106. Vitispiranes, Important Constituents of Vanilla Aroma

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Summary

The preparation of the vitispiranes **9** and **10**, identified among the volatiles of vanilla, from the theaspiranes **1** and **2** *via* the intermediates **4** and **5** and the allyl alcohols **7** and **8**, respectively, is described. The theaspiranes **1** and **2** can be obtained from the compounds **11**–**15** or **24**–**26**.

Vitispirane[1]) (**9**/**10**), one of the most recently discovered ionone-like spiro-ethers, was identified in the volatiles of grape juice and distilled grape spirits, and in table and fortified wines [1]. We found the diastereoisomers **9** and **10** of vitispirane to be important aroma components of vanilla. Gas-chromatographic (GC.) analysis of the volatiles of a vanilla extract on a glass capillary column UCON HB 5100 revealed the presence of the mixture **9**/**10** in the region between acetophenone and 5-methylfurfural. It appeared in an incompletely resolved double peak in which the ratio of **9** and **10** was about 1:3[2]). The isomers showed practically identical mass spectra [1].

Since it was not possible to separate **9** and **10** by preparative GC., stereoselective synthesis was undertaken. The naturally occurring theaspiranes[1]), a mixture of the diastereoisomeric **1** and **2** [2–4] which unlike vitispirane (**9**/**10**) can be separated by fractional distillation, were the suitable starting material. Separate treatment of *cis*- and *trans*-theaspirane (**1** and **2**, respectively)[3]) with *m*-chloroperbenzoic acid yielded varying proportions of the diastereoisomeric epoxides **3** and **4**, and **5** and **6**, respectively, which were separated [6]. When treated with aluminium triisopropoxide at 140°, the main epoxidation products **4** and **5**[4]) gave in excellent yield exclusively the racemic allyl alcohols **7** and **8**[5]), respectively. **7** (m.p. 70–71°), when treated with cold $POCl_3$/pyridine, yielded *cis*-vitispirane (**9**) in over 50% yield, its diastereo-

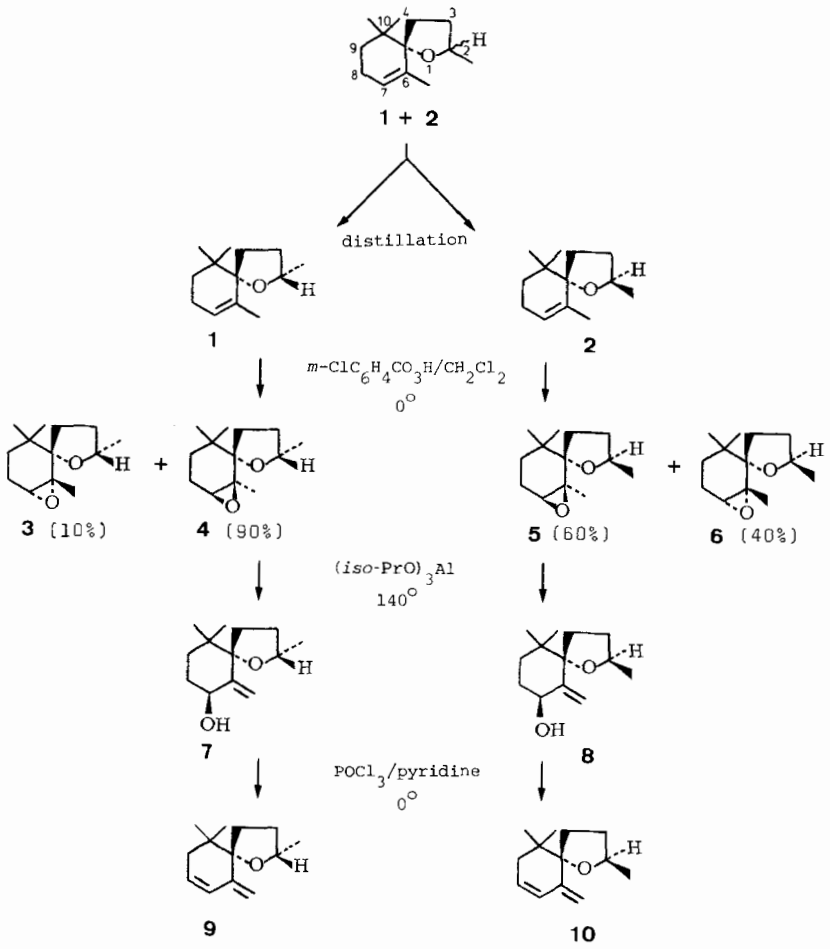
[1]) For systematic names see exper. part.

[2]) The NMR. spectra of the natural products show that the discoverers [1] of vitispirane also had a mixture of diastereoisomers. We thank Dr. *Williams* for this information and the spectra.

[3]) The configuration of the theaspiranes **1** and **2** has already been established by direct linking with the known *cis*- and *trans*-theaspirone, respectively [5].

[4]) These products were also isolated from tea flavour [4] (*cf.* also [7]).

[5]) The optically active compounds have been prepared independently in the same way [8]. We thank Drs. *Kaiser* and *Lamparsky* for the communication of the conference manuscript.

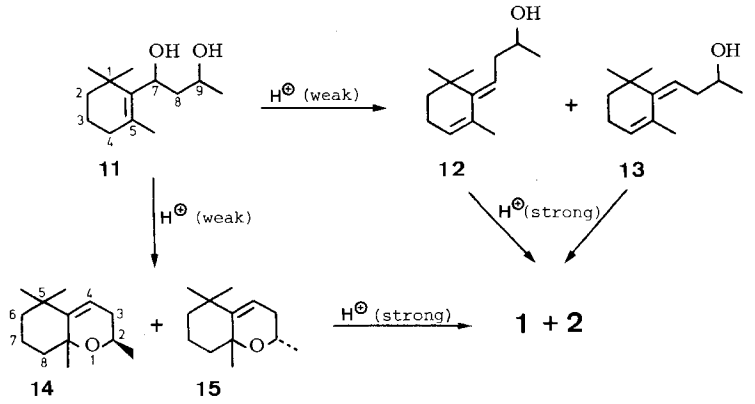


isomer **8** (m.p. 52–53°) being similarly converted into *trans*-vitispirane (**10**). The retention indices [9] (*cf.* exper. part) and the mass spectra of the dienyl-spiro-ethers thus synthesized were identical with those of *cis*- and *trans*-vitispirane (**9** and **10**, respectively) isolated from vanilla extract.

The odour of the diastereoisomeric vitispiranes **9** and **10** is unmistakably different. The *cis*-compound **9** is fresher and more intense than the *trans*-compound **10**. **9** is reminiscent of the green odour of chrysanthemum, and, in addition, has a flowery-fruity wine note. **10** is characterized by a heavy scent of exotic flowers with an earthy-woody undertone, and has a note of dry wines as in marc. The odour intensity and quality of **9** and **10** are definitely different from those of the theaspiranes **1** and **2**.

7-Hydroxy-7,8-dihydro-β-ionol (**11**)[6]) was the starting material for the racemic

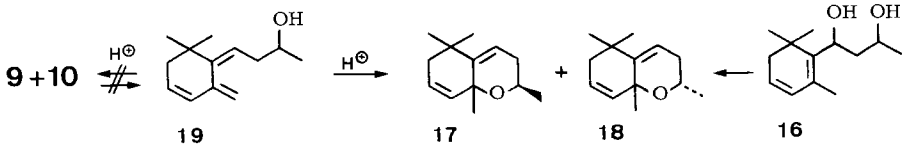
[6]) Ionone (4-(2,6,6-trimethylcyclohex-1-enyl)but-3-en-2-on) numbering and derived nomenclature according to 'Tentative Rules for the Nomenclature of Carotenoids (IUPAC)' (O. Isler, "Carotenoids", Birkhäuser Verlag, Basel 1971).



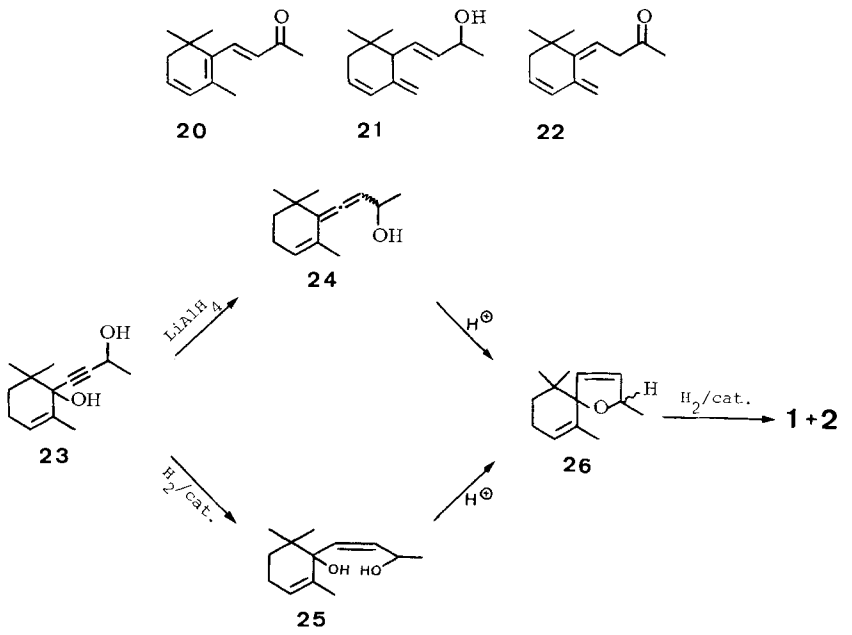
spiro-ethers **1** and **2**. Heating of **11** to 80–90° in the presence of $KHSO_4$ yielded exclusively a 1:1 mixture of the diastereoisomeric theaspiranes **1** and **2** [6]. This conversion is assumed to involve the stereoisomeric *retro*-ionols **12** and **13** [10a, 10b] as intermediates. Indeed, **12** and **13** were isolated in over 80% yield when **11** was treated with dilute phosphoric acid in acetone at room temperature. Only under energetic acid-catalysis the reaction proceeded to the stable end products **1** and **2** (*cf.* also [11]). The dihydroedulanes[1]) **14** and **15** [12], obtained as by-products on mild acid treatment of diol **11**[7]), were also unstable in the presence of strong acids and isomerized to **1** and **2**. The reaction **11** → **1** + **2** is remarkable inasmuch as the acid-catalysed reaction of the corresponding dehydro compound **16** gave only the diastereoisomeric edulanes[1]) **17** and **18** [14].

It seems likely that the ethers **1** and **2** are biogenetically related with **14** and **15**. Similar relations could exist between the edulanes **17** and **18** and the vitispiranes **9** and **10**, especially since *in vivo* formation of *retro*-3,4-dehydro-γ-ionol (**19**) from the dehydro-ionone derivatives **20** and **21**, both found in tobacco [15], appears to be possible *via* **22**. Contrary to our expectations, acid treatment of **19** did not result in the formation of vitispirane (**9**/**10**), edulane (**17**/**18**; 1:9 mixture) being the sole cyclization product under all conditions tried (34% yield; $HClO_4$/nitropropane). Likewise, upon the same acid treatment, vitispirane (**9**/**10**) formed neither trienol **19**, the hypothetical equilibrium intermediate, nor edulane (**17**/**18**) in quantities detectable by GC.

A further route to the theaspiranes **1** and **2** consists in partial hydrogenation of theaspirene (**26**) [16]. We succeeded in obtaining **26** from the known diol **23** [16] by

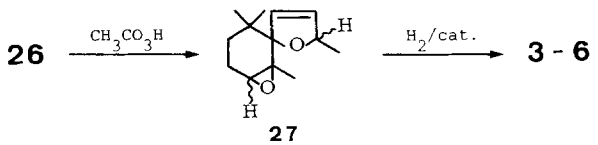


[7]) Their formation is probably the result of an intramolecular dehydration at the allylic position, a reaction that has been extensively investigated with analogous systems [13].



two new ways. Treatment of **23** with $LiAlH_4$ gave good yields of *retro*-7,8-dehydro-α-ionol (**24**) which was easily cyclized to the spiro-ethers **26** in the presence of acid catalysts, a possibility we have already suggested [16]. Alternatively, partial catalytic hydrogenation of the triple bond in **23** readily yielded (*Z*)-6-hydroxy-α-ionol (**25**) which gave **26** in the presence of dilute acids. This method proved to be particularly advantageous since **23** was converted into **26** in almost quantitative yield.

However, the naturally occurring mixture of the diastereoisomeric vitispiranes **9** and **10** is best made from the diastereoisomeric epoxy-spiro-ethers **27** which were formed regioselectively and quantitatively when **26** was treated with peracetic acid. Subsequent catalytic hydrogenation converted **27** completely to the diastereoisomeric dihydro compounds **3–6**.



Experimental Part

(with the collaboration of *Ch. Linder* and *B. Egger*)

General. Melting points were taken on a *Kofler* apparatus and are not corrected. The IR. spectra were recorded on a *Perkin-Elmer* 125, typical bands in cm^{-1}. The 60-MHz-^{1}H-NMR. spectra were recorded on a *Varian* A 60 and a *Hitachi Perkin-Elmer* R-20B, and the 90-MHz-^{1}H-NMR. spectra on a *Bruker* instrument, type HFX-90/15″, using $CDCl_3$ as solvent (unless otherwise stated) and TMS ($\delta = 0.00$ ppm) as internal standard; abbreviations: *s* = singlet, *d* = doublet, *t* = triplet, *qa* = quadruplet, *m* = multiplet, br. = broad. Chemical shifts are given in ppm, spin-spin coupling constants *J* in Hz. Mass

spectra (MS.) were measured on an *Atlas* CH_4, inlet temp. *ca.* 150°, electron energy *ca.* 70 eV; the molecular ions (*M*) and fragment ions are given as *m/e* with relative peak intensities in % of the most abundant peak. For gas-chromatography (GC.) on packed glass columns a *Carlo Erba* GT and a *Varian* Aerograph (series 1800) instrument were used; carrier gas: 40 ml He/min; column carrier: *Chromosorb* W/60–80 mesh. For GC. on metal capillary columns (specified in the text) a *Perkin-Elmer* 266 was used; carrier gas: 1–1,4 atm. He. The silica gel (0.05 to 0.2 mm) used for column chromatography was obtained from *E. Merck AG*, Darmstadt. – Other abbreviations: RT. = room temperature.

1. Identification of vitispirane (9/10) in vanilla flavour. – The isolation of the volatile components from vanilla oleoresin (about 250 ppm) and their GC. analysis were performed as described [4], except that for the GC./MS. analysis a *Varian* MAT 112 mass spectrometer was used. On slow programmation (60–170°, 1°/min) a small, partially resolved double peak with a ratio of *ca.* 3:1 appeared between the peaks of 5-methylfurfural and acetophenone. The MS. of the components of this double peak are practically identical with those of vitispirane (**9/10**) [1], the major component being the *trans*-compound **10**. The retention indices [9] $I = 1427$ and 1424 of the diastereoisomers correspond exactly to the values of the synthetic vitispiranes **9** and **10** (*cf.* below). Quantitative analysis (GC.) of vanilla oleoresin revealed 1 ppm of the mixture **9/10**.

2. 7-Hydroxy-7,8-dihydro-β-ionols (11a/b). – The mixture of the diastereoisomeric diols **11a/b** [17] was separated by column chromatography on silica gel with toluene/methyl acetate 9:1.

Diol **11a**: 90% of the mixture, m.p. 117° (needles from hexane). – IR. (KBr): 3350 (assoc. OH). – ^{1}H-NMR. (60 MHz, CCl_4): 0.95 and 1.14 (2 *s*, 6 H, $(CH_3)_2C$); 1.21 (*d*, $J = 6$, 3 H, 3 H–C(10)); 1.81 (*s*, 3 H, H_3C–C(5)); 4.0 (*m*, 1H, H–C(9)); 4.58 (*d*×*d*, $J = 9$ and 2, 1H, H–C(7)). – MS.: 212 (*M*, 3), 153 (100), 135 (75), 123 (50), 109 (78), 43 (75).

Diol **11b**: *ca.* 10% of the mixture, shorter retention time than **11a**; m.p. 113° (crystals from hexane). – IR. (KBr): 3320 (OH). – ^{1}H-NMR. (60 MHz, CCl_4): 0.95 and 1.12 (2 *s*, 6H, $(CH_3)_2C$); 1.22 (*d*, $J = 7$, 3H, 3 H–C(10)); 1.88 (*s*, 3 H, H_3C–C(5)); 4.05 (*m*, 1H, H–C(9)); 4.52 (*d*×*d*, $J = 9$ and 3, 1H, H–C(7)). – MS.: 212 (*M*, 3), 153 (65), 135 (100), 121 (58), 107 (70), 43 (70).

3. *retro*-α-Ionols 12/13 and 7,8-dihydro-edulanes 14/15 (= *cis*- and *trans*-2,5,5,8a-tetramethyl-3,5,6,7,8,8a-hexahydro-2*H*-1-benzopyrans). – To a solution of 15 g of the *ca.* 9:1 mixture of **11a/b** in 150 ml of acetone 30 ml of 30% H_3PO_4 solution were added, and the mixture was stirred at RT. until the diols had completely disappeared (*ca.* 2 days). The mixture was concentrated *in vacuo*, diluted with water and ether, and the ether phase washed with $NaHCO_3$-solution. The separated and dried ether phase yielded 13.7 g of oil which was subjected to chromatography on 20 times its quantity of SiO_2 with toluene/methyl acetate 9:1. First, 2.5 g of a mixture containing the dihydro-edulanes **14/15** in a ratio of 8:2, and then 10.8 g (*ca.* 80%) of a *ca.* 1:20 mixture of the *retro*-ionols **12/13** were obtained. Separation by GC. on *Carbowax* yielded in the order of increasing retention times:

cis-*7,8-Dihydro-edulane* (**14**; 8% of the mixture): $n_D = 1.4795$, $d^{20} = 0.9279$. – IR. (film): 3075, 1645, 820 (C=CH), 1060 (C–O). – ^{1}H-NMR. (60 MHz, CCl_4): 1.10 and 1.12 (2 *s*, 6 H, $(CH_3)_2C$); 1.15 (*d*, $J = 6$, 3 H, H_3C–C(2)); 1.22 (*s*, 3 H, H_3C–C(8a)); 3.43 (*m*, 1H, H–C(2)); 5.5 (*t*, $J = 4$, 1H, H–C(4)). – MS.: 194 (*M*, 24), 179 (75).

trans-*7,8-Dihydro-edulane* (**15**; 2% of the mixture): $n_D = 1.4829$, $d^{20} = 0.9374$. – IR. (film): 812 (C=CH), 1060 (C–O). – ^{1}H-NMR. (60 MHz, CCl_4): 1.01 and 1.08 (2 *s*, 6 H, $(CH_3)_2C$); 1.1 (*d*, $J = 6$, 3 H, H_3C–C(2)); 1.38 (*s*, 3 H, H_3C–C(8a)); 3.7 (*m*, 1H, H–C(2)); 5.38 (*m*, 1H, H–C(4)). – MS.: 194 (*M*, 17), 179 (100).

(E)-retro-*α-Ionol* (**12**): $n_D = 1.5111$, $d^{20} = 0.9913$. – IR. (film): 3350 (OH), 818 (C=CH). – ^{1}H-NMR. (60 MHz, CCl_4): 1.02 (2 *s*, superimposed, 6 H, $(CH_3)_2C$); 1.13 (*d*, $J = 6$, 3 H, 3 H–C(10)); 1.95 (*d*, $J = 2$, 3 H, H_3C–C(5)); 3.72 (*m*, 1H, H–C(9)); 5.22 and 5.4 (2 *m*, 2 H, H–C(4) and H–C(7)). – MS.: 194 (*M*, 26), 176 (1), 135 (100).

(Z)-retro-*α-Ionol* (**13**): $n_D = 1.5171$, $d^{20} = 0.9501$. – IR. (film): 3350 (OH), 818 (C=CH). – ^{1}H-NMR. (60 MHz, CCl_4): 1.2 (2 *s*, superimposed, 6 H, $(CH_3)_2C$); 1.18 (*d*, $J = 6$, 3 H, 3 H–C(10)); 1.78 (*d*, $J = 2$, 3 H, H_3C–C(5)); 3.78 (*m*, 1H, H–C(9)); 5.3 and 5.55 (2 *m*, 2 H, H–C(4) and H–C(7)). – MS.: 194 (*M*, 27), 176 (2).

Compounds **12** [10a], **13** [10b], **14** and **15** [12] were found to be identical with authentic samples. The by-products (*ca.* 18%) were not investigated, but theaspirane (**1/2**) was only detected in traces (GC.).

4. Preparation of theaspiranes 1/2 (= 2,6,10,10-tetramethyl-1-oxaspiro[4.5]dec-6-enes)[8]. – 4.1. *From the diols* **11a/b**. Heating 5 g of the mixture **11a/b** with 1 g of $KHSO_4$ in a small distillation apparatus for 30 min at 75–80°/30 Torr yielded a mixture which distilled at 100°/12 Torr. The distillate (4.5 g) contained (GC.) *ca.* 85% of the theaspiranes **1** and **2** (6:4), identified by comparing the spectra with those of authentic samples [5]. Besides **1** and **2**, only small quantities of the dihydro-edulanes **14/15** and the *retro-α*-ionols (**12/13**) were detected.

4.2. *From the* retro-*α-ionols* (**12/13**). 5 g of a *ca.* 1:9 mixture of **12** and **13**, and 0.5 g of $KHSO_4$ were heated at *ca.* 90°/30 Torr as above yielding 4 g of a 6:4 mixture of the theaspiranes **1** and **2**.

4.3. *From the dihydro-edulanes* **14/15**. A solution of 3.6 g of a *ca.* 9:1 mixture of **14** and **15** in 30 ml of toluene containing 0.2 g of *p*-toluenesulfonic acid was kept at 100° under N_2. After *ca.* 60 min the reaction was terminated (GC. control). Distillation (bulb tube) at 65–70°/3 Torr yielded 3.2 g of a mixture which contained about 80% of **1** and **2** in a ratio of 6:4 (GC. analysis).

4.4. *Isolation of the pure isomers* **1** *and* **2**. The mixtures **1/2** (see 4.1–4.3) were completely separated by fractional distillation on a *Fischer* slit-tube column at 3 Torr.

cis-Theaspirane[9]) (**1**): b.p. 68–69°/3 Torr. – ^{1}H-NMR. (90 MHz). 0.90 and 0.96 (2 *s*, 6 H, $(CH_3)_2C$); 1.28 (*d*, $J = 6$, 3 H, $H_3C-C(2)$); 1.74 (br. *s*, 3 H, $H_3C-C(6)$); 1.4–2.2 (*m*, 8 H, 4 CH_2); 4.15 (*m*, 1H, H–C(2)); 5.27 (br. *s*, 1H, H–C(7)). – MS.: 194 (M, < 1), 179 (3).

trans-*Theaspirane*[9]) (**2**): b.p. 71–72°/3 Torr. – ^{1}H-NMR. (90 MHz): 0.87 and 1.00 (2 *s*, 6 H, $(CH_3)_2C$); 1.28 (*d*, $J = 6$, 3 H, $H_3C-C(2)$); 1.73 (br. *s* with fine structure, 3 H, $H_3C-C(6)$); 4.03 (*m*, 1H, H–C(2)); 5.42 (br. *t*, 1H, H–C(7)). – MS.: 194 (M, < 1), 179 (2).

5. Theaspirane-epoxides (= 2,6,10,10-tetramethyl-6,7-epoxy-1-oxaspiro[4.5]decane; 3–6). – 5.1. *Epoxides* **3/4**: A solution of 15.9 g of *m*-chloroperbenzoic acid (85%) in 100 ml of CH_2Cl_2 was added dropwise at 0–5° to 12.2 g of *cis*-theaspirane (**1**) in 50 ml of CH_2Cl_2. After 1 h at 10–20° an excess of 2N NaOH was added, and the organic phase was washed neutral. Drying (Na_2SO_4) and evaporation gave 13.4 g (98%) of a *ca.* 1:9 mixture of **3** and **4** which was separated by distillation (packed column).

For further purification **3** was chromatographed on silica gel with hexane/ethyl acetate *ca.* 9:1. – ^{1}H-NMR. (90 MHz): 0.81 and 0.95, (2 *s*, 6 H, $(CH_3)_2C$); 1.25 (*d*, $J = 6$, 3 H, $H_3C-C(2)$); 1.40 (*s*, 3 H, $H_3C-C(6)$); 1.45–2.35 (*m*, 8 H, 4 CH_2); 2.99 (br. *s* with fine structure, 1H, H–C(7)); 4.28 (*m*, 1H, H–C(2)). – MS.: 210 (M, 17), 195 (6), 177 (< 1), 167 (2), 154 (36), 139 (20), 126 (81), 111 (31), 95 (10), 83 (21), 69 (44), 55 (52), 43 (100).

4 was twice recrystallized from EtOH/H_2O, m.p. 27.5°. – ^{1}H-NMR. (90 MHz): 0.79 and 0.87 (2 *s*, 6 H, $(CH_3)_2C$), 1.26 (*d*, $J = 6$, 3 H, $H_3C-C(2)$); 1.33 (*s*, 3 H, $H_3C-C(6)$); 1.4–2.4 (*m*, 8 H, 4 CH_2); 3.07 (br. *s* with fine structure, 1H, H–C(7)); 4.06 (*m*, 1H, H–C(2)). – MS.: 210 (M, 24), 195 (7), 182 (3), 167 (3), 154 (59), 139 (25), 126 (74), 111 (35), 97 (14), 85 (28), 69 (49), 55 (62), 43 (100).

5.2. *Epoxides* **5/6**: The epoxidation of **2** as described above yielded 95% **5** and **6** in a ratio of 3:2, which were separated by distillation on a *Fischer* slit-tube column.

Epoxide **5**, b.p. 67–70°/0.4 Torr. – ^{1}H-NMR. (90 MHz): 0.90 and 0.93 (2 *s*, 6 H, $(CH_3)_2C$); 1.28 (*d*, $J = 6$, 3 H, $H_3C-C(2)$); 1.31 (*s*, 3 H, $H_3C-C(6)$); 1.4–2.8 (*m*, 8 H, 4 CH_2); 3.04 (*t*, $J = 2$, 1H, H–C(7)); 4.16 (*m*, 1H, H–C(2)). – MS.: 210 (M, 26), 195 (5), 182 (2), 167 (3), 154 (64), 139 (26), 136 (45), 111 (27), 97 (12), 85 (27), 69 (38), 55 (60), 43 (100).

Epoxide **6**, b.p. 79°/0.4 Torr, m.p. 41.5° (from EtOH/H_2O). – ^{1}H-NMR. (90 MHz): 0.76 and 0.90 (2 *s*, 6H, $(CH_3)_2(CH_3)_2C$); 1.30 (*d*, $J = 6$, 3H, $H_3C-C(2)$); 1.32 (*s*, 3H, $H_3C-C(6)$); 1.4–2.2 (*m*, 8H, 4CH_2); 2.97 (br. *s*, 1H, H–C(7)); 3.90 (*m*, 1H, H–C(2)). – MS.: 210 (M, 17), 195 (7), 177 (< 1), 167 (3), 154 (70), 139 (33), 126 (56), 112 (45), 97 (11), 85 (26), 69 (39), 55 (61), 43 (100).

6. 2,10,10-Trimethyl-6-methylidene-1-oxaspiro[4.5]decan-7-ols 7/8. – 6.1. (2R*,5R*)-*alcohol* **7**. A stirred mixture of 10.5 g of epoxide **4** and 500 mg of aluminium triisopropoxide was heated slowly to 140°, and kept at this temp. for 4 h. he resulting orange mixture was distilled (bulb) at 90–100°/0.1 Torr to yield 9.3 g (88%) of **7**, m.p. 52–53° (crystals from ether/hexane). – IR. ($CHCl_3$): 3595, 3420, 3090, 1640, 903. – ^{1}H-NMR. (60 MHz): 0.83 and 0.93 (2 *s*, 6 H, $(CH_3)_2C$); 1.18 (*d*, $J = 6$, 3 H, $H_3C-C(2)$); 1.2–3.2 (*m*, 9 H, 4 CH_2, HO); 3.90 (*m*, $J = 6$, 1H, H–C(2)); 4.48 (*m*, 1H, H–C(7)); 4.93 and 5.18 (2 *d*,

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[8]) Other methods for preparing **1/2** are described in the literature [18].

[9]) **1** has the relative configuration (2*R**,5*R**) and **2** (2*R**,5*S**).

J=2, 2 H, H_2C=C(6)). - MS.: 210 (M, 6), 193 (24), 177 (15), 165 (26), 153 (80), 141 (66), 125 (50), 111 (35), 95 (39), 85 (100), 69 (44), 55 (78), 43 (82), 29 (32).

6.2. (*2S*,5R*)-alcohol* **8**. 6.3 g of **5** gave with 0.6 g aluminium triisopropoxide (see above) 3.8 g (60%) of **8**, m.p. 70-72°. - IR. ($CHCl_3$): 3600, 3400, 3090, 1640, 900. - ^{1}H-NMR. (60 MHz): 0.80 and 0.92 (2 *s*, 6 H, $(CH_3)_2C$); 1.18 (*d*, J=6, 3 H, H_3C-C(2)); 1.2-2.3 (*m*, 9 H, 4 CH_2, HO); 4.05 (*m*, 1H, H-C(2)); 4.52 (*m*, 1H, H-C(7)); 4.95 and 5.10 (br. *s* with fine structure, 2 H, H_2C=C(6)). - MS.: practically identical with that of 7.

7. Vitispiranes 9/10 (=2,10,10-trimethyl-6-methylidene-1-oxaspiro[4.5]dec-7-enes. - 7.1. (±)-(*2R*,5R*)-vitispirane* (**9**). A solution of 1.53 g of phosphorus oxychloride in 10 ml of ether was added dropwise at 0-5° to a stirred solution of 4.2 g of **7** and 3.16 g of pyridine in 100 ml of dry ether. Then the mixture was further stirred for 1 h at 5-10°, and hydrolysed with ice water. The ether solution was washed successively with 2N HCl, water, saturated $NaHCO_3$- and saturated NaCl-solution, dried (Na_2SO_4) and evaporated. The residue was chromatographed on silica gel with cyclohexane/ethyl acetate 9:1 to give 1.96 g (51%) of **9**, b.p. 57-59°/0.2 Torr. - IR. (film): 3085, 1640, 1600, 890. - ^{1}H-NMR. (90 MHz): 0.90 and 0.96 (2 *s*, 6H, $(CH_3)_2C$); 1.25 (*d*, J=6, 3H, H_3C-C(2)); 1.3-2.35 (*m*, 6H, 3 CH_2); 4.33 (*m*, J=6, 1H, H-C(2)); 4.89 and 5.09 (2 br. *s* with fine structure, 2 H, H_2C=C(6)); 5.63 (*d*×*d*, J=10 and 5, 1H, H-C(8)); 6.10 (*d* with fine structure, J=10, 1H, H-C(7)). - MS.: 192 (M, 100), 177 (51), 163 (7), 149 (28), 136 (46), 121 (44), 107 (24), 93 (70), 77 (20), 70 (15), 55 (27), 43 (38).

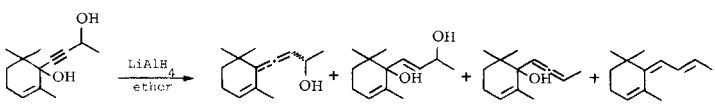
7.2. (±)-(*2S*,5R*)-vitispirane* (**10**). **10** was obtained from **8** as above in 48% yield, and purified by prep. GC. (*Carbowax*). - IR. (film): 3085, 1640, 1600, 890. - ^{1}H-NMR. (90 MHz): 0.92 and 0.99 (2 *s*, 6 H, $(CH_3)_2C$); 1.36 (*d*, J=6, 3 H, H_3C-C(2)); 1.4-2.4 (*m*, 6 H, 3 CH_2); 4.06 (*m*, 1H, H-C(2)); 4.91 (*d*, J=2, 1H, H-C=C(6)); 5.22 (br. *s* with fine structure, 1H, H-C=C(6)); 5.62 (*m*, 1H, H-C(8)); 6.10 (*d*×*d*, J=10 and 4, 1H, H-C(7)). - MS.: practically identical with that of **9**.

The spectral data of **9** and **10** correspond to those of the natural compounds [1].

8. Edulanes (=2,5,5,8a-tetramethyl-3,5,6,8a-tetrahydro-2*H*-1-benzopyrans) 17/18 by cyclization of 19. - A stirred solution of 80 mg of $HClO_4$-solution (70%) in 25 ml of 2-nitropropane under N_2 was cooled to −30° and mixed with 2 g of trienol **19** [19] in 2 ml of 2-nitropropane. The mixture was stirred for 45 min at −30° and then allowed to reach RT. After 4 h **19** had disappeared (GC.). Saturated $NaHCO_3$-solution (10 ml) was added and the mixture extracted with ether. After evaporation the distillation of the residue (2.1 g) in a bulb tube (80-90°/0.05 Torr) yielded 650 mg (34%) of a 1:9 mixture of *cis*- (**17**) and *trans*-edulane (**18**). The spectra of **17** and **18** were identical with those of authentic samples [14].

Other cyclization experiments of **19** were carried out with *Lewis* acids (BF_3 · etherate and $SnCl_4$) and *Brønstedt* acids (H_2SO_4, H_3PO_4 and $CH_3C_6H_4CO_2H$). The formation of **9** and **10** was never observed (GC.).

9. 6,7-Dehydro-α-ionol (24). - A solution of 5 g of diol **23** [16] in 80 ml of abs. ether was added dropwise under N_2 to a well stirred mixture of 1.8 g of $LiAlH_4$ and 150 ml of ether. The mixture was stirred for *ca.* 20 h, when **23** had disappeared (GC.), and **24** and **28**-**30** formed in a ratio of *ca.* 65:15:15:5. The mixture was treated with ice water and extracted with ether, giving 4.4 g of crude product which was distilled at 10^{-2} Torr (bulb tube) to yield 4 g of product and 0.3 g of residue. Distillation through a *Vigreux* column resulted in enrichment of the components, but complete separation was achieved by prep. GC. (*Carbowax*). The liquid alcohol **24** (65% of the distillate) had a b.p. of *ca.* 44-46°/0.01 Torr. - IR. (film): 3300 (br., OH), 1925 (C=C=C). - ^{1}H-NMR. (60 MHz, CCl_4): 1.06 (2 *s*, superimposed, 6 H, $(CH_3)_2C$); 1.27 (*d*, J=6, 3 H, 3 H-C(10)); 1.5 (*t*, J=6, 2 H, 2 H-C(2)); 1.71 (*m*, 3 H, H_3C-C(5)); 2.2 (*m*, 2 H, 2 H-C(3)); 4.27 (*m*, 1H, H-C(9)); 5.45 and 5.52 (2 *m*, 2 H, H-C(4) and H-C(8)). - MS.: 192 (M, 37), 177 (2), 148 (70), 133 (100), 119 (25), 105 (45), 92 (60), 77 (20), 45 (30).



23 **24** (65%) **28** (15%) **29** (15%) **30** (5%)

Diol **28**: liquid, 15% of the distillate. - IR. (film): 3450 (OH, assoc.), 3600 (OH, free), 990 (CH=CH, *trans*). - ^{1}H-NMR. ($CDCl_3$/DMSO): 0.9 and 0.99 (2 *s*, 6 H, $(CH_3)_2C$); 1.32 (*d*, J = 6.5, 3 H, 3 H−C(10)); 1.62 (*m*, 3 H, H_3C−C(5)); 4.34 (*m*, 1H, H−C(9)); 5.46 (*m*, 1H, H−C(4)); 5.7 (*m*, 2 H, H−C(7), −C(8)).

Alcohol **29** (mixture of *cis/trans* isomers): liquid, *ca.* 15% of the distillate. - IR. (film): 3550 (OH), 1960 (C=C=C). - ^{1}H-NMR. (60 MHz, CCl_4): 0.92 (2 *s*, superimposed, 6 H, $(CH_3)_2C$); 1.62 and 1.7 (*d*, J = 2, 3 H, H_3C−C(5)); 1.65 and 1.76 (2 *d*, J = 6, 3 H, 3 H−C(10)); 5.0–5.5 (*m*, 3 H, H−C(4), −C(7), −C(9)). - MS.: 192 (*M*, 10), 177 (6), 159 (8), 139 (75), 121 (90), 95 (40), 43 (100).

Megastigma-4,6,8-triene (**30**): liquid mixture of isomers. **30** is known [20] and was recently found in nature [21]. Our spectra are identical with those of authentic material [22].

10. (*Z*)-6-Hydroxy-α-ionol (25). - Diol **23** (20 g) in 250 ml ethyl acetate were shaken with 4 g *Lindlar*-catalyst under 1 atm H_2 until 2.2 l of H_2 were absorbed. After filtration and evaporation 19.8 g of **25** were obtained as a semicrystalline mixture of diastereoisomers. Recrystallization from cyclohexane gave pure **25** of m.p. 55–58°. - IR. (film): 3350 (OH), 1645, 820 (C=CH). - ^{1}H-NMR. (60 MHz): 0.88 and 0.92 (2 *s*, 6 H, $(CH_3)_2C$); 1.21 (*d*, J = 6, 3 H, 3 H−C(10)); 1.63 (*d*, J = 2, 3 H, H_3C−C(5)); 4.75 (*m*, 1H, H−C(9)); 5.32 (*m*, 1H, H−C(4)); 5.5 (*m*, 2 H, H−C(7) and H−C(8)). - MS.: 208 (*M*, < 1), 192 (6), 177 (2), 154 (35), 136 (100), 119 (99), 107 (50), 93 (77), 77 (16), 69 (10), 55 (23), 43 (57).

11. Preparation of theaspirene (26) (= 2,6,10,10-tetramethyl-1-oxaspiro[4.5]deca-3,5-diene; mixture of *cis/trans*-isomers). - 11.1. *From* **24**. An ice-cold solution of 20 g of **24** in 200 ml of petrol ether was vigourously stirred while 10 g of polyphosphoric acid were added. After 2 h at 10° GC. showed complete disappearance of **24**. The mixture was poured into ice water and extracted with ether. The organic layer was dried (Na_2SO_4), evaporated and the residue distilled to give 9 g of a mixture containing 70% of **26**, *ca.* 29% of unidentified products and *ca.* 1% of β-damascone [23]. By fractional distillation (*Fischer* slit tube column) 5.2 g of pure **26** (*cis/trans ca.* 1:1) were isolated (b.p. 70–72°/3 Torr).

11.2. *From* **25**. A solution of 1 g of **25** (crude mixture of diastereoisomers) in 5 ml of petrol ether and 1 ml of H_2SO_4 solution (30%) was stirred under N_2 until reaction was complete (GC.). After addition of 10 ml of ice water, the organic layer was extracted, washed with water, $NaCO_3$-solution and again with water, then evaporated. Distillation of the residue (bulb tube) furnished 0.82 g (*ca.* 90%) of pure **26** as a *cis/trans* mixture (*ca.* 3:2) identical in all spectroscopic details with an authentic sample [16].

12. Theaspirene-epoxide (27) (= 2,6,10,10-tetramethyl-6,7-epoxy-1-oxaspiro[4.5]dec-3-ene; mixture of *cis/trans* isomers). - To an ice-cooled and stirred mixture of 34.5 g of **26** and 22 g of anhydrous sodium acetate in 100 ml of CH_2Cl_2 were added dropwise 41 g of peracetic acid (40%). The stirring was continued for 12 h. After the addition of 50 ml of ice water the organic layer was separated, washed (Na_2CO_3) till alkaline, once with H_2O and finally with a saturated NaCl-solution. Drying (Na_2SO_4) and evaporation under reduced pressure gave 37.5 g (*ca.* 100%) of crude **27** (*cis/trans ca.* 3:2). - ^{1}H-NMR. (60 MHz, CCl_4): 0.70 and 0.72 (2 *s*, 3 H, $(CH_3)_2C$); 0.86 (*s*, 3 H, $(CH_3)_2C$); 1.13 (*s*, 3 H, H_3C−C(6)); 1.23 and 1.27 (2 *d*, J = 6, 3 H, H_3C−C(2)); 2.92 (*m*, 1H, H−C(7)); 4.90 (*m*, 1H, H−C(2)); 5.76 (*m*, 2 H, H−C(3) and H−C(4)). - MS.: 208 (*M*, 1), 193 (5).

13. Theaspirane-epoxides 3–6 (mixture of *cis/trans* isomers). - A solution of 37.5 g of crude **27** in 375 ml of ethanol was stirred under H_2 over 0.75 g of 5% Pd/C. After 3 h 3.75 l of H_2 were absorbed. The solution was filtered and the filtrate evaporated under reduced pressure to obtain 37.5 g (*ca.* 100%) of **3–6** as a colourless oil of > 95% purity. Submitted to the reaction sequence described under 6. and 7. this mixture yielded 29 g of a mixture containing the allyl alcohols 7 and **8** (intermediates) and finally the vitispiranes **9** and **10** in an overall yield of *ca.* 15 g (43%).

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