of **24** was carried out rapidly, at ca. 100°, mixtures of **25** and **27** were obtained. On redistillation of **25** at 12 Torr [section 17], rearrangement to give **27** occurred. When neat **25** was left at 0°, crystals formed very slowly. These probably consist of the amine oxide **24**.

16. *Methylation of* **25** *and* Hofmann *elimination*. a) With lithium diisopropylamide: A solution of 751 mg of **25** (3.37 mmol) in 10 ml of ether was treated with 0.8 ml of methyl fluorosulfonate, at 5°. A white solid precipitate formed rapidly. Stirring at 5° was continued for 2 h and 1.02 g of crude salt **28** (3.04 mmol, 90%) were isolated by filtration (glass filter) and washing with ether. It was suspended in 10 ml of glyme and treated with a solution of 7.35 mmol of lithium diisopropylamide in 10 ml of glyme/ hexane [prepared as described in section 11] at – 30°, with stirring. The mixture was stirred for 20 min at – 30°, for another 10 min at 5° and then poured into dilute aqueous mineral acid. Extraction with pentane, work-up and distillation (b.p. 101–110°/12 Torr) gave 201 mg of a distillate. According to GC. (2.3 m, 150°) it consisted of a mixture of **23** (*ca.* 8%), **29** (*ca.* 34%), **30** (*ca.* 16%), **31** (*ca.* 17%) and **32** (*ca.* 25%). These compounds were separated by GC. (2.3 m, 140–160°, peaks in the order **30**, **29**, **32**, **31**, **23**). For the spectral data of **23** and **31**, see sections 12 and 18. Alcohols **23** and **32** are probably formed from unreacted **28**, during work-up.

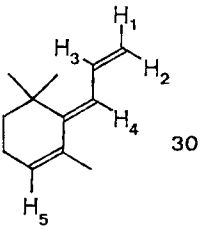
Spectral data of ketone **29**: NMR. (90 MHz): 5.85–6.65 (3H, *m*); 1.54 (3H, *s*); 1.03 (6H, *s*). On addition of 20 mg of $Eu(FOD)_3$, the vinyl protons gave the following signals: 7.94 (H_1, $d \times d$



29

(broad, further fine structure), $J_{12} = 17$, $J_{13} = 10$ Hz); 7.05 (H_2, *d* (broad, further fine structure), $J_{12} = 17$ Hz); 6.37 ppm (H_3, *d* (broad, further fine structure), $J_{13} = 10$ Hz). – IR.: 2960, 2930, 2870, 1680, 1655 s, 1610, 1600, 1465 m, 1430 w, 1395 s, 1380, 1360, 1290, 1270, 1235 m, 1205 w, 1165 m, 1120, 1060, 1040, 1030 w, 990, 960, 930 m, 830, 795, 760 w. – MS.: 178 (M^+, 54), 163 (100), 123 (71), 121 (24), 107 (31), 93 (23), 81 (58), 55 (90), 43 (24), 41 (42), 39 (24).

Spectral data of the triene **30**: NMR. (90 MHz): 7.09 (H_3, $d \times d \times d$, $J_{13} = 10$, $J_{23} = 16$, $J_{34} = 11.5$ Hz); 6.10 (H_4, *d*, $J_{34} = 11.5$ Hz); 5.81 (H_5, '*t*' (broad), $J = ca.$ 5 Hz); 5.05–5.35 (H_1, H_2, *m*); 1.95–2.30 (2H, *m*); 1.88 (3H, apparent *q*, 'J' = 2 Hz); 1.51 (2H, *t*, $J = 6$ Hz); 1.28 (6H, *s*).



30

Saturation of the gem-dimethyl signal (1.28 ppm) changed the intensity of the signals of H_1, H_2 (–10%) and of H_3 (+21%), while saturation of the signal of the other methyl group (1.88 ppm) changed the intensity of signals of H_1, H_2 (–8%), of H_4 (+26%) and of H_5 (+20%). – IR.: 3090, 3020 m, 2990, 2960, 2920, 2870, 2850 s, 1700 w, 1620, 1460, 1450 s, 1410, 1390 w, 1380, 1360 m, 1345, 1335, 1325, 1290, 1275 w, 1210, 1190, 1145, 1120, 1080, 1030, 1000 m, 985 s, 960 m, 900 s, 875, 860 w, 800 m, 690, 670 w, 650 m. – MS.: 162 (M^+, 61), 147 (100), 121 (22), 119 (73), 106 (59), 105 (87), 91 (81), 79 (27), 77 (30), 55 (32), 41 (41).

Spectral data of the alcohol **32**: NMR. (90 MHz): 6.10 (1H, $d \times d \times d$, $J_1 = 4.5$, $J_2 = 10$, $J_3 = 17$ Hz); 5.0–5.45 (2H, *m*); 4.75 (1H, *m*); 1.76 (3H, *s*); 1.12, 0.98 (6H, *s*). Complexation with $Eu(FOD)_3$ gave a simplified spectrum. – IR.: 3400 s, 3080, 3010 s, 2960, 2930, 2910, 2870 s, 2830 m, 1635 w, 1450, 1375, 1360 m, 1205, 1145, 1170, 1130, 1120, 1095, 1060 w, 1030, 1010 m, 980, 915 m, 890, 880, 840 w, 740 m. – MS.: 180 (M^+, 26) 147 (100), 123 (92), 119 (58), 109 (62), 105 (93), 81 (74), 79 (47), 55 (81), 43 (56), 41 (85).

b) With aqueous $Ba(OH)_2$: 2.12 g of **28** (6.30 mmol), prepared from **25** as described [section 16a] were treated with a solution of 1.23 g of $Ba(OH)_2$ (3.50 mmol) in 15 ml of water and 15 ml of hexane were added. The resulting mixture was stirred at 80° for 18 h. The hexane layer was then separated and the aqueous layer was extracted with ether. Work-up of the combined extracts and distillation gave: fraction I, b.p. 92–97°/12 Torr, 723 mg, and fraction II, b.p. *ca.* 115°/12 Torr, 178 mg. According to GC. (2.3 m, 135°), fraction I consisted mainly of **30** and fraction II consisted mainly of a mixture of **23**, **31** and **32** (peaks in the order **30**, **32**, **31**, **23**), and contained none of **29**. These compounds were isolated by GC. and identified by their spectra [see section 16a]. The peak corresponding to **32** showed a shoulder (which was not observed in the run described in section 16a) and the NMR.-spectrum of the isolated material (**32** + shoulder) showed the presence of a minor component, probably of alcohol **33**.

17. *Thermolysis of* **25**: During distillation of 2.10 g of **25** (b.p. 112–115°/12 Torr), complete rearrangement to give **27** occurred. Yield 1.83 g (87%).

27: $C_{14}H_{25}NO$ (223.4) Calc. C 75.28 H 11.28 N 6.27% Found C 74.59 H 11.06 N 7.00%

Spectral data of **27**: NMR. (60 MHz): 6.04 (1H, *d* (broad), $J_1 = 16$ Hz); 5.45 (1H, $d \times t$, $J_1 = 16$, $J_2 = 6$ Hz); 2.50 (6H, *s*); 1.66 (3H, *s*); 0.99 (6H, *s*). – IR: 2990, 2960, 2930, 2860, 2850 s, 2830, 2810, 2770 m, 1690, 1640 w, 1470, 1440 s, 1380, 1370 m, 1360 s, 1210 m, 1170, 1140, 1120, 1095 w, 1030 s, 1000 m, 970 s, 935 m.

18. *Methylation of* **27** *and* Hofmann *elimination*. a) With lithium diisopropylamide: 204 mg of **27** (0.92 mmol) were methylated with methyl fluorosulfonate to give **34** which was then treated with 2.2 mmol of lithium diisopropylamide in glyme for 2 min, at –30°, as described in section 11. Work-up and distillation (b.p. *ca.* 120°/12 Torr) gave 95 mg of a *ca.* 3:1 mixture (GC.) of **31** and **23** (combined yield 58%). Compounds **23** and **31** were separated by GC. (2.3 m, 160°, peaks in the order **31**, **23**). Alcohol **23** is probably formed by hydrolysis of unreacted **34**.

Spectral data of β-cyclocitrylidene acetaldehyde (**31**) (see also ref. [26] [27]): NMR. (60 MHz): 9.51 (1H, *d*, $J_1 = 7$ Hz); 7.24 (1H, *d* (broad), $J_2 = 16$ Hz); 6.05 (1H, $d \times d$, $J_1 = 7$, $J_2 = 16$ Hz); 1.95–2.30 (2H, *m*); 1.80 (3H, *s*); 1.45–1.75 (2H, *m*); 1.10 (6H, *s*). – IR.: 2960, 2930, 2870 s, 2820, 2720 m, 1685, 1600 s, 1450 m, 1420, 1380, 1370 w, 1360 m, 1300, 1285, 1270, 1200, 1170 w, 1125 s, 1060, 1040, 1025, 1005 w, 970 m. – MS.: 178 (M^+, 8), 164 (13), 163 (100), 121 (13), 107 (16), 93 (19), 91 (17), 79 (15), 55 (15), 41 (24), 39 (16).

b) With aqueous $Ba(OH)_2$: 347 mg of **27** (1.56 mmol) were methylated with methyl fluorosulfonate and then treated with 1.05 mmol of $Ba(OH)_2$ in water/hexane as described in section 16b, at 80°, for 18 h. After work-up and distillation (b.p. *ca.* 100°/12 Torr), 94 mg of a *ca.* 8:1 mixture (GC.) of **31** and **23** (0.06 mmol of **23**, 0.47 mmol of **31**, combined yield 34%) were obtained.

19. *N-Geranyl-N, N-dimethylamine* (**52**): To a stirred solution of 3.90 g of dimethylamine in 20 ml of tetrahydrofuran was added dropwise (*ca.* 20 min) a solution of 5.00 g of geranyl bromide (**53**) (18.9 mmol) in 10 ml of tetrahydrofuran, at 5°, and the resulting solution was kept at 5° for 3 h. Work-up as described [section 2] for step **3** → **4**, and distillation (b.p. 93–95°/12 Torr) gave 2.90 g of **52** (16.0 mmol, 85%). GC. (120°, 5 m) showed the presence of a small amount of N-neryl-N, N-dimethylamine (**54**).

Spectral data of **52**: NMR. (60 MHz): 4.90–5.30 (2H, *m*), 2.85 (2H, *d* (broad), $J = 7$ Hz); 2.09 (6H, *s*); 1.5–1.7 (9H, *m*). – MS.: 181, (M^+, 21), 112, (94), 98 (100), 93 (40), 81 (23), 69 (94), 46 (35), 45 (63), 44 (55), 42 (34), 41 (85).

20. *Preparation and thermolysis of N-geranyl-N, N-dimethylamine oxide* (**35**): A stirred solution of 3.40 g of **52** (18.6 mmol) (containing a small amount of **54**) in 12 ml of methanol, was treated with 9 ml of 35% aqueous H_2O_2, at 5°, and the resulting homogenous mixture was left at room temperature for 25 h. After decomposing the excess H_2O_2 and distilling off the methanol and water as described [sections 3, 8 and 15], the crude amine oxide **35** was obtained as a viscous liquid. Thermolysis combined with distillation (75–80°/0.05 Torr, 1 h) as described gave 2.98 g of **37** (15.1 mmol, 81%). A sample was redistilled (b.p. 88–90°/12 Torr) for analysis and was found to be unchanged after standing at room temperature for 1 year.

37: $C_{12}H_{23}NO$ (197.3) Calc. C 73.04 H 11.75 N 7.10% Found C 73.23 H 11.82 N 6.95%

Spectral data of O-linalyl-N, N-dimethylhydroxylamine (**37**): NMR. (60 MHz): 5.87 (1H, $d \times d$, $J_1 = 10$, $J_2 = 18$ Hz); 4.80–5.20 (2H, *m*); 2.40 (6H, *s*); 1.50–1.65 (6H, *m*); 1.22 (3H, *s*). – IR: 3090 w, 2950, 2850 s, 2810 m, 2760, 1640 w, 1460, 1440, 1410, 1370, 1360 m, 1200, 1175, 1150 w, 1100, 990 m, 910, 890 s, 830 w.

21. *Thermolysis of* **37** (in benzene solution): A solution of 1.15 g of **37** in 5 ml of benzene was heated to 120° for 5 h in a sealed tube. Evaporation of the solvent and distillation (b.p. 90–95°/12 Torr) gave 981 mg of a *ca.* 3:1 mixture of **38** and **39** (combined yield 85%).

The thermolysis of **37** was also effected in the injector block of a gas chromatograph (injector 205°, oven 120°, 5 m) and gave **38** and **39**, and in addition some of **52** and **54**. Compounds **38** and **39** were isolated by GC. – *NMR. of* **38** (60 MHz): 4.85–5.45 (2H, *m*); 4.02 (2H, *d* (broad), $J = 7$ Hz); 2.46 (6H, *s*); 1.95–2.10 (4H, *m*); 1.50–1.70 (9H, *m*). – *NMR. of* **39** (60 MHz): very similar to that of **34**, except for the shape of the multiplets at 1.95–2.10 (4H), and 1.50–1.70 (9H), and for the signal of the dimethylamino group at 2.44 (6H).

22. *Linalool* (**40**) *from* **37**: To a solution of 200 mg of **37** (1.10 mmol) in 2 ml of acetic acid were added 300 mg of zinc powder (4.6 mmol) and this mixture was stirred at 35° for 20 h. Addition of water and 2% aqueous H_2SO_4, extraction with ether, washing (H_2O, $NaHCO_3$ sol.),

drying and distillation (b.p. *ca.* 75°/12 Torr) afforded 146 mg of very pure **40** (0.95 mmol, 86%) (GC., 2.3 m, 150°), which was identified by its spectra.

23. *Thermolysis of* **37** (at 300° in a quartz tube): A pentane solution of 200 mg of **37** was slowly introduced into a quartz tube (150 × 12 cm) which was filled with quartz rings and heated to *ca.* 300°, at 12 Torr of N_2. The thermolysate was collected in two liquid nitrogen-cooled traps. The contents of the traps were taken up in pentane, washed with water and concentrated. Distillation (b.p. 60–65°/12 Torr) gave 91 mg of a complex mixture. GC. (3 m, 100 → 200°) indicated the presence of at least 20 components. The two major components were collected by GC. (peaks in the order **55**, **44**). Limonene (**55**) was identified by its spectra.

Spectral data of N,N-dimethyl-O-α-terpinylhydroxylamine (**44**): NMR. (90 MHz): 5.37 (1H, *m*); 2.50 (6H, *s*); 1.63 (3H, *m*); 1.08, 1.14 (6H, *s*). The MS. showed *m/e*: 137 (**44** – $ONMe_2$).

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