173. Solvolytic Ring-opening of Alkoxychlorofluorocyclopropanes: A Ready Access to Fluorinated α,β-Unsaturated Aldehydes and Ketones[1])

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Summary

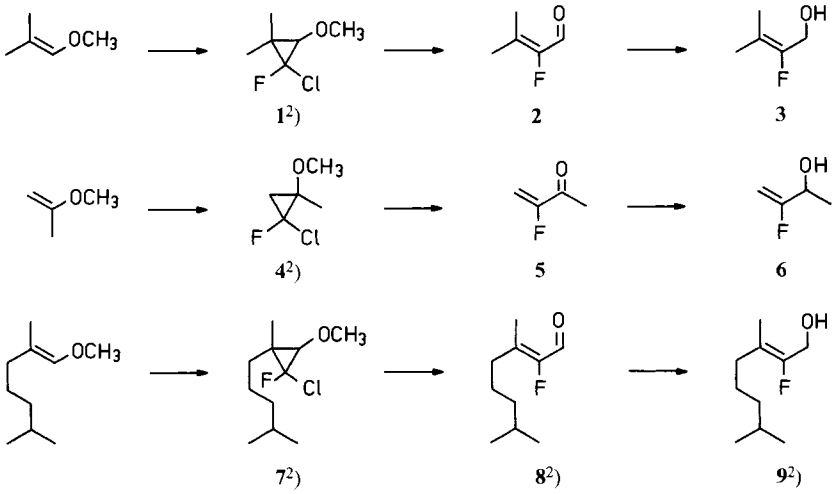
Alkoxychlorofluorocyclopropanes are easily prepared by chlorofluorocarbene addition to en-ethers in a two-phase system and converted by simple heating in an aqueous solvent mixture to 2-fluoro-2-alkenals which can be reduced to the corresponding alcohols.

Silver-catalysed ring-opening of chlorofluorocyclopropanes derived from simple alkenes offers a convenient access to fluoroalkenols containing a tertiary hydroxy group [1] [2]. In acidic medium these tertiary alcohols (or their acetates) slowly undergo allylic migration and are converted to the thermodynamically more stable isomers having a primary oxygen function [2]. Numerous 2-fluoro-2-alken-1-ols (or acetates thereof) have been prepared in this manner [3]. This communication describes an easier and more efficient entry into this class of compounds.

In a two-phase system [3] en-ethers can be converted rapidly in high yields into alkoxylated chlorofluorocyclopropanes which have previously been prepared by a very similar method but could be isolated only in exceptional cases. The high temperatures and the special conditions which were employed promote instantaneous ring opening of the cyclopropane products to yield 2-fluoro-2-alkenal acetals [4]. In fact, the alkoxychlorofluorocyclopropanes now obtained proved to be much more susceptible towards solvolysis than ordinary chlorofluorocyclopropanes (for facile solvolysis of alkoxy-dichloro- and alkoxy-dibromo-cyclopropanes, see [5]). They undergo clean ring-opening in an aqueous medium at reflux temperatures whereas their non-alkoxylated analogues are completely inert in the absence of catalytically active silver salts. The products of hydrolysis, α,β-unsaturated and fluorinated aldehydes or ketones, can easily be reduced with lithium aluminium hydride to afford fluorinated allyl alcohols with a primary or secondary hydroxyl group. Thus (see *Scheme 1*), in over-all yields about 50%, methyl 2-methyl-1-propenyl ether was transformed through cyclopropane **1** and aldehyde **2** into 2-fluoro-3-methyl-2-buten-1-ol (**3**, 'fluoroprenol'), methyl 2-propenyl ether (through cyclopropane **4** and ketone **5**) into 2-fluoro-1-buten-3-ol and methyl-

[1]) Part VIII of the series 'Syntheses of Organofluorine Compounds'; for the preceding paper see [1].

Scheme 1



1[2]) 2 3

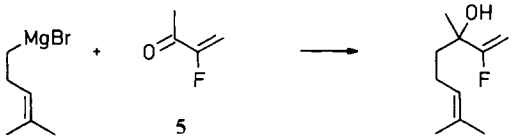
4[2]) 5 6

7[2]) 8[2]) 9[2])

2,6-dimethyl-1-hepten-1-yl ether (*Z*/*E*-mixture) into 2-fluoro-3,7-dimethyl-2-octen-1-ol (**9**, again a *Z*/*E*-mixture).

3-Fluoro-3-buten-2-one (**5**) (see *Scheme 2*) reacted with 4-methyl-3-penten-yl-magnesium bromide at the carbonyl group and afforded pure 2-fluoro-3,7-dimethyl-1,6-octadien-3-ol ('fluorolinalool') with a yield of 46%.

Scheme 2



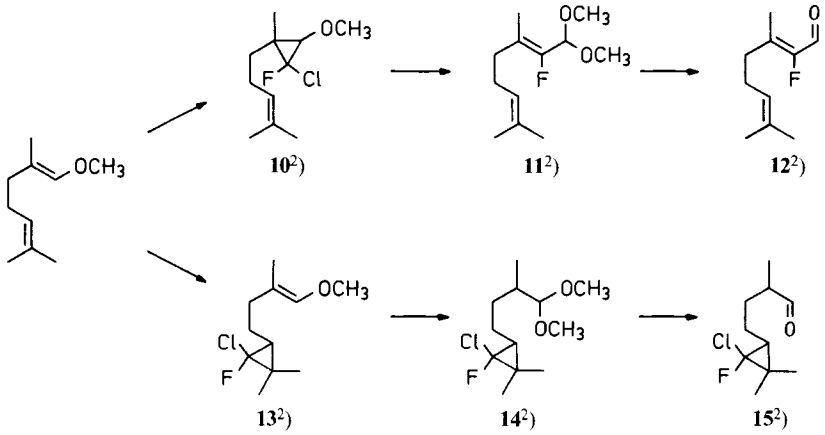
5

As one would expect, 1-methoxy-2,6-dimethyl-1,5 heptadiene (see *Scheme 3*) formed a mixture of the regioisomeric cyclopropanes **10** and **13**. Each of them was composed of four diastereoisomers and the mixture could not be separated. Fortunately, however, the alkoxychlorofluorocyclopropane **10** could be ring-opened selectively under mild solvolytic conditions. In aqueous solution and in the presence of pyridine the fluorocitral **12** (about 30%) was obtained, **13** being recovered unchanged. In methanol the acetals **11** and **14** were formed, which could be hydrolysed to give the aldehydes **12** and **15**.

The ring opening reaction of 1-chloro-2-ethoxy-1-fluoro-3-methylcyclopropane (**16**) merits special attention (see *Scheme 4*). Although it consisted of four diastereoisomers (the precursor en-ether being already a mixture of *Z*- and *E*-isomers), *Z*-2-fluoro-2-butenal (*Z*-**17**, 'fluorocrotonaldehyde') was obtained as the overwhelming reaction product. Reduction with lithium aluminium hydride converted

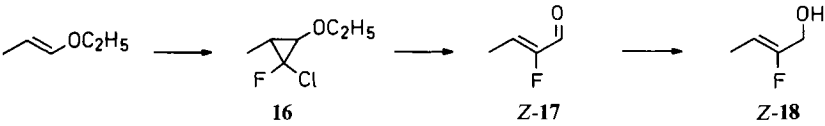
[2]) Mixture of two or more diastereoisomers.

Scheme 3



Z-**17** into pure *Z*-2-fluoro-1-buten-1-ol (*Z*-**18**; 83% yield based on en-ether). No trace of *E*-fluorocrotonaldehyde (*E*-**17**) was detected even under very mild reaction conditions (0°, slightly basic solution containing silver-ions).

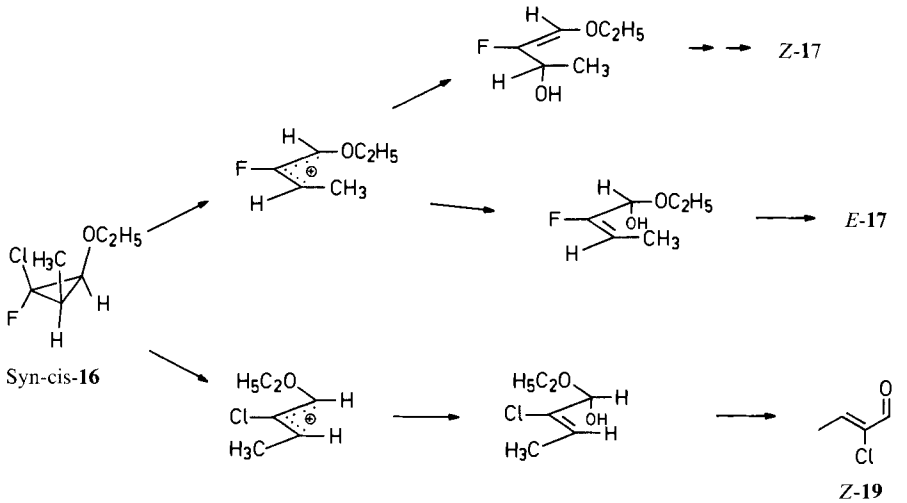
Scheme 4



The solvolytic opening of halocyclopropanes (see *Scheme 5*) takes place by either of two possible disrotatory motions of the carbon centers flanking halogen-bearing carbon atom. As the chlorine atom is expelled, a methyl group *trans* to the chlorine will be rotated to an *exo*-position of the resulting allyl cation, whereas a methyl group *cis* to the chlorine will end up in an *endo*-position. Therefore, two stereoisomers, *syn-cis*-**16** and *anti-trans*-**16**, are supposed to generate allyl cations having the methyl group in the *endo*-position and eventually lead to *E*-**17**. That this is not the case may be explained in several ways. First one could postulate a preferential attack of water at the carbon atom next to the methyl group of the intermediate cation, thus producing a secondary alcohol which may, after rotation and allylic migration, directly afford *Z*-**17**. Or, *E*-**17** can isomerize to give *Z*-**17** inspite of the mild reaction conditions. Less likely appears to be an isomerization occurring at the stage of the intermediate cations since the twisted allylic species would no longer benefit from the resonance-stabilizing effect of the ethoxy-group delocalizing the positive charge. [The shift of a methyl group from an *endo*-position to an *exo*-position would establish a sufficient driving force in order to restrict such an isomerization step to one direction (see also [6]). The isolation of small quantities (0.5%) of *Z*-2-*chloro*-2-butenal (*Z*-**19**) provides additional evidence for the instability of *endo*- and, especially, *endo-endo*-cations. Apparently the extrusion of fluorine, though a poor leaving group, can compete with that of chlorine by virtue

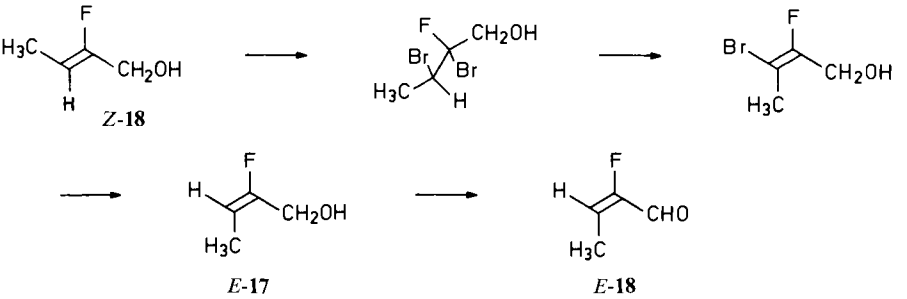
of a disrotary motion which avoids the formation of a sterically hindered cationic intermediate (for an analogy see [4])].

Scheme 5



Conversion of *Z*-**18** to its *E*-isomer was readily effected (see *Scheme 6*) by a reaction sequence consisting of bromine addition, dehydrobromination and bromine/hydrogen exchange. While the well-known *Hückel/Birch* procedure [7] [8] and a number of other methods failed in the last step, reduction with hydrazine in the presence of palladium [9] gave very satisfactory results.

Scheme 6



Treatment of *E*-**18** with manganese dioxide [10] led almost exclusively to *Z*-**17**; in other words the oxidation was accompanied by an isomerization around the double bond. At 0 °C or temperatures below, however, the thermodynamically less stable aldehyde *E*-**17** was obtained in good yield and containing little of the other isomer.

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Experimental part

General remarks: see [1] [2] [11].

1. Alkoxychlorofluorocyclopropanes. – a) *1-Chloro-1-fluoro-3-methoxy-2,2-dimethyl-cyclopropane* (**1**). Over a period of 30 min dichlorofluoromethane (Freon-21®; 90 g, 0.9 mol) was added dropwise or in small portions (cooled dropping funnel!) to a vigorously stirred mixture of methyl 2-methyl-1-propenyl ether (30.2 g, 0.35 mol), aqueous potassium hydroxide (100 ml 55% in weight, 1.35 mol) and 1,4,7,10,13,16-hexaoxa-cyclooctadecane (2 g, 8 mmol), kept at around −15° by means of an ice-salt bath. After an additional 2 h of stirring at 0°, enough water was added in order to just dissolve the precipitate, the two layers were separated and the organic liquid distilled from potassium carbonate (25 g) to afford 40.0 g (75%) of *syn*- and *anti*-**1**; b.p. 58–60°/80 Torr. – ^{1}H-NMR.: 3.48 (*s*, methoxyl); 3.03 (*d*, J = 15, methine *cis* to F); 2.92 (*s*-like, br., methine *trans* to F); 1.2 (*m*, methyl groups). – ^{19}F-NMR. (of *syn*-**1**): −66 (*d*× *hept*, J = 14 and 2).

$C_6H_{10}ClFO$ (152.6) Calc. C 47.23 H 6.61% Found C 47.11 H 6.79%

b) *1-Chloro-1-fluoro-2-methoxy-2-methylcyclopropane* (**4**). – Following the same procedure described above, methyl 2-propenyl ether (72 g, 1.0 mol) was converted to 109.5 g (79%) of a mixture of *syn*- and *anti*-**4**; b.p. 52–53°/75 Torr. – ^{1}H-NMR.: 3.38 (*s*, methoxyl); 1.50 (*d*, J = 2, methyl group of each of the two diastereoisomers); 1.4–1.0 (*m*, H of cyclopropane). ^{19}F-NMR.: −62 (rel. intensity 2, *t*× *q*, J = 12 and 2, *syn*-**4**) and −72 (rel. intensity 1, *d*× *d*× *q*, J = 21, 9 and 2, *anti*-**4**).

c) *1-Chloro-1-fluoro-3-methoxy-2-methyl-2-(4-methyl-1-pentyl)-cyclopropane* (**7**). Similarly, a *Z*/*E* mixture of methyl-2,6-dimethyl-1-hepten-1-yl-ether (7.8 g, 50 mmol; prepared from 6-methyl-1-heptanone and triphenylphosphoniomethoxymethylide [12] in 75% yield) was converted to a mixture of the four diastereoisomers of **7** (7.3 g, 66%); b.p. 48–50°/0.3 Torr). – ^{1}H-NMR.: 3.44 (*s*, methoxyl); 2.97 (*d*, J = 13.5, H of cyclopropane *cis* to F); 2.86 (*d*, J = 2, H of cyclopropane *trans* to F); 1.4 (*m*, 3 methylene and 1 methine group); 1.1 (*m*, methyl attached to the ring); 0.90 (*d*, J = 6, 2 methyl group in the side chain). – ^{19}F-NMR.: −50 (*d*, J = 13.5); −52 (*d*, J = 13.5); −68 (*d*, J = 2); −70 (*d*, J = 2; all with approximately equal intensities).

d) *1-Chloro-1-fluoro-3-methoxy-2-methyl-2-(4-methyl-3-penten-1-yl)-cyclopropane* (**10**). The same cyclopropanation procedure transformed a *Z*/*E* mixture of methyl 2,6-dimethyl-1,5-heptadien-1-yl ether (7.7 g, 50 mmol; prepared from 6-methyl-5-hepten-2-one and triphenylphosphoniomethylide [12] in 59% yield[3])) to a mixture of products: **10** (4 diastereoisomers), *1-chloro-1-fluoro-3-(4-methoxy-3-methyl-3-buten-1-yl)-2,2-dimethylcyclopropane* (**13**, 4 diastereoisomers) and, probably bisadducts (6 diastereoisomers) with two cyclopropane rings. The first two components distilled at 65–75°/0.2 Torr (4.6 g, 42%), the latter one at 80–100°/0.2 Torr (1.6 g, 11%).

10 (disregarding signals due to **13** present in the same mixture). – ^{1}H-NMR.: 5.10 (*t*, J = 6.5, olefin. H); 3.44 (*s*, methoxyl); 3.01 (*d*, J = 14, H of cyclopropane *cis* to F); 2.89 (*s*-like, H of cyclopropane *trans* to F); 2.0 (*m*, allylic methylene); 1.67 and 1.60 (2 *s*-like, 2 allylic methyl groups); 1.4 (*m*, other methylene); 1.1 (*m*, methyl attached to the ring).

e) *1-Chloro-2-ethoxy-1-fluoro-3-methylcyclopropane* (**16**). Ethyl 1-propenyl ether (*Z*+*E*; 86 g, 1.0 mol) afforded **16** (129 g, 85%) as a mixture of 4 diastereoisomers; b.p. 43–45°/28 Torr. – ^{1}H-NMR.: 3.5 (*m*, methylene [diastereotopic!] and methine next to O); 1.7 (*m*, other methine); 1.22 (*t*, J = 6.5, methyl of ethoxy group); 1.1 (*m*, methyl attached to the ring). – ^{19}F-NMR.: −54 (*m*); −73 (*m*).

$C_6H_{10}ClFO$ (152.6) Calc. C 47.23 H 6.61% Found C 46.96 H 7.02%

Even when sealed under argon, **16** decomposes in the course of a few days at 25°.

2. Solvolytic ring-opening Reactions. – a) *2-Fluoro-3-methyl-2-butenal* (**2**). Cyclopropane **1** (35 g, 0.23 mol) was added to an aqueous solution (60 ml, 0.015M) of sodium dodecylsulfate [13] which contained also a small quantity (about 0.1 g) of hydroquinone. After 150 min of heating under reflux, the mixture was cooled and then extracted with diethyl ether (3× 20 ml). The organic layer was dried (magnesium sulfate), concentrated and distilled to afford aldehyde **2**; 17.5 g (75%); b.p. 70–72°/80 Torr. – IR.: 3000–2870*m* (C–H); 2750*w* (C(O)–H); 1690*s* (C=C–C=O); 1450*m*, 1380*m*, 1300*m* (the latter band split into a doublet, CH_3?); 1200*s*, 930*m* and 810*s* (all three bands C–C and C–F?). – ^{1}H-NMR.: 9.79 (*d*, J = 14, formyl); 2.15 and 1.94 (2 *d*, J = 3.5 and 4, respectively, 2 methyl groups). – ^{19}F-NMR.: −56 (*d*× *hept*, J = 14 + 3.5).

C_5H_7FO (102.1) Calc. C 58.82 H 6.91% Found C 58.86 H 7.04%

[3]) $C_{10}H_{18}$ (154.3) Calc. C 77.87 H 11.76% Found C 78.04 H 11.94%.

b) *2-Fluoro-1-buten-3-one* (**5**, see also [14]). A heterogeneous mixture of cyclopropane **4** (25 g, 0.18 mol) and hydroquinone (about 0.05 g) in an aqueous solution (50 ml, 0.015M) of sodium dodecylsulfate was heated under gentle reflux. The reaction product was distilled off continuously as formed in a slow stream of nitrogen over a period of 5 h. The condensate (19 g) consisting of ethanol, the ketone **5** and unreacted cyclopropane **4** was dried for 3 h at −25° with calcium chloride (4 g), filtered, treated with a trace amount of hydroquinone and redistilled to give 7.9 g of pure **5** (50%); b.p. 65–68°. – ^{1}H-NMR.: 5.55 (*d*×*d*, *J*=45 and 3, olefin. H *trans* to F); 5.14 (*d*×*d*, *J*=14 and 3, olefin. H *cis* to F); 2.28 (*d*, *J*=3, methyl). – ^{19}F-NMR.: −38 (*d*×*d*×*q*, *J*=44, 14 and 3).

The *Grignard* reagent [15] prepared from 4-methyl-3-penten-1-yl bromide (4.8 g, 29 mmol), magnesium (0.8 g, 0.03 mol) in ether (20 ml) was added to **5** (2.2 g, 35 mmol) in ether (15 ml) and the mixture allowed to stand for 90 min at 25° before hydrolysis. After extraction (3×20 ml ether) and distillation, pure *2-fluoro-3,7-dimethyl-1,6-octadien-3-ol* ('2-fluoro linalool') was obtained: 2.0 g (46%); b.p. 63–65°/2 Torr. – IR. (CCl_4): 3620*m* and 3500*s* br. (free and bonded O–H, resp.); 2950*s* br. (C–H); 1680*s* (C=C). – ^{1}H-NMR.: 5.20 (*m*, *t*-like, *J*~7, olefin. methine); 4.66 (*d*×*d*, *J*=50 and 30, olefin. H *trans* to F); 4.65 (*d*×*d*, *J*=19 and 3, olefin. H *cis* to F); 2.41 (*s*, hydroxyl); 2.0 (*m*, 2 methylene groups); 1.69 and 1.62 (2 *s* br., 2 allylic methyl groups); 1.34 (*d*, *J*=1.5, other methyl). – ^{13}C-NMR.: 170 (*d*, *J*=263, fluorine-bearing C); 132 (*s*, quartern. olefin. C); 124 (*s*, olefin. methine C); 89 (*d*, *J*=18, terminal olefin. C); 73 (*d*, *J*=29, hydroxyl-bearing C); 39, 26, 25, 23 and 18 (2 methylene groups and 3 methyl C). – ^{19}F-NMR.: −30 (*d*×*d*, *J*=51 and 18).

$C_{10}H_{17}FO$ (172.2) Found C 69.73 H 9.95% Calc. C 69.73 H 10.22

c) A mixture of cyclopropane **7** (2.2 g, 9.9 mmol) and hydroquinone (0.05 g) in 10 ml of 0.015M aqueous sodium dodecylsulfate was heated under reflux for 4 h. Extraction with ether (4×5 ml) and distillation afforded a mixture of *Z*- and *E*-**8**: 1.2 g (70%), b.p. 68–70°/0.2 Torr. – IR.: 2960–2870*s* (C–H); 2750*w* (C(O)–H); 1695*vs* and 1640*s* (C=C–C=O); 1470*m*, 1380*m* and 1300*m* (CH_3?); 1190*m* and 1140*m*. – ^{1}H-NMR.: 9.77 and 9.76 (2 *d*, *J*=13 and 14, formyl in two diastereoisomers); 2.5 (*m*, allylic methylene in *Z*- and *E*-**8**); 2.12 and 1.92 (2 *d*, *J*=3.5 and 4, resp., allylic methyl in two diastereoisomers); 1.4 (*m*, methine +2 methylene groups); 0.91 (*d*, *J*=6, 2 methyl groups). – ^{19}F-NMR.: −39 and −41 (2 *d*×*m*, *J*=14 and 3).

$C_{10}H_{17}FO$ (172.2) Calc. C 69.73 H 9.95% Found C 69.91 H 9.97%

d) *2-Fluoro-3,7-dimethyl-2,6-octadienal* (**12**, '2-fluorocitral'). When the same solvolytic conditions were applied to a mixture of cyclopropanes **10** and **13** as described above (section 2c), most of the aldehyde **12** formed from **10** was destroyed at the end of 150 min. When, however, pyridine (0.8 ml, 0.01 mol) was added to the reaction mixture (containing 1.4 g of cyclopropanes **10** and **13** in about equal amounts, together 6.3 mmol), a 1:1 mixture (0.65 g) of unreacted cyclopropane **13** and fluorocitral **12** could be isolated by distillation; b.p. 60–75°/0.2 Torr. **12** (*Z*+*E*) and **13** (4 diastereoisomers) were separated by prep. GC. (3 m, 20% SE-30*, 150°). **12.** – ^{1}H-NMR.: 9.67 and 9.61 (rel. intensities ~10:9, 2 *d*, *J*=12 and 14, resp., formyl in two diastereoisomers); 5.11 (*t*-like *m* br., *J*~7, olefin. H); 2.5–2.1 (*m*, 2 allylic methylene groups); 2.10 and 1.91 (2 *d*, *J*=3.5 and 4, resp., methyl in the vicinity of F in two diastereoisomers); 1.69 and 1.61 (2 *s*, two geminal methyl groups). **13.** – ^{1}H-NMR.: 5.77 (*m*, *s*-like, olefin. H); 3.51 (*s*, methoxyl); 2.3–1.6 (*m*, allylic and simple methylene group); 1.5 (*m*, *s*-like, allylic methyl); 1.3 and 1.1 (2 *m*, 2 methyl groups attached to the ring).

In another run, a mixture of **10** and **13** (together 1.0 g) was dissolved in 0.5 ml pyridine and 2 ml methanol and heated 20 h at 75°. As NMR. analysis of the product mixture revealed the presence of 2-fluoro-1,1-dimethoxy-3,7-dimethyl-2,6-octadien (**11**, *Z*+*E*) and 1-chloro-1-fluoro-3-(3-dimethoxymethyl-1-butyl)-2,2-dimethylcyclopropane (**14**, 4 diastereoisomers), the crude reaction product was treated with an aqueous solution (5 ml, 0.015M) of sodium dodecylsulfate containing a small quantity of hydroquinone at 70° for 20 h. Extraction (4×5 ml diethyl ether) and evaporation of the solvent yielded a crude mixture (0.7 g) of *Z*- and *E*-fluorocitral **12** (about 35%) and 1-chloro-1-fluoro-3-(3-formyl-1-butyl)-2,2-dimethylcyclopropane (**15**, 4 diastereoisomers; about 40%) which was separated by prep. GC. (3 m, 20% SE-30*, 160°). **15.** – ^{1}H-NMR.: 9.61 (*d*, *J*=1.5, formyl group); 2.3 (*m*, *hex*-like, methine next to formyl); 1.8–1.2 (*m*, methylene groups+ ring hydrogen atoms); 1.2 (*m*, 3 methyl groups).

e) *Z-2-Fluoro-2-butenal* (*Z*-**17**). An aqueous solution of sodium dodecylsulfate (500 ml, 0.03M), to which cyclopropane **16** (93 g, 0.61 mol) and a small amount of hydroquinone were added, was heated under nitrogen under reflux for 7 h. After extraction (8×50 ml diethyl ether) and evaporation (again

nitrogen atmosphere!) of the solvent, a wet fraction was collected and dried with calcium chloride. Redistillation under nitrogen gave *Z*-**17**; 33.5 g (62%); b.p. 52–54/80 Torr. A second fraction obtained from the residue (4 g) of the first distillation, proved to be *Z-2-chloro-2-butenal* (*Z*-**19**); 0.30 g (0.5%); b.p. 45–50°/10 Torr.

Z-**17**. – IR.: 3040–2740*w* br. (C–H?); 2925*m* (C(O)–H); 1700*s* br. (C=C–C=O); 1445, 1390 and 1335*m-s* (CH_3?); 1215*s*, 1085*m*, 1000*s* and 845*m* (all together C–C and C–F?). – ^{1}H-NMR.: 9.03 (*d*, *J* = 17, formyl); 5.91 (*d*×*q*, *J* = 32 and 7.5, olefin. H); 1.90 (*d*×*d*, *J* = 7.5 and 2.5, methyl). – ^{19}F-NMR.: −56 (*d*×*d*×*q*, *J* = 33, 20 and 2.5).

C_4H_5FO (88.1) Calc. C 54.55 H 5.72% Found C 54.40 H 5.84%

Z-**19** [4]. – IR.: 2950*w* br. (CH); 2810*m* and 2720*w* (C(O)–H); 1710*s*, 1630*s* (C=C–C=O); 1435*m*, 1370*m* and 1295*m* (CH_3?); 1170*s*, 1065*m*, 970*m*, 760*s* and 605*m* (all together C–C and C–Cl?). – ^{1}H-NMR.: 9.45 (*s*, formyl); 7.10 (*q*, *J* = 7, olefin. H); 2.13 (*d*, *J* = 7, methyl). – MS.: 104 (48%, M^+[^{35}Cl]); 41 (50%); 39 (100%).

Distillation in the absence of nitrogen gave lower yields (40%) of the product. Smaller scale reactions (20 g of **1**) do not require, however, such precautions, a typical yield being 71%.

3. Reduction with lithium aluminium hydride. – a) *2-Fluoro-3-methyl-2-buten-1-ol* (**3**, '2-fluoroprenol'). To an ice-cooled suspension of lithium aluminium hydride (1.0 g, 26 mmol) in 75 ml diethyl ether, aldehyde **2** (5.2 g, 51 mol) was added. After 15 min stirring at 0° the mixture was hydrolysed by dropwise addition of enough water (about 1 ml) so that the precipitate turned just white. The precipitate was filtered off and washed with diethyl ether (20 ml). The combined organic layers were evaporated through a *Widmer* column and the remaining liquid distilled (b.p. 60–63/17 Torr). The product **3** (4.1 g, 77%) thus obtained was identical in every respect with the previously described material [3].

b) *2-Fluoro-1-buten-3-ol* (**6**). Ketone **5** (3.8 g, 43 mmol) was reduced with the metal hydride (0.8 g, 0.02 mol) in 50 ml ether. Yield 2.5 g (64%); b.p. 102–105°. – IR. (CCl_4): 3620*m* and 3360*s* br. (free and bound O–H); 3000*s* (olefin. C–H); 2950*m* and 2890*m* (aliph. CH); 1670*s* (C=C); 1220*s*, 1120*s* and 1085*s* (C–O); 945*s*, 920*s* and 870*s* (–CF=CH_2?). – ^{1}H-NMR.: 4.62 (*d*×*d*, *J* = 17 and 3, olefin. H *trans* to F); 4.56 (*d*×*d*, *J* = 50 and 3, olefin. H *cis* to F); 4.3 (*m*, masked by other signals, methine); 3.76 (*s*, hydroxyl); 1.35 (*d*, *J* = 6.5, methyl). – ^{19}F-NMR.: −32 (*d*×*d*×*d*, *J* = 50, 19 and 10).

C_4H_7FO (90.1) Calc. C 53.32 H 7.83 Found C 53.41 H 7.99

c) *2-Fluoro-3,7-dimethyl-2-octen-1-ol* (**9**). Aldehyde **8** (*Z* + *E*; 1.0 g, 5.8 mmol) was reduced with the metal hydride (0.15 g, 4.0 mmol) in 10 ml ether to afford *Z*- and *E*-**9**; 0.80 g (79%); b.p. 76–78°/0.2 Torr. – IR. (2% in CCl_4): 3620*m*, sharp (O–H free); 3400*m* br. (O–H assoc.); 2960*s* br. (C–H); 1700*m* (C=C); 1470*s*; 1385*m* and 1370*m*; 1260*s* and 1230*s*; 1005*s*. – ^{1}H-NMR.: 4.15 (*d*, *J* = 23, oxygen-bearing methylene); 3.12 (*s*, hydroxyl); 2.0 (*m*, *t*-like, allylic methylene); 1.66 (*d*, *J* = 3, allylic methyl); 1.5 (*m*, methine); 1.3 (*m*, 2 methylene groups); 0.88 (*d*, *J* = 6, geminal methyl groups).

$C_{10}H_{19}FO$ (174.3) Calc. C 68.93 H 10.99% Found C 69.06 H 11.05%

d) *Z-2-Fluoro-2-buten-1-ol* (*Z*-**18**, '2-fluorocrotyl alkohol'). Aldehyde *Z*-**17** (19 g, 0.22 mol) was reduced with the metal hydride (4.2 g, 0.11 mol) in 100 ml ether. Distillation gave 16.5 g *Z*-**18** (83%); b.p. 43–45/12 Torr. – IR.: 3380*s* br. (O–H); 2940*m* and 2880*m* (C–H); 1720*m* (C=C); 1000*s* (C–O); 950*m*; 830*m* and 810*m*. – ^{1}H-NMR.: 4.86 (*d*×*q*, *J* = 36 and 7, olefin. H); 4.04 (*d* with fine-structure, *J* = 16, hydroxyl-bearing methylene); 3.42 (*s*, hydroxyl); 1.64 (*d*×*m*, *J* = 7, methyl). – ^{13}C-NMR.: 159 (*d*, *J* = 255, fluorine-bearing C); 102 (*d*, *J* = 15, hydroxyl-bearing C); 61 (*d*, *J* = 33, other olefin. C); 9 (*d*, *J* = 5, methyl C). – ^{19}F-NMR.: −43 (*d*×*t*×*q*, *J* = 36.5 + 16 + 2.5).

C_4H_7FO (90.1) Calc. C 53.32 H 7.83% Found C 53.36 H 8.02%

4. Configurational inversion of the fluorocrotyl alcohol. – a) *Z-3-bromo-2-fluoro-2-buten-1-ol.* Bromine (38.4 g, 13.2 ml, 240 mmol) in anhydrous tetrachloromethane (250 ml) was dropwise added to a solution of *Z*-2-fluoro-2-buten-1-ol (*Z*-**19**; 22.5 g, 25 mmol) in tetrachloromethane (20 ml), kept initially at −15° and towards the end of the addition at 0°. As soon as the bromine color had disappeared, the solvent was stripped off in a RV. at 0°. – ^{1}H-NMR.: 4.62 (*d*×*q*, *J* = 20 and 7, methine); 4.19 (*d*×*d*, *J* = 11 and 2[4]), methylene); 3.0 (*m*, large, without fine-structure, hydroxyl); 1.96 (*d*, *J* = 7, methyl).

[4]) This fine splitting may sometimes disappear, especially when the solution is highly concentrated.

The crude product (25 g, 0.10 mol) was dissolved in anhydrous benzene (50 ml). At 0° 1.5-diazabicyclo[5.4.0]-5-undecene (30 g, 0.20 mol) were added dropwise. The mixture was warmed up to 65°, cooled down again after 1 h and treated with 5N HCl (60 ml). The organic layer was washed with water (20 ml) and brine (20 ml), then evaporated under reduced pressure. Distillation afforded *Z*-3-bromo-2-fluoro-2-buten-1-ol (14.8 g, 88%); b.p. 75–78°/0.2 Torr. – IR.: 3340*s* br. (O–H); 2970*m*, 2930*w* and 2870*w* (C–H); 1700*m*; 1435*m*, 1390*m* and 1365*m* (methyl); 1250*m* and 1210*m*; 1115*s*; 1015*s* (C–O); 830*m*; 665*m*. – ^{1}H-NMR.: 4.26 (*d*, J = 21); 4.20 (*d*, J = 1, hydroxyl); 2.29 (*d*, J = 4, methyl). – ^{13}C-NMR.: 154 (*d*, J = 252, fluorine-bearing C); 103 (*d*, J = 23, bromine-bearing C); 57 (*d*, J = 30, hydroxyl-bearing C); 21 (*s*, methyl C). – ^{19}F-NMR.: −22 ($t \times q$, J = 21 and 3.5).

C_4H_6BrFO (169.0) Calc. C 28.43 H 3.58% Found C 28.24 H 3.73%

b) E-*2-fluoro-2-buten-1-ol* (*E*-**18**). 10% Pd/C (3 g) was added to a solution of *Z*-3-bromo-2-fluoro-2-buten-1-ol (23.9 g, 140 mmol) and hydrazine hydrate (75 ml, 80% in weight hydrazine) in methanol (150 ml). The mixture was heated 1 h under gentle reflux. After cooling and filtration, the solvent was evaporated, the residue neutralized with acetic acid (approximately 80 ml) and extracted with diethyl ether (4 × 30 ml). The combined organic layers were washed (3 × 20 ml water), dried ($MgSO_4$) and distilled. 8 g (63%) of *E*-**18** were collected in the boiling range 42–44°/10 Torr. – IR.: 3380*s* (O–H); 3010*sh*, 2960*m* and 2890*m* (C–H); 1740*s* (C=C); 1180*s*, 1105*s*, 1045*s* and 1000*s* (all C–O?); 850*m* and 815*m* (=CH– + C–F?). – ^{1}H-NMR.: 5.20 ($d \times q$, J = 21 + 7.5, olefin. H); 4.17 (*d*, J = 21.5, methylene); 3.80 (*s*, hydroxyl); 1.64 ($d \times d$, J = 7.5 and 2.5). – ^{19}F-NMR.: −35 ($d \times q$, J = 21 and 2.4).

C_4H_7FO (90.1) Calc. C 53.32 H 7.83% Found C 53.20 H 8.01%

c) E-*2-fluoro-2-butenal* (*E*-**17**). *E*-**18** (5.4 g, 60 mmol), active manganese dioxide (60 g) and anhydrous pentane (100 ml) were vigorously stirred throughout 7 days at 0°. The heterogenous mixture was brought into a column filled with pentane and basic alumina (50 g) and cooled at −20° in order to separate the product from manganese dioxide and unreacted *E*-**18**. When the elution was complete (200 ml pentane), the solvent was carefully evaporated under reduced pressure (30 cm column with internal spiral, 50 Torr, bath temperature 0°, column spiral and condenser cooled to −20°). The residue distilled at 15–18°/5 Torr; 3.3 g (62%) **17**; *Z*/*E*-ratio 1:4 (2 m, 20% C-20-M*, 80° [4 min] → 200°; 2 *m*, 20% Ap-L*, 60° [4 min] → 200°). A pure sample of *E*-**17** was separated by prep. GC. (3 m, 20% C-20-M*, 80°). – IR. (CCl_4): 3005*sh*, 2940*m*, 2840*m* and 2760*w* (C–H); 1705*s* and 1650*s* (C=C–C=O); 1230*s*, 1175*s* and 1100*s*; 860*s* (=CH–?); 620*m* (C–F?). – ^{1}H-NMR.: 9.50 (*d* + fine splitting, J = 11, formyl H); 6.00 ($d \times q$ + fine splitting, J = 38 and 8, olefin. H); 2.01 ($d \times d$, J = 8 and 3, methyl). – ^{19}F-NMR.: −57 ($d \times d \times q$, J = 32, 19 and 2.5).

Z-**17** polymerizes (or oligomerizes) at RT. in the course of a few hours.

C_4H_5FO (88.1) Calc. C 54.55 H 5.72% Found C 54.56 H 5.88%

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