59. An Alternative Access to (±)-α-Irones and (±)-β-Irone *via* Acid-Mediated Cyclisation

by **Karl H. Schulte-Elte, Hervé Pamingle, Arnold P. Uijttewaal,** and **Roger L. Snowden***

Firmenich SA, Research Laboratories, P.O.B. 239, CH-1211 Geneva 8

(16.XII.91)

Acid-mediated cyclisation of trienone **8**, readily available from 2,3-dimethylbutanal (**1**; five steps: 47% yield), using fluorosulfonic acid (6.8 mol-equiv.) in 2-nitropropane at −70°, afforded a 14:9:1 mixture (70% yield) of (±)-*cis*-α-irone (**9**), (±)-*trans*-α-irone (**10**), and (±)-β-irone (**11**). Other acidic conditions examined, using 95% aq. H_2SO_4 solution, 85% aq. H_3PO_4 solution, or $SnCl_4$, gave inferior results.

Introduction. – As representatives of the irone family of odorants naturally occurring in *Iris* oil [1][1]), *cis*-α-irone (**9**), *trans*-α-irone (**10**), and β-irone (**11**) have attracted considerable synthetic interest over the past forty years[2]). An overwhelming majority of the reported syntheses of **9**–**11** employs an acid-mediated cyclisation strategy in which the transient carbocationic intermediates **I** or **II** are derived from an appropriate acyclic or monocyclic precursor (*cf. Scheme 1*). In this context, we now describe the preparation and subsequent acid-mediated cyclisation of an alternative precursor for **I**, the hitherto unreported diastereoisomeric mixture of trienones **8**, which thus provides a novel access to a mixture of racemic **9**, **10**, and **11**.

Results and Discussion. – *Synthesis of* **8** (*cf. Scheme 2*). *Knoevenagel* condensation of 2,3-dimethylbutanal (**1**)[3]) with methyl acetoacetate, followed by deconjugative de(methoxycarbonylation) of the crude condensation products **2a**,**b**[4]), employing standard *Krapcho* conditions [8], resulted in the formation of a 13:1 mixture of β,γ-enone **3** ((*E*)/(*Z*) 2.2:1) and α,β-enone (*E*)-**4** (77% yield from **1**)[5]). A subsequent *Wadsworth-Emmons* reaction using the sodium salt of methyl (dimethoxyphosphoryl)acetate afforded dienoate **5** (87%) which was then reduced with $LiAlH_4$ to dienol **6** (94%). Both **5** and **6**

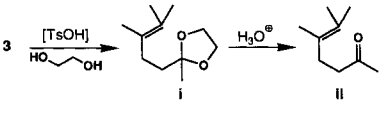
[1]) For the biosynthesis of irones, see [2]; for work related to the absolute configuration of naturally occurring irones, see [3] [4].

[2]) For reviews, see [5]; for syntheses of racemic α- and β-irones, see [6]; for enantioselective syntheses, see [3c] [7].

[3]) Aldehyde **1** was conveniently prepared from 3-methylbutanal *via* a *Mannich* reaction followed by catalytic hydrogenation of the resultant 3-methyl-2-methylidenebutanal.

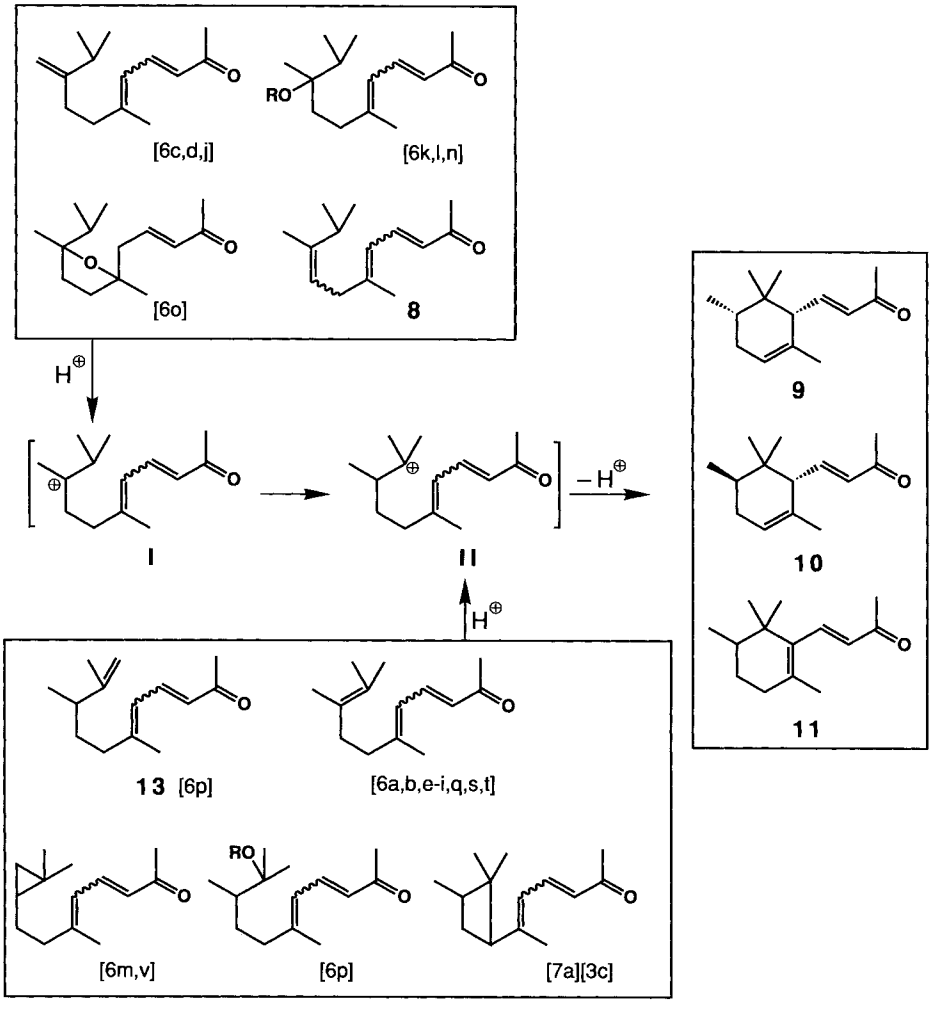
[4]) The condensation product consists of a 3:1 mixture of the α,β- and β,γ-unsaturated α-acetylcarboxylates **2a** ((*E*)/(*Z*) 1.5:1) and **2b** ((*E*)/(*Z*) 1.5:1), respectively (*cf.* ^{1}H-NMR data, *Exper. Part*).

[5]) Under these conditions, further isomerisation of **3** to the known γ,δ-enone **ii** was not observed, but could be otherwise achieved (*ca.* 70% yield) by acid-catalysed treatment of **3** in the presence of ethylene glycol, followed by hydrolysis of the resulting acetal **i**.



i ii

Scheme 1. *Acid-Mediated Cyclisation Strategies for Irones* **9–11**

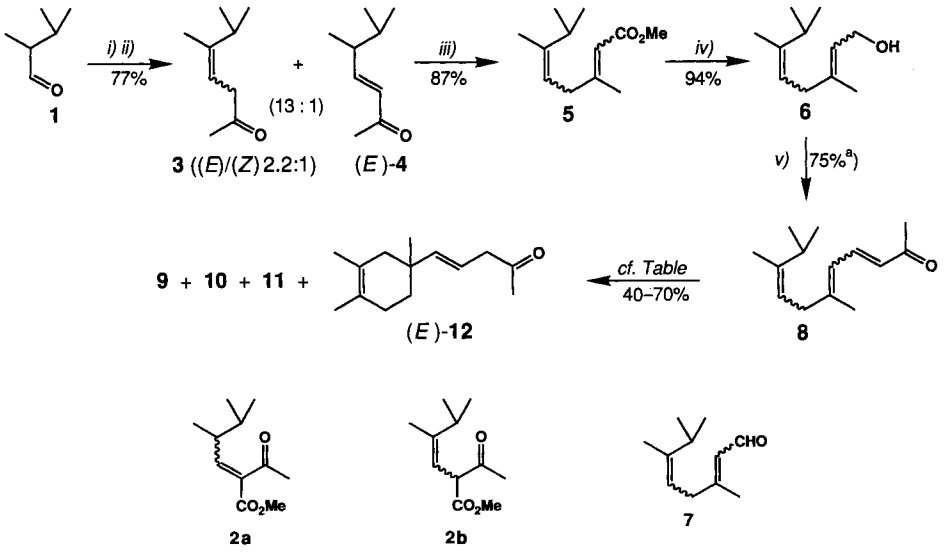


consist of a 5.4: 2.4: 2.2:1 mixture of (2*E*,5*E*)-, (2*E*,5*Z*)-, (2*Z*,5*E*)-, and (2*Z*,5*Z*)-diastereoisomers. In analogy with a reported precedent [6b], involving a tandem *Oppenauer* oxidation and an aldol condensation, **6** was now heated with acetone in the presence of aluminium tris(isopropoxide) to give **8** (52%; 6.5: 3: 2:1 mixture of (3*E*,5*E*,8*E*)-, (3*E*,5*E*,8*Z*)-, (3*E*,5*Z*,8*E*)-, and (3*E*,5*Z*,8*Z*)-diastereoisomers)[6]).

Acid-Mediated Cyclisation of **8** (*cf. Table*). With **8** in hand, we were now ready to investigate its behaviour in the presence of several *Brønsted* and *Lewis* acids. Firstly,

[6]) The presumed intermediate aldehyde **7** (diastereoisomeric mixture), independently prepared by oxidation of **6** with MnO_2 (see *Exper. Part*), was not detected during this tandem process.

Scheme 2



[a]) Calculated taking into account recovered **6** (*ca.* 30%; *cf. Exper. Part*). *i*) $MeC(O)CH_2CO_2Me$, [piperidine/AcOH], cyclohexane, reflux. *ii*) LiCl, $DMSO/H_2O$, 150°. *iii*) $(MeO)_2P(O)CH_2CO_2Me$, NaH, THF. *iv*) $LiAlH_4$, Et_2O. *v*) $Al(i\text{-}PrO)_3$, acetone, reflux.

treatment of **8** with FSO_3H in 2-nitropropane at low temperature (*cf. Entry 1*) afforded a product mixture containing **9** (41%), **10** (26%), and **11** (3%). In contrast, 95% aq. H_2SO_4 solution in CH_2Cl_2 at −20° (*cf. Entry 2*) gave a mixture of the same three components, but in different proportions: 6, 17, and 20%, respectively; also detected was a small amount (2%) of the known β,γ-enone (*E*)-**12** [6p] (see *Scheme 2*). A third *Brønsted* acid, 85% aq. H_3PO_4 solution, furnished a mixture **9**–**11** (52%) in which **10** (36%) predominated, together with (*E*)-**12** (7%; *cf. Entry 3*). Finally, use of a *Lewis* acid, $SnCl_4$ in CH_2Cl_2, resulted in the formation of a mixture containing **9** (18%), **10** (15%), and **11** (7%), in which no trace of (*E*)-**12** was detected. It is important to note that, in all four experiments,

Table. *Acid-Mediated Cyclisation of* **8**[a])

Entry	Acid[b])	Solvent, *T* [°C]	Yields [%][c])			
			9	**10**	**11**	(*E*)-**12**
1	FSO_3H	Me_2CHNO_2, −70°	41	26	3	–
2	95% aq. H_2SO_4	CH_2Cl_2, −20°	6	17	20	2
3	85% aq. H_3PO_4	0–35°	9	36	7	7
4	$SnCl_4$	CH_2Cl_2, r.t.	18	15	7	–

[a]) Diastereoisomer mixture (3*E*,5*E*,8*E*)/(3*E*,5*E*,8*Z*)/(3*E*,5*Z*,8*E*)/(3*E*,5*Z*,8*Z*) 6.5:3:2:1.

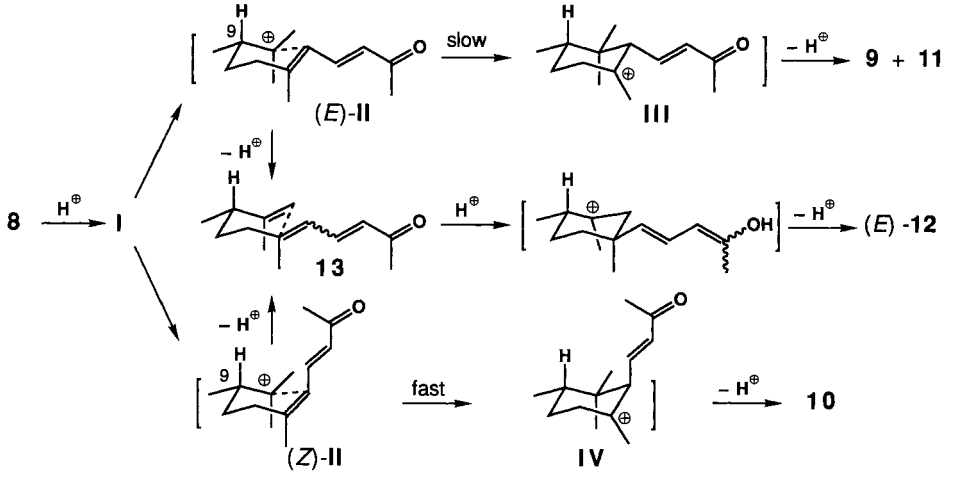
[b]) Acid employed in excess, *i.e.* FSO_3H (6.8 mol-equiv.), H_2SO_4 (7.4 mol-equiv.), H_3PO_4 (10 mol-equiv.), and $SnCl_4$ (1.8 mol-equiv.).

[c]) Yields estimated by GC analysis of distilled product; the missing yield is accounted for by an intractable mixture of non-volatile components.

the product distributions are kinetically controlled[7]) and remain constant throughout the course of the reactions.

In view of the fact that **8** is a diastereoisomeric mixture, a complete mechanistic rationalisation of the cyclisation results is not possible; nevertheless, a non-synchronous process (see *Scheme 3*) appears to be roughly consistent with the observed data[8]). Thus,

Scheme 3. *Acid-Mediated Cyclisation of* **8**



protonation of **8** to carbocation **I** is followed by rapid transformation to the thermodynamically favoured tertiary carbocations (*E*)- and (*Z*)-**II**; subsequent cyclisation, *via* chair-like transition states in which Me–C(9) is pseudoequatorial, leads to cyclohexyl cations **III** and **IV**, respectively[9]). Finally, deprotonation generates either **9** and **11** from **III**, or **10** from **IV**[10]). Deprotonation of (*E*)- and (*Z*)-**II** prior to cyclisation may also afford trienone **13**, whose ring closure, initiated by protonation of the carbonyl group, explains the formation of (*E*)-**12**.

---

[7]) Kinetic control of these acid-mediated cyclisations is further demonstrated by the fact that, even after prolonged treatment, the product distributions remain unchanged. In this context, the thermodynamic equilibrium mixture **9**–**11** was shown to consist of **9** (10%), **10** (37%), and **11** (53%) [3a].

[8]) For related acid-mediated cyclisations, see [9].

[9]) The cyclisation of (*Z*)-**II** to **IV** is predicted to be faster than that of (*E*)-**II** to **III**; this hypothesis is consistent with the MM2 energies of **III** and **IV** (21.6 and 20.5 kcal/mol, resp.) calculated using the MACROMODEL program [10].

[10]) Deprotonation of **III**, *via* preferential loss of a vicinal pseudoaxial H-atom, would be expected to selectively afford **11**, possessing the more substituted double bond. On the other hand, concerted deprotonation from C(7) during ring closure would lead to **9**. Similarly, if deprotonation is faster than conformational inversion of the cyclohexane ring, **IV** would exclusively generate **10**.

Experimental Part

(with the collaboration of *P. Sonnay*)

1. *General.* See [11]. ^{1}H-NMR and MS data of (*E*)/(*Z*)-isomers were obtained from their mixtures.

2. *5,6-Dimethylhept-4-en-2-one* (**3**; (*E*)/(*Z*) 2.2:1) *and (*E*)-5,6-Dimethylhept-3-en-2-one* ((*E*)-**4**). A mixture of 2,3-dimethylbutanal (**1**; 42 g, 0.42 mol), methyl acetoacetate (= methyl 3-oxobutanoate; 64 g, 0.55 mol), AcOH (7.2 g, 0.12 mol), piperidine (2.3 g, 0.027 ml), and cyclohexane (200 ml) was heated at reflux during 3 h with continual azeotropic removal of H_2O (*Dean-Stark* apparatus). Concentration and fractional distillation *i.v.* of the residual oil afforded a 3:1 mixture of *methyl-2-acetyl-4,5-dimethylhex-2-enoate* (**2a**; (*E*)/(*Z*) 1.5:1) and *methyl-2-acetyl-4,5-dimethylhex-3-enoate* (**2b**; (*E*)/(*Z*) 1.5:1) as a pale-yellow oil (74 g; b.p. 50–60°/0.05 Torr).

*Data of (*E*)-***2a***: ^{1}H-NMR: 2.32 (*s*, 3H); 3.84 (*s*, 3H); 6.69 (*d*, *J* = 11, 1H).
*Data of (*Z*)-***2a***: ^{1}H-NMR: 2.36 (*s*, 3H); 3.79 (*s*, 3H); 6.77 (*d*, *J* = 11, 1H).
*Data of (*E*)-***2b***: ^{1}H-NMR: 2.18 (*s*, 3H); 3.74 (*s*, 3H); 4.30 (*d*, *J* = 10, 1H); 5.49 (*d*, *J* = 10, 1H).
*Data of (*Z*)-***2b***: ^{1}H-NMR: 2.20 (*s*, 3H); 3.74 (*s*, 3H); 4.40 (*d*, *J* = 10, 1H); 5.38 (*d*, *J* = 10, 1H).

Without further purification, crude **2a**/**2b** (3:1) was stirred with DMSO (500 ml), H_2O (7.4 g, 0.41 mol), and LiCl (17.5 g, 0.41 mol) at 135–142° (oil bath: 150°) during 2 h (evolution of CO_2). The cooled mixture was then poured into cold H_2O (2 l) and continuously extracted with petroleum ether (b.p. 30–50°). Concentration and fractional distillation *i.v.* afforded a 13:1 mixture **3** ((*E*)/(*Z*) 2.2:1)/(*E*)-**4** as a colourless oil (45.2 g, 77%; b.p. 63–68°/10 Torr). This mixture was used without further purification (*vide infra*).

*Data of (*E*)-***3***: ^{1}H-NMR: 1.01 (*d*, *J* = 7, 6H); 1.60 (*s*, 3H); 2.14 (*s*, 3H); 2.30 (*m*, 1H); 3.12 (*d*, *J* = 7, 2H); 5.36 (br. *t*, *J* = 7, 1H). MS: 140 (0.5, M^+), 122 (28), 107 (12), 97 (29), 69 (22), 55 (100), 43 (82).
*Data of (*Z*)-***3***: ^{1}H-NMR: 0.97 (*d*, *J* = 7, 6H); 1.66 (*s*, 3H); 2.15 (*s*, 3H); 2.73 (*m*, 1H); 3.15 (*d*, *J* = 7, 2H); 5.24 (br. *t*, *J* = 7, 1H). MS: 140 (0.5, M^+), 122 (28), 107 (14), 97 (28), 69 (22), 55 (100), 43 (82).
*Data of (*E*)-***4***: ^{1}H-NMR: 0.90 (*dd*, *J* = 7, 7, 6H); 1.04 (*d*, *J* = 7, 3H); 2.26 (*s*, 3H); 6.04 (*d*, *J* = 15, 1H); 6.73 (*dd*, *J* = 15,7, 1H). MS: 140 (3, M^+), 125 (9), 98 (43), 83 (47), 55 (37), 43 (100).

3. *Methyl 3,6,7-Trimethylocta-2,5-dienoate* (**5**; (2*E*,5*E*)/(2*E*,5*Z*)/(2*Z*,5*E*)/(2*Z*,5*Z*) 5.4:2.4:2.2:1). A soln. of methyl (dimethoxyphosphoryl)acetate (64 g, 0.35 mol) in THF (100 ml) was added dropwise within 30 min to a stirred slurry of NaH (55% dispersion in oil (*Fluka*); 16.5 g, 0.38 mol) in THF (900 ml) at r.t. under N_2. After a further 30 min, a soln. of the foregoing 13:1 mixture **3** ((*E*)/(*Z*) 2.2:1)/(*E*)-**4** (42 g, 0.30 mol) in THF (250 ml) was added dropwise within 20 min at 25°. After 1 h at r.t., sat. aq. NH_4Cl soln. (200 ml) was cautiously added dropwise to the cooled mixture (0–5°), the H_2O phase extracted with Et_2O (200 ml), and the combined org. phase washed with sat. aq. NaCl soln. (3 × 250 ml), dried (Na_2SO_4), and concentrated. Fractional distillation *i.v.* afforded **5** (48 g, 82%; b.p. 65–70°/5 Torr). Colourless oil.

*Data of (2*E*,5*E*)-***5***: ^{1}H-NMR: 1.01 (*d*, *J* = 7, 6H); 1.59 (*s*, 3H); 2.14 (*s*, 3H); 2.16 (*s*, 3H); 2.28 (*m*, 1H); 2.82 (*d*, *J* = 7, 2H); 3.69 (*s*, 3H); 5.16 (*t*, *J* = 7, 1H); 5.68 (br. *s*, 1H). MS: 196 (14, M^+), 153 (13), 125 (100), 121 (48), 93 (62), 83 (57).
*Data of (2*E*,5*Z*)-***5***: ^{1}H-NMR: 0.97 (*d*, *J* = 7, 6H); 1.65 (*s*, 3H); 2.16 (*s*, 3H); 2.76 (*m*, 1H); 2.85 (*d*, *J* = 7, 2H); 3.69 (*s*, 3H); 5.05 (*t*, *J* = 7. 1H); 5.68 (br. *s*, 1H). MS: 196 (20, M^+), 153 (13), 125 (95), 121 (61), 93 (81), 83 (62), 55 (100).
*Data of (2*Z*,5*E*)-***5***: ^{1}H-NMR: 0.98 (*d*, *J* = 7, 6H); 1.62 (*s*, 3H); 1.84 (*s*, 3H); 2.92 (*m*, 1H); 3.41 (*d*, *J* = 7, 2H); 3.68 (*s*, 3H); 5.03 (*t*, *J* = 7, 1H); 5.65 (br. *s*, 1H). MS: 196 (9, M^+), 153 (5), 125 (100), 121 (41), 93 (51), 83 (42).
*Data of (2*Z*,5*Z*)-***5***: ^{1}H-NMR: 0.98 (*d*, *J* = 7, 6H); 1.64 (*s*, 3H); 1.86 (*s*, 3H); 2.25 (*m*, 1H); 3.39 (*d*, *J* = 7, 2H); 3.68 (*s*, 3H); 5.14 (*t*, *J* = 7, 1H); 5.65 (br. *s*, 1H). MS: 196 (8, M^+), 153 (6), 125 (100), 121 (41), 93 (51), 83 (43).

4. *3,6,7-Trimethylocta-2,5-dienol* (**6**; (2*E*,5*E*)/(2*E*,5*Z*)/(2*Z*,5*E*)/(2*Z*,5*Z*) 5.4: 2.4:2.2:1). A soln. of **5** (47 g, 0.24 mol) in Et_2O (150 ml) was added dropwise within 20 min to a stirred slurry of $LiAlH_4$ (7.6 g, 0.2 mol) in Et_2O (350 ml) at 0° under N_2. The mixture was allowed to attain r.t. during 2 h, cooled to 0°, and H_2O (7.6 ml), 15% aq. NaOH soln. (7.6 ml), and H_2O (22.8 ml) were successively added dropwise. Filtration (*Hyflo*), concentration of the filtrate, and fractional distillation *i.v.* afforded **6** (38 g, 94%; b.p. 100–112°/6 Torr). Colourless oil. ^{1}H-NMR: 0.96, 0.97, 0.99 (3*d*, *J* = 7); 4.94, 5.05, 5.16 (3*t*, *J* = 7); 5.41 (*m*).

*Data of (2*E*,5*E*)-***6***: MS: 168 (3, M^+), 150 (24), 107 (100), 91 (70), 79 (68), 55 (63).
*Data of (2*E*,5*Z*)-***6***: MS: 168 (0, M^+), 150 (22), 107 (100), 91 (66), 79 (62), 55 (58).
*Data of (2*Z*,5*E*)-***6***: MS: 168 (0, M^+), 150 (20), 107 (100), 91 (61), 79 (60), 55 (47).
*Data of (2*Z*,5*Z*)-***6***: MS: 168 (0, M^+), 150 (18), 107 (100), 91 (52), 79 (52), 55 (37).

5. *3,6,7-Trimethylocta-2,5-dienal* (**7**; (2*E*,5*E*)/(2*E*,5*Z*) 2.2:1). A mixture of **6** (7 g, 0.042 mol) and activated MnO_2 (*Fluka*, 100 g) in pentane (300 ml) was stirred at 25° during 17 h. Filtration, concentration, and distillation *i.v.* afforded **7** (4.4 g, 64%). Colourless oil. B.p. (bulb-to-bulb dist.) 130–150°/10 Torr. IR: 2950, 1676, 1440, 1380, 1190, 1178, 1118, 1002, 922.

Data of (2E,5E)-**7**: ^{1}H-NMR: 1.01 (*d*, *J* = 7, 6H); 1.59 (*s*, 3H); 2.16 (*s*, 3H); 2.28 (*m*, 1H); 2.90 (*d*, *J* = 8, 2H); 5.17 (br. *t*, *J* = 8, 1H); 5.88 (br. *d*, *J* = 8, 1H); 10.00 (*d*, *J* = 8, 1H). ^{13}C-NMR: 191.2 (*d*); 163.3 (*s*); 145.3 (*s*); 127.2 (*d*); 116.6 (*d*); 38.8 (*t*); 36.9 (*d*); 21.4 (2*q*); 17.6 (*q*); 13.6 (*q*). MS: 166 (21, $M^{+\cdot}$), 133 (20), 123 (52), 109 (26), 105 (34), 95 (100).

Data of (2E,5Z)-**7**: ^{1}H-NMR: 0.97 (*d*, *J* = 7, 6H); 1.65 (*s*, 3H); 2.16 (*s*, 3H); 2.75 (*m*, 1H); 2.92 (*d*, *J* = 8, 2H); 5.05 (br. *t*, *J* = 8, 1H); 5.91 (br. *d*, *J* = 8, 1H); 10.00 (*d*, *J* = 8, 1H). ^{13}C-NMR: 191.1 (*d*); 163.4 (*s*); 144.7 (*s*); 127.1 (*d*); 111.8 (*d*); 38.3 (*t*); 28.6 (*d*); 20.7 (2*q*); 18.1 (*q*); 17.7 (*q*). MS: 166 (20, $M^{+\cdot}$), 133 (17), 123 (49), 109 (24), 105 (28), 95 (100).

6. *6,9,10-Trimethylundeca-3,5,8-trien-2-one* (**8**; (3*E*,5*E*,8*E*)/(3*E*,5*E*,8*Z*)/(3*E*,5*Z*,8*E*)/(3*E*,5*Z*,8*Z*) 6.5:3:2:1). A stirred mixture of **6** (25.2 g, 0.15 mol), aluminium isopropylate (32 g, 0.16 mol), acetone (370 ml), and toluene (370 ml) was heated during 15 h at reflux under N_2. The cooled mixture was then filtered (*Hyflo*) and the filtrate concentrated. Fractional distillation *i.v.* afforded unreacted **6** (7.7 g, 31%; b.p. 46–68°/0.03 Torr) and **8** (colourless oil, 16 g, 52%; b.p. 72–98°/0.03 Torr). IR: 2950, 1620, 1440, 1360, 1280, 980.

Data of (3E,5E,8E)-**8**: ^{1}H-NMR: 1.01 (*d*, *J* = 7, 6H); 1.60 (*s*, 3H); 2.27 (*m*, 1H); 2.83 (*d*, *J* = 7, 2H); 5.16 (*t*, *J* = 7, 2H); 6.01 (*d*, *J* = 11, 1H); 6.08 (*d*, *J* = 15, 1H); 7.44 (*dd*, *J* = 15, 11, 1H); 7.44 (*dd*, *J* = 15, 11, 1H). MS: 206 (3, $M^{+\cdot}$), 163 (18), 121 (23), 109 (100), 93 (25), 55 (25), 43 (79).

Data of (3E,5E,8Z)-**8**: ^{1}H-NMR: 0.97 (*d*, *J* = 7, 6H); 1.65 (*s*, 3H); 2.78 (*m*, 1H); 2.85 (*d*, *J* = 7, 2H); 5.05 (*t*, *J* = 7, 2H); 6.01 (*d*, *J* = 11, 1H); 6.09 (*d*, *J* = 15, 1H); 7.44 (*dd*, *J* = 15, 11, 1H); 7.44 (*dd*, *J* = 15, 11, 1H). MS: 206 (3, $M^{+\cdot}$), 163 (17), 121 (23), 109 (100), 93 (25), 55 (26), 43 (79).

Data of (3E,5Z,8E)-**8**: ^{1}H-NMR: 0.98 (*d*, *J* = 7, 6H); 1.57 (*s*, 3H); 1.85 (*s*, 3H); 2.99 (*d*, *J* = 7, 2H); 5.07 (*t*, *J* = 7, 1H); 6.00 (*d*, *J* = 11, 1H); 6.07 (*d*, *J* = 15, 1H); 7.46 (*m*, 1H). MS: 206 (1, $M^{+\cdot}$), 163 (27), 120 (27), 109 (100), 93 (32), 55 (25), 43 (86).

Data of (3E,5Z,8Z)-**8**: ^{1}H-NMR: 1.00 (*d*, *J* = 7, 6H); 1.65 (*s*, 3H); 1.85 (*s*, 3H); 3.02 (*d*, *J* = 7, 2H); 4.95 (*t*, *J* = 7, 2H); 6.00 (*d*, *J* = 11, 1H); 6.09 (*d*, *J* = 15, 1H); 7.46 (*m*, 1H). MS: 206 (3, $M^{+\cdot}$), 163 (23), 120 (31), 109 (95), 93 (38), 55 (28), 43 (100).

7. *Acid-Mediated Cyclisation of* **8**. 7.1. *With FSO_3H*. A soln. of **8** (0.2 g, 1 mmol) in 2-nitropropane (10 ml) was added dropwise (syringe pump), within 20 min, to a stirred soln. of FSO_3H (0.68 g, 6.8 mmol) in 2-nitropropane (10 ml) at −70° under N_2. After 1 h at −70°, the mixture was poured into ice-water and extracted (Et_2O). The combined org. phase was washed to neutrality with sat. aq. NaCl soln., dried (Na_2SO_4), and evaporated: distillation *i.v.* afforded **9**–**11** (0.14 g, 70%; see *Table* for product distribution). Colourless oil. B.p. (bulb-to-bulb dist.) 140°/0.5 Torr.

7.2. *With H_2SO_4*. Trienone **8** (5 g, 0.024 mol) was added dropwise (syringe pump), within 20 min, to a stirred mixture of 95% aq. H_2SO_4 soln. (10 ml) and CH_2Cl_2 (50 ml) at −20° under N_2. After 1 h at −20°, the mixture was poured into ice-water and extracted (Et_2O). Workup and isolation (*vide supra*) afforded **9**–**12** (2.2 g, 45%; see *Table* for product distribution).

7.3. *With H_3PO_4*. Trienone **8** (13 g, 0.063 mol) was added dropwise (syringe pump), within 20 min, to a stirred mixture of 85% aq. H_3PO_4 soln. (52 g) at 0° under N_2. The mixture was then heated at 35° during 15 min, poured into ice-water, and extracted (Et_2O). Workup and isolation (*vide supra*) afforded **9**–**12** (9 g, 59%; see *Table* for product distribution).

7.4. *With $SnCl_4$*. Trienone **8** (0.5 g, 2.4 mmol) was added dropwise (syringe pump), within 20 min, to a stirred mixture of $SnCl_4$ (0.5 ml) in toluene (5 ml) at r.t. under N_2. After 1 h, the mixture was poured into ice-water and extracted (Et_2O). Workup and isolation (*vide supra*) afforded **9**–**11** (0.2 g, 40%; see *Table* for product distribution).

7.5. *Separation of* **9**–**12**. Separation was effected by prep. GLC (5 m 15% *Carbowax* column), and the spectral data of the purified **9**–**12** were found to be identical to those of authentic samples [3] [6p].

Supplementary Data of **11**: ^{13}C-NMR: 198.5 (*s*); 144.1 (*d*); 136.3 (*s*); 134.0 (*s*); 132.6 (*d*); 39.1 (*d*); 37.3 (*s*); 32.2 (*t*); 27.6 (*q*); 27.1 (*q*); 26.7 (*t*); 22.2 (*q*); 21.8 (*q*); 16.2 (*q*).

Supplementary Data of (E)-**12**: ^{1}H-NMR: 0.98 (*s*, 3H); 1.60 (br. *s*, 6H); 1.89 (*m*, 4H); 2.11 (*s*, 3H); 3.09 (*d*, *J* = 7, 2H); 5.41 (*dt*, *J* = 15, 7, 1H); 5.54 (*d*, *J* = 15, 1H). ^{13}C-NMR: 207.6 (*s*); 144.3 (*d*); 124.5 (*s*); 123.8 (*s*); 118.9 (*d*); 48.1 (*t*); 43.6 (*t*); 35.2 (*s*); 34.7 (*t*); 29.5 (*t*); 29.1 (*q*); 26.3 (*q*); 19.3 (*q*); 18.7 (*q*). MS: 206 (2, $M^{+\cdot}$), 178 (13), 148 (6), 133 (6), 121 (15), 107 (12), 91 (11), 82 (38), 67 (19), 43 (100).

REFERENCES

[1] B. Maurer, A. Hauser, J.-C. Froidevaux, *Helv. Chim. Acta* **1989,** *72*, 1400, and ref. cit. therein.

[2] a) L. Jaenicke, F. J. Marner, *Prog. Chem. Org. Nat. Prod.* **1986,** *50*, 1; b) F. J. Marner, L. Jaenicke, *Helv. Chim. Acta* **1989,** *72*, 287.

[3] a) V. Rautenstrauch, G. Ohloff, *Helv. Chim. Acta* **1971,** *54*, 1776; b) *ibid.* **1972,** *55*, 2686; c) V. Rautenstrauch, B. Willhalm, W. Thommen, G. Ohloff, *ibid.* **1984,** *67*, 325.

[4] W. Krick, F. J. Marner, L. Jaenicke, *Helv. Chim. Acta* **1984,** *67*, 318.

[5] E. Gildemeister, F. Hoffmann, in 'Die ätherischen Öle', Eds. W. Treibs and D. Merkel, Akademie-Verlag, Berlin, 1963, Band IIIc, p. 395; A. Storni, Doctoral Dissertation ETH, 1963.

[6] a) Y.-R. Naves, A. V. Grampoloff, P. Bachmann, *Helv. Chim. Acta* **1947,** *30*, 1810; b) H. Schinz, L. Ruzicka, C. F. Seidel, C. Tavel, *ibid.* **1947,** *30*, 1810; c) H. Grütter, R. Helg, H. Schinz, *ibid.* **1952,** *35*, 771; d) Y.-R. Naves, P. Ardizio, C. Favre, *Bull. Soc. Chim. Fr.* **1954,** *21*, 968; e) R. Dulou, G. Gliment, *Fette, Seifen, Anstrichm.* **1955,** *57*, 595 (*CA*: **1957,** *51*, 17833i); f) I. K. Sarycheva, G. A. Vorobeva, A. S. Vasilenko, G. G. Vinokurova, S. A. Elkina, N. A. Preobrazhenski, *Zh. Obshch. Khim.* **1955,** *25*, 1775 (*CA*: **1956,** *50*, 7090d); g) V. N. Belov, N. A. Daev, S. D. Kustova, K. V. Leets, S. S. Poddubnaya, E. I. Skvortsovs, A. K. Shumeiko, *ibid.* **1957,** *27*, 1384 (*CA*: **1958,** *52*, 3740g); h) I. K. Sarycheva, G. A. Vorobeva, N. A. Preobrazhenski, *ibid.* **1957,** *27*, 2662 (*CA*: **1958,** *52*, 7139g); i) W. Kimel, J. D. Surmatis, J. Weber, G. O. Chase, N. W. Sax, A. Ofner, *J. Org. Chem.* **1957,** *22*, 1611; j) M. J. Gorjajew, D. R. Dschalilow, *Nachr. Akad. Wiss. Kasachst. SSSR, Ser. Chem.* **1959,** 83; k) D. H. R. Barton, M. Mousseron-Canet, *J. Chem. Soc.* **1960,** 271; l) M. Mousseron-Canet, C. Levallois, *Bull. Soc. Chim. Fr.* **1963,** *30*, 993; M. Mousseron-Canet, M. Mousseron, C. Levallois, *ibid.* **1964,** *31*, 297; m) D. Felix, M. Stoll, A. Eschenmoser, *Chimia* **1964,** 174; *Firmenich SA,* French Patent 1,393,451, 1965 (*CA*: **1966,** *64*, 768); n) E. H. Eschinasi, M. L. Cotter, *Tetrahedron Lett.* **1964,** 3481; o) *ibid.* **1964,** 3487; p) W. Hoffmann, H. Pasedach, H. Pommer, W. Reif, *Liebigs Ann. Chem.* **1971,** *747*, 60; q) T. Ishihara, T. Kitahara, M. Matsui, *Agric. Biol. Chem.* **1974,** *38*, 439; r) S. Torii, K. Uneyama, S. Matsunami, *J. Org. Chem.* **1980,** *45*, 16; s) T. Mandai, K. Nishikawa, H. Yamaguchi, M. Kawada, J. Otera, *Chem. Lett.* **1981,** 473; t) *Taiyo Perfumery Co. Ltd.*, Jap. Patent 5,782,333, 1982 (*CA*: **1983,** *98*, 16893c); u) C. Nussbaumer, G. Frater, *J. Org. Chem.* **1987,** *52*, 2096; v) *Givaudan SA*, Eur. Patent 418,690, 1991 (*CA*: **1991,** *114*, 228428d).

[7] a) H. E. Eschinasi, *J. Am. Chem. Soc.* **1959,** *81*, 2905; *J. Org. Chem.* **1961,** *26*, 3140; b) M. Miyashita, N. Makino, M. Singh, A. Yoshikoshi, *J. Chem. Soc., Perkin Trans. 1* **1982,** 1303; c) D. Helmlinger, G. Frater, *Helv. Chim. Acta* **1989,** *72*, 1515.

[8] A. P. Krapcho, *Synthesis* **1982,** 805, 893.

[9] P. A. Bartlett, in 'Asymmetric Synthesis', Ed. J. D. Morrison, Academic Press, New York, 1984, Vol. 3, p. 341 (review); J.-P. Ferezou, M. Julia, *Tetrahedron* **1985,** *41*, 1277.

[10] F. Mohamadi, N. G. J. Richards, W. C. Guida, R. Liskamp, M. Lipton, C. Caulfield, G. Chang, T. Hendrickson, W. C. Still, *J. Comput. Chem.* **1990,** *11*, 440.

[11] R. L. Snowden, S. M. Linder, B. L. Muller, K. H. Schulte-Elte, *Helv. Chim. Acta* **1987,** *70*, 1858.