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(54) Title: CYCLOPROPANATION PROCESS

(57) Abstract: A process for the cyclopropanation of a substituted alkene, comprising the reaction of the alkene with a carbenoid, generated from dibromomethane and a tri-(C2 - C8)-alkyl aluminium compound, in the presence of a catalytic amount of a metal compound selected from the group consisting of Lewis acids, metallocenes and metal carbonyl complexes. The process advantageously uses transition metal compounds as catalysts and the dibromomethane can be recovered. The process is especially useful for the preparation of ingredients for the flavour and fragrance industry.



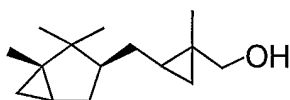
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CYCLOPROPANATION PROCESS

This invention relates to a process of preparing cyclopropanated compounds.

- 5 A common cyclopropanation reaction is the Simmons-Smith reaction (see Simmons, H. E; Cairns, T. L.; Vladuchick, S. A.; Hoiness, C. M. *Org. React. (N. Y.)* **1973**, *20*, 1 - 131), which utilises diiodomethane and Zn(Cu). The reaction takes place via the formation of a carbenoide, that is an intermediate of the type M-CH₂-X (M = metal, X = halide), which is generated and consumed during a cyclopropanation reaction. Modifications of this reaction
10 have been introduced by Furukawa (Furukawa, J.; Kawabata, N.; Nishimura, J. *Tetrahedron* **1968**, *24*, 53 - 58) and later on by Friedrich et al., who replaced diiodomethane by dibromomethane.

The latter carbenoide precursor is not only less expensive, but it also avoids undesirable iodine
15 and iodide wastes. The use of dibromomethane, however, has the disadvantage that it is less reactive than diiodomethane in this reaction. In order to activate the zinc-copper couple for carbenoide formation, it is necessary to use ultrasound (Friedrich, E. C.; Domek, J. M.; Pong, R. Y. *J. Org. Chem.* **1985**, *50*, 4640 - 4642) or additives such as copper halides and acetyl halides (Friedrich, E. C.; Niyati-Shirkhodaee, F. *J. Org. Chem.* **1991**, *56*, 2202 - 2205). An
20 example of a compound whose preparation utilizes the latter method is



a molecule that has been commercialized successfully as a fragrance component (see
EP 0 801 049). A remaining disadvantage of this method, however, is the generation of
25 environmentally-unfriendly zinc- and copper-based wastes.

One theoretical possibility of circumventing these disadvantages is the combination of dibromomethane and a trialkyl aluminum compound. However, this was hitherto not regarded as a viable option. For example, in his paper in *J. Org. Chem.* **1991**, *56*, 2202 - 2205, Friedrich states that "...the use of CH₂Br₂ was examined only (for cyclopropanation) when the
30 Zn/Cu procedure was employed because, with ZnEt₂ or AlEt₃, dibromomethane has not been reported to react." The theoretical possibility was mentioned in EP 0 801 049, but no teaching on how to achieve it was supplied.

It has now been found that it is possible to utilise dibromomethane and a trialkyl aluminum compound efficiently in a cyclopropanation reaction, if certain metal compounds are added in catalytic amounts.

5 The invention therefore provides a process for the cyclopropanation of a substituted alkene, comprising the reaction of the alkene with a carbenoide, generated from dibromomethane and a tri-(C₂ - C₈)-alkyl aluminium compound in the presence of a catalytic amount of a metal compound selected from the group consisting of Lewis acids other than tri-(C₂ - C₈)-alkyl aluminium compounds, metallocenes and metal carbonyl complexes.

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By "catalytic amount" is meant an amount of less than one molar equivalent of metal compound with more than one molar equivalent of reactant with the result that more than one molar equivalent of product is obtained.

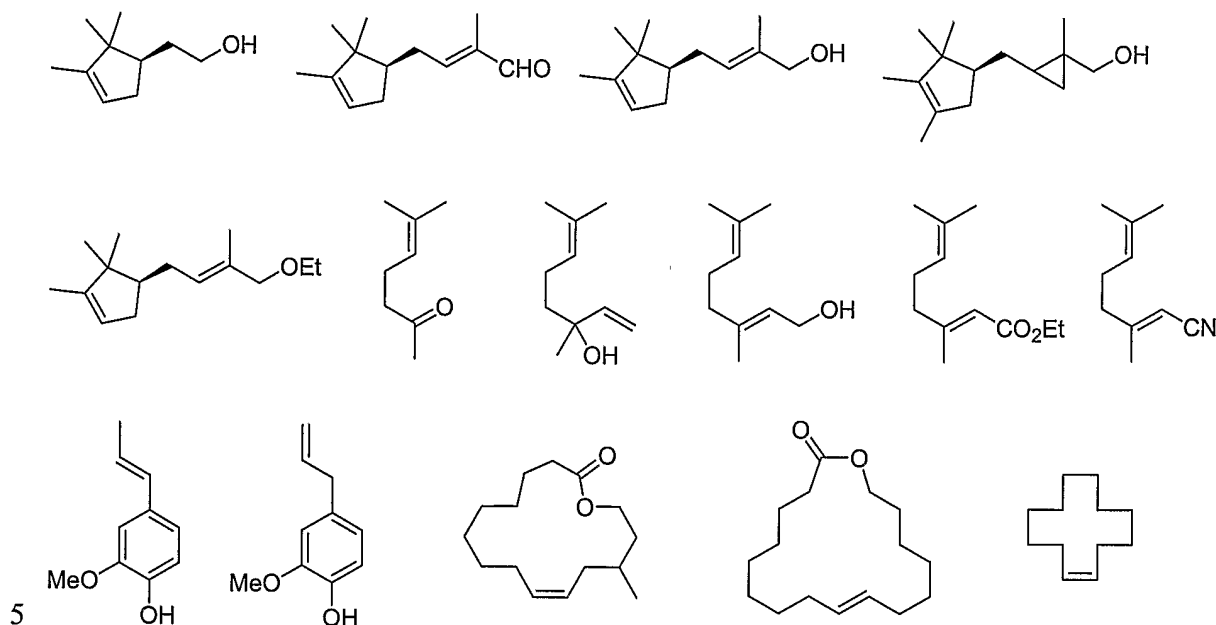
15 This method not only gives good yields of the product but is also free from the generation of zinc- and copper-containing residues. The advantage gained by the metal compounds is that the reaction rate of the cyclopropanation reaction is enhanced, thus allowing the use of less dibromomethane and trialkyl aluminum as well as a significantly decreased reaction temperatures.

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The C₂ - C₈ alkyl moieties may include alkanes, substituted alkanes, cycloalkanes and substituted cycloalkanes. The (C₂ - C₈) alkyl aluminium compound is preferably triisobutyl aluminium (TIBA).

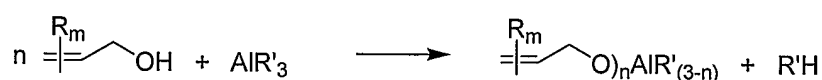
25 The method is applicable to electron-rich alkenes. Examples of such alkenes include mono-, di-, tri- or tetra-substituted alkenes. The substituents may be selected from saturated and unsaturated alkyl and aryl groups, which themselves may be substituted with functional groups, such as (but not limited to) acids, esters, alcohols, ethers, allyl alcohols, allyl ethers, amines, allyl amines, imines, alkenes, aldehydes, cyclopropanes and ketones. Alkenes with
30 which the invention works especially well are alkenes bearing at least three substituents including alkenes embedded in ring structures with ring sizes of 3 to 20 carbon- or hetero-atoms, which rings themselves can be substituted, for example, with the same substituents as hereinabove described.

Examples of alkenes that undergo the cyclopropanation reaction of this invention, including combinations of reactive alkenes and unreactive alkenes in the same molecule, include those with the following structures:



The alkenes may also include in the same molecule alkene moieties that are not electron-rich or alkenes that contain functional groups in their allylic position, which undergo complex formation with the alkyl aluminium compound, e.g.

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thus shielding these alkenes sterically against cyclopropanation. Examples of these unreactive alkenes are allylic alcohols, allylic amines, as well as electron-deficient alkenes such as

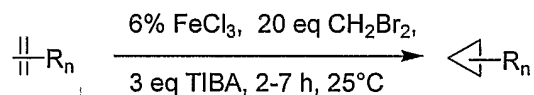
15 conjugated carbonyl compounds, conjugated nitriles, conjugated imines and conjugated oximes. If these unreactive alkenes are combined in the same molecule with electron-rich reactive ones, only the latter will undergo cyclopropanation, with high chemoselectivity.

The metal compounds whose presence is essential to the working of the invention are selected

20 from the group consisting of metallocenes, metal carbonyl complexes and Lewis acids other than tri-(C₂ - C₈)-alkyl aluminium compounds. One or more of these metal compounds can be used. Although tri-(C₂ - C₈)-alkyl aluminium compounds are themselves weak Lewis acids, it

has been found that they alone do not give the benefits of the invention, and when Lewis acids are desired as the metal compounds, Lewis acids other than these tri-(C₂ - C₈)-alkyl aluminium compounds must be added.

- 5 The rate enhancement brought about by the use of these metal compounds ranges from slight to very significant. Examples of efficient Lewis acids include FeCl₂ and FeCl₃, which are preferably used at a concentration of 0.01 – 30%, preferably 1 - 10%, with respect to the alkene to be cyclopropanated (the starting material). Examples of efficient metallocenes are those with at least one cyclopentadienyl-ligand, e.g. cyclopentadienyltitanium trichloride CpTiCl₃ or
 10 cyclopentadienyliron dicarbonyl dimer [CpFe(CO)₂]₂, which are used at the concentrations hereinabove described. An example of a metal carbonyl complex is iron pentacarbonyl Fe(CO)₅. The addition has the advantage of allowing the reaction to be carried out in less dibromomethane, typically 20 molar equivalents instead of 30 eq, and at lower temperatures, thus increasing the margin of safety, because above 85°C an exothermic decomposition of the
 15 reaction mass is possible. For example, with FeCl₃, this reaction proceeds as follows:



In a preferred embodiment, the excess dibromomethane is recovered. Although not essential to
 20 the working of the invention, such a recovery reduces costs and makes the process more industrially viable. The recovery is carried out by the steps of:

- (i) adding the reaction mixture to aqueous base at a temperature from -10° - 0°C;
- (ii) warming slowly the resulting two-phase mixture to room temperature;
- 25 (iii) separating the phases;
- (iv) adding isopropanol to the organic phase; and
- (v) drying azeotropically and evaporating the dibromomethane under reduced pressure.

In a typical example, using the preferred TIBA, recovery may be achieved by the following
 30 steps:

- (i) The reaction mixture is added to aqueous base (preferably 25% NaOH) at a temperature of from -10° - 0°C. Isobutane is cleaved from the isobutyl aluminium reagent and remains liquefied in the target vessel.

- (ii) The resulting two-phase mixture is slowly and under stirring warmed to room temperature. This causes the release of gaseous isobutane, which is collected in a cooling device;
- (iii) after phase separation and addition of isopropanol to the organic phase, the organic phase is dried azeotropically and the excess dibromomethane is evaporated under reduced pressure
- 5 and finally purified by distillation.

The process described in this invention permits the cyclopropanation of electron-rich olefins in a cheap and efficient manner. The aluminium- and iron-containing wastes are environmentally of relatively low concern, the solvent dibromomethane can be recycled, and the collected

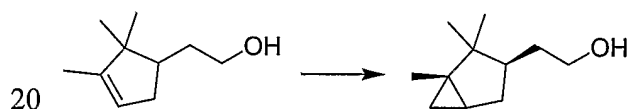
10 isobutane can be used for other purposes or can be burned.

The process has many uses, including the relatively easy and inexpensive manufacture of flavour and fragrance ingredients.

- 15 The invention is now further described with reference to the following non-limiting examples.

Example 1:

Cyclopropanation of Campholene alcohol: *trans*-2-(1,2,2-trimethyl-bicyclo[3.1.0]hex-3-yl)-ethanol



Campholene alcohol (EP 0 116 903) (8 g, 50 mmol) in dibromomethane (72 ml) is treated under cooling (10° - 20°C) with neat TIBA (6.5 ml, 25 mmol) via syringe. After 15 min stirring anhydrous FeCl₃ (0.5 g, 3 mmol) is added followed by neat TIBA (39 ml, 0.15 mol).

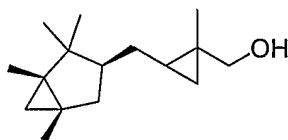
- 25 The mixture is stirred for 3 h at 25°C, then cooled to -10° - 0°C and pumped via double-needle on to 25% NaOH at -10° - 0°C. Under stirring the biphasic mixture is slowly warmed to room temperature. The phases are separated. The organic phase is washed with 4% oxalic acid, then with conc. NaHCO₃ until pH ~ 8, dried over MgSO₄ and filtered. After evaporation of the solvents under reduced pressure, the oily residue is purified by bulb-to-bulb-distillation (bp
- 30 108°C / 0.1 Torr), giving 7.3 g (85%) of a colorless oil. Odour: Camphoraceous, oily. ¹H-NMR

(CDCl₃, 400 MHz): 3.65 (ddd, 1 H), 3.5 (ddd, 1 H), 1.7 (dd, 1 H), 1.6 (m, 1 H), 1.4 (m, 1 H), 1.3 (m, 1 H), 1.2 (m, 1 H), 1.05 (s, 3 H), 1.0 (m, 1 H), 0.89 (s, 1 H), 0.78 (s, 1 H), 0.45 (dd, 1 H), 0.02 (dd, 1 H) ppm. ¹³C-NMR (CDCl₃, 400 MHz): 62.6 (t), 41.4 (s), 40.6 (d), 33.4 (t), 32.3 (t), 31.2 (s), 22.8 (d), 22.7 (q), 19.8 (q), 17.4 (q), 13.9 (t) ppm. Relative configuration

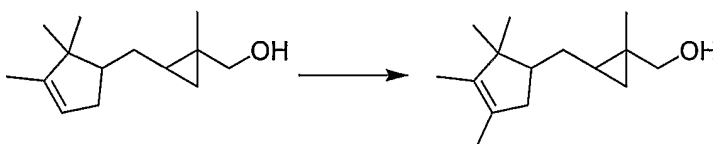
- 5 determined by HSQC, COSYDQF, HMBC, NOESY. GC/MS: 168 (1%, [M]⁺), 153 (60%, [M - CH₃]⁺), 109 (90%), 81 (80%), 55 (83%), 41 (100%). IR (film): 3325 (m), 2951 (s), 2868 (m), 1464 (m), 1451 (m), 1363 (m), 1056 (m), 1034 (m).

Example 2:

- 10 *trans*-[1-Methyl-2-(1,2,2,5-tetramethyl-bicyclo[3.1.0]hex-3-ylmethyl)-cyclopropyl]methanol.



- (i) Preparation of the precursor: *trans*-[1-Methyl-2-(2,2,3,4-tetramethyl-cyclopent-3-enylmethyl)-cyclopropyl]methanol:



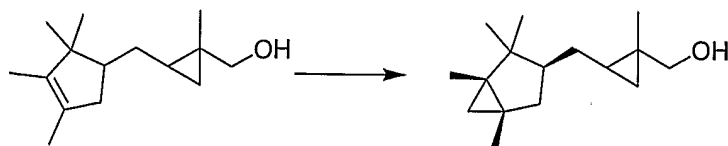
- 15 *trans*-[1-Methyl-2-(2,2,3-trimethyl-cyclopent-3-enylmethyl)-cyclopropyl]-methanol (dr = 1:1) (Bajgrowicz, J. A.; Frank, I.; Frater, G.; Hennig, M., *Helv. Chim. Acta* **1998**, *81*, 1349 - 1358) (10 g, 48 mmol), dihydropyran (4.3 g, 51 mmol) and a few drops of conc. HCl (50 mg) are stirred for 4 h at 25°C. After addition of methyl *tert*-butyl ether the organic phase is washed with conc. NaHCO₃ and conc. NaCl until pH = 7. Drying over MgSO₄, filtration and
- 20 evaporation gives 14 g (93%) of the crude THP-ether as an oil (4 isomers, 93% purity and M = 292 according to GC/MS), which is subjected to the next epoxidation step without further purification.

The thus-obtained crude THP-ether (11.7 g, 40 mmol) is dissolved in dichloromethane (20 ml). After addition of water-free Na₂CO₃ (5.9 g, 56 mmol) the mixture is heated to 42°C, where

40% peracetic acid (10 ml, 56 mmol) are added over 2 h. The reaction is stirred for another 1 h at this temperature. Water (50 ml) is carefully added and the phases are separated. The water phase is extracted with dichloromethane. The organic phase is washed with 10% NaOH and water until pH = 7. Drying over MgSO₄, filtration and evaporation gives 12.3 g (87%) of the
5 crude THP-protected epoxide as an oil (4 isomers, 87% purity and M = 308 according to GC/MS), which is subjected without further purification to the next Grignard addition / elimination step.

The thus-obtained THP-protected epoxide (8.6 g, 28 mmol) is treated with 3M methyl magnesiumchloride in tetrahydrofuran (94 ml, 0.28 mol). After 3 days at 70°C the solution is
10 poured upon NH₄Cl at 0°C. Methyl *tert*-butyl ether extraction and washing of the organic phase with water until pH = 7, MgSO₄-drying, filtration and evaporation gives 10 g of an orange oil, which is treated with methanol (10 g) and *para*-toluenesulfonic acid (0.1 g). After 16 h at 25°C the methanol is evaporated, conc. NaHCO₃ and methyl *tert*-butyl ether are added and the phases are separated. MgSO₄-drying, filtration and evaporation of the organic phase
15 gives 7 g of an orange oil, which is purified by flash chromatography (hexane / methyl *tert*-butyl ether) over silicagel giving after evaporation of the solvents and Kugelrohr distillation 1.9 g (31%) of *trans*-[1-Methyl-2-(2,2,3,4-tetramethyl-cyclopent-3-enylmethyl)-cyclopropyl]-methanol as a colorless oil (dr = 1:1, 84% GC-purity). Odour: Sandalwood, substantive. ¹H-NMR (CDCl₃, 400 MHz): 3.35 (2 H), 2.3 (m, 1 H), 1.95 (m, 1 H), 1.75 (m, 1 H), 1.6 (s, 3 H),
20 1.5 (s, 3 H), 1.5 – 1.2 (5 H), 1.15 (s, 3 H), 0.95 (s, 3 H), 0.7 (d, 3 H), 0.65 (m, 1 H), 0.5 (m, 1 H), 0 (2 m, 1 H) ppm. ¹³C-NMR (CDCl₃, 400 MHz): 139.04 and 139.03 (2 s), 128.6 and 128.5 (2 s), 72.7 and 72.6 (2 t), 49.7 and 49.3 (2 d), 48.0 and 47.8 (2 s), 41.62 and 41.59 (2 t), 29.1 and 28.6 (2 t), 26.2 and 26.1 (2 q), 22.7 and 21.8 (2 s), 21.3 and 21.0 (2 d), 19.7 and 19.6 (2 q),
17.0 and 16.5 (2 t), 15.7 (q), 15.1 (q), 14.2 (q), 9.45 and 9.43 (2 q). GC/MS: 222 (3%, [M]⁺),
25 150 (22), 135 (35%), 121 (55%), 107 (100%). IR (film): 3327 (m), 2951 (s), 2851 (s), 2915 (m), 2861 (m), 1445 (m), 1382 (m), 1359 (m), 1027 (s), 881 (w).

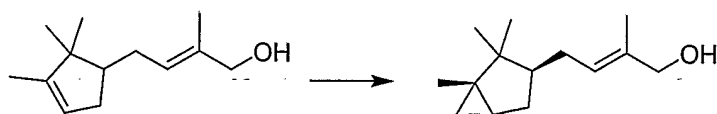
(ii) Cyclopropanation reaction: Preparation of *trans*-[1-Methyl-2-(1,2,2,5-tetramethyl-bicyclo[3.1.0]hex-3-ylmethyl)cyclopropyl]methanol:



Prepared as described in example 1 from *trans*-[1-Methyl-2-(2,2,3,4-tetramethyl-cyclopent-3-enylmethyl)-cyclopropyl]-methanol (0.5 g, 2.2 mmol), dibromomethane (3 ml, 45 mmol), TIBA (2 ml, 8 mmol) and FeCl₃ (22 mg, 0.13 mmol) giving after bulb to bulb-distillation (bp 128°C / 0.2 Torr) 0.46 g (85%) of a colorless oil (dr = 1:1, 91% GC-purity). Odour: Sandalwood, substantive. ¹H-NMR (CDCl₃, 400 MHz): 3.3 (m, 2 H), 1.9 (m, 1 H), 1.5 (s, 1 H, OH), 1.3 - 1.1 (3 H), 1.1 (2 s, 3 H), 1.0 (s, 1H), 0.95 (s, 1 H), 0.89 (s, 1 H), 1.0 - 0.8 (2 H), 0.75 (d, 3 H), 0.6 - 0.4 (3 H), 0.0 and -0.1 (2 t, 1 H), -0.3 (d, 1 H) ppm. ¹³C-NMR (CDCl₃, 400 MHz): 72.7 and 72.6 (2 t), 44.8 and 44.4 (2 d), 42.6 and 42.5 (2 s), 39.94 and 39.89 (2 t), 34.9 and 34.8 (2 s), 29.4 and 28.8 (2 t), 26.2 and 26.1 (2 s), 23.1 and 23.0 (2 q), 22.8 and 21.9 (2 s), 21.6 and 21.2 (2 d), 19.8 and 19.7 (2 t), 19.6 and 19.5 (2 q), 18.4 (2 q), 17.1 and 16.5 (2 t), 15.7 and 15.1 (2 q), 14.02 and 14.01 (2 q) ppm. GC/MS: 236 (0.2%, [M]⁺), 218 (1%), 203 (5%), 175 (5%), 164 (15%), 149 (30%), 135 (85%), 121 (80%), 107 (60%), 95 (80%), 82 (80%), 55 (85%), 41 (100%). IR (film): 3323 (m), 3064 (w), 2866 (s), 1452 (s), 1381 (m), 1362 (m), 1028 (s), 1012 (s), 880 (w).

Example 3:

20 Distal-selective cyclopropanation of Nor-Radjanol: *trans*-2-Methyl-4-(1,2,2-trimethyl-bicyclo[3.1.0]hex-3-yl)but-2-en-1-ol.



To Nor-Radjanol (Bajgrowicz, J. A.; Frank, I.; Frater, G.; Hennig, M., *Helv. Chim. Acta* **1998**, *81*, 1349 - 1358) (194 g, 1 mol) in dibromomethane (1.4 l, 20 mol) neat TIBA (100 g, 0.5

mol) is added under cooling (10° - 20°C) via double-needle. After 15 min anhydrous FeCl₃ (22 mg, 0.13 mmol) is added in one portion followed by TIBA (620 g, 3.1 mol) via double needle. The mixture is stirred for 4.5 h at 25°C, then cooled to -10° - 0°C and pumped via double needle on to cooled (-10° - 0°C) 25% NaOH. Under stirring (Caution !) the biphasic mixture is

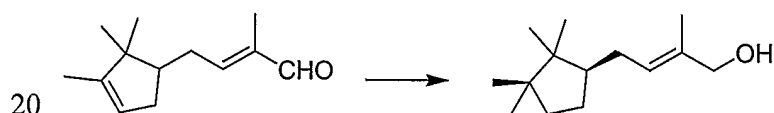
5 slowly warmed to room temperature. The evolving isobutane is collected in a cooling trap at -78°C. The phases are separated. The organic phase is washed with 4% oxalic acid, then with conc. NaHCO₃ until pH ~ 8. Isopropanol (110 g, 1.8 mol) is added to the organic phase and the water is removed azeotropically under reduced pressure. Then, the remaining water-free dibromomethane is removed under reduced pressure, followed by distillation of the residue (bp

10 160°C / 0.1 Torr) giving 190 g (93%) of a colorless oil (86% GC-purity, 2% Nor-Radjanol 7% bis-cyclopropanated byproduct), whose analytical data (NMR, MS, IR, odour) are consistent with the ones described in the literature (Bajgrowicz, J. A.; Frank, I.; Frater, G.; Hennig, M., *Helv. Chim. Acta* **1998**, *81*, 1349 - 1358).

15 Example 4:

This is a comparative example that uses no metal compound.

trans-2-Methyl-4-(1,2,2-trimethyl-bicyclo-[3.1.0]hex-3-yl)but-2-en-1-ol from Nor-Radjaldehyde via solvent-free DIBAH reduction.



To Nor-Radjaldehyde (US 4,052,341) (192 g, 1 mol) is added at 0°C and stirring neat DIBAH (179 ml, 1 mol) via double needle. The solution is stirred for 30 min at 25°C. Dibromomethane (2.1 l, 30 mol) is added and the solution heated to 60°C, where neat TIBA (595 g, 3 mol) is

25 added over 2 h via double-needle. The reaction temperature is maintained by slight external cooling at 65 - 75°C for another 2 - 4 h, until complete conversion is detected by GC. Work-

up, as described in example 3, gives 227 g (>91%) of crude product as a slightly yellow oil, whose analytical data (NMR, IR, MS, odour) are consistent with the ones described for this compound in the literature (Bajgrowicz, J. A.; Frank, I.; Frater, G.; Hennig, M., *Helv. Chim. Acta* **1998**, *81*, 1349 - 1358).

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In comparison with Example 1, it can be seen that, without FeCl₃, more TIBA and dibromomethane are required and that a higher reaction temperature is necessary. The use of FeCl₃ allows a better, more economic process.

10 Example 5:

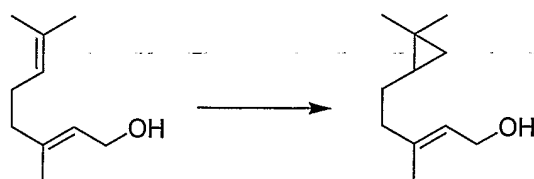
Distal-selective cyclopropanation of Linalool: 5-(2,2-Dimethyl-cyclopropyl)-3-methyl-pent-1-en-3-ol



15 Prepared as described in example 1 from Linalool (31 g, 0.2 mol), dibromomethane (280 ml), neat TIBA (140 g, 0.7 mol) and anhydrous FeCl₃ (2 g, 60 mmol). Work-up after 6 h at 25°C and distillation (bp 55°C / 0.05 Torr) gives 22.5 g (67%) of the cyclopropanation product as colorless oil, whose analytical data are consistent with the ones described in WO 01/006853. Odour: citrus, green, cool, metal.

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Example 6: Distal-selective cyclopropanation of Geraniol: *E*-5-(2,2-Dimethyl-cyclopropyl)-3-methyl-pent-2-en-1-ol



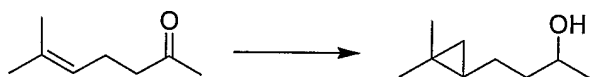
Prepared as described in example 3 from *E*-Geraniol (154 g, 1 mol), dibromomethane (1.4 l, 20 mol), neat TIBA (700 g, 3.5 mol) and anhydrous FeCl₃ (10 g, 60 mmol). Work-up after 7 h at 25°C gives 175 g of the crude cyclopropanation product (81% GC-purity) as yellowish oil, which is instable to distillation (H₂O elimination) and on prolonged standing. Odour: weak

- 5 Geraniol. ¹H-NMR (CDCl₃, 400 MHz): 5.4 (t, 1 H), 4.15 (d, 2 H), 2.1 (dd, 2 H), 1.7 (s, 1 H), 1.6 (s, 3 H), 1.4 (m, 2 H), 1.03 (s, 3 H), 1.02 (s, 3 H), 0.4 (1 H), 0.35 (dd, 1 H), -0.15 (dd, 1 H) ppm. ¹³C-NMR (CDCl₃, 400 MHz): 140.0 (s), 123.2 (d), 59.3 (t), 40.0 (t), 28.2 (t), 27.6 (q), 24.3 (d), 19.9 (q), 19.6 (t), 16.3 (q), 15.4 (s) ppm. GC/MS: 153 (2%, [M - 15]⁺), 150 (2%, [M - H₂O]⁺), 137 (18%), 107 (25%), 82 (45%), 67 (55%), 55 (100%).

10

Example 7:

Reduction / Cyclopropanation of 6-Methyl-hept-5-en-2-one: 4-(2,2-Dimethyl-cyclopropyl)-butan-2-ol.



- 15 FeCl₃ (0.5 g, 3 mmol) is added under stirring to 6-Methyl-hept-5-en-2-one (6.3 g, 50 mmol) in dibromomethane (70 ml, 1 mol) at 10° - 20°C, followed by slow addition of neat TIBA (38 ml, 0.15 mol) at this temperature. The mixture is stirred for 7 h at 25°C, then poured carefully on to 25% NaOH at -10° - 0°C. Work-up as described in example 1 and distillation (bp 50°C / 0.07 Torr) gives 4.8 g (67%) of a colorless oil (80% GC-purity, dr ~ 1:1). The analytical data
- 20 (NMR, MS, IR) are consistent with the ones described in the literature (Perraud, R; Arnaud, P. Bull. Chem. Soc. Chim. Fr. **1968**, 1540 - 1542).

Example 8:

Cyclopropanation of Isoleugenol: *trans*-2-Methoxy-4-(2-methyl-cyclopropyl)phenol



Prepared as described in example 3 from Isoeugenol (100 g, 0.61 mol), dibromomethane (850 ml, 12.2 mol), neat TIBA (422 g, 2.15 mol) and anhydrous FeCl₃ (6 g, 37 mmol). After 7 h at 25°C (conversion 44 : 56) the mixture is cooled to -10° - 0°C and pumped via double needle on to 2 M HCl cooled to -10° - 0°C. Under stirring (Caution !) the biphasic mixture is slowly
5 warmed to room temperature. The organic phase is separated and washed with 5% citric acid and water until pH = 7. Drying with MgSO₄, filtration and evaporation of the solvent, followed by distillation (bp 65°C / 0.03 Torr) gives 50.1 g (46%) of the cyclopropanation product as colorless oil (93% GC-purity). The analytical data (NMR, MS, IR, odour) are consistent with the ones described for this compound in EP 1 269 982.

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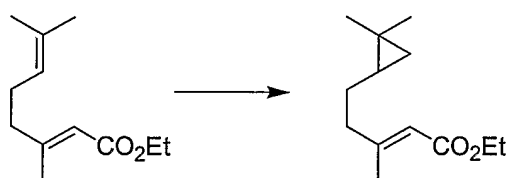
Example 9:

Cyclopropanation of Eugenol: 4-Cyclopropylmethyl-2-methoxy-phenol



Prepared as described in example 8 from Eugenol (50 g, 0.3 mol), dibromomethane (425 ml,
15 6.1 mol), neat TIBA (212 g, 1.06 mol) and anhydrous FeCl₃ (3 g, 18 mmol). The mixture is worked-up after 20 h at 25°C (57:43 conversion) as described in example 8. Distillation at 75°C / 0.03 Torr separates the substrate (bp 50°C, 0.03 Torr) from the cyclopropanation product (bp 75°C, 0.03 Torr) giving 21 g (41%) of the latter compound as colorless oil, whose analytical data (NMR, MS, IR, odour) are consistent with the ones described in EP 1 269 982 .

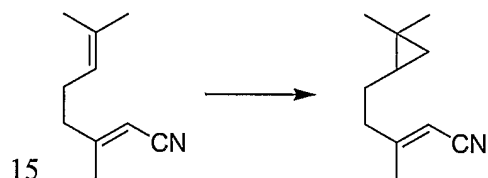
20

Example 10:Distal-selective cyclopropanation of Geranic acid ethyl ester: *E*-5-(2,2-Dimethyl-cyclopropyl)-3-methyl-pent-2-enoic acid ethyl ester

Prepared as described in example 7 from anhydrous FeCl_3 (0.1 g, 0.7 mmol), Geranic acid ethyl ester (2.2 g, 11 mmol), dibromomethane (31 ml, 0.44 mol) and neat TIBA (17 ml, 66 mmol). Work-up after 6 h at 25°C , as described in example 1, and Kugelrohr distillation (bp $92^\circ\text{C} / 0.2$ Torr) gives 1.2 g (52%) of a colorless oil. Odour: fruity, pear. $^1\text{H-NMR}$ (CDCl_3 , 400 MHz): 5.7 (s, 1 H), 4.15 (q, 2 H), 2.2 (t, 1 H), 2.18 (s, 3 H), 1.5 (1 H), 1.3 (t, 3 H), 1.1 (s, 3 H), 1.0 (s, 3 H), 0.9 (2 H), 0.45 (1 H), 0.4 (1 H), -0.1 (1 H) ppm. $^{13}\text{C-NMR}$ (CDCl_3 , 400 MHz): 166.7 (s), 160.1 (s), 115.4 (d), 59.2 (t), 41.4 (t), 28.0 (t), 27.4 (q), 24.1 (d), 19.8 (q), 19.6 (t), 18.7 (q), 15.4 (s), 14.2 (q) ppm. GC/MS: 210 (0.1%, M^+), 195 (4%, $[\text{M} - 15]^+$), 153 (10%), 136 (35%), 82 (45%), 55 (100%). IR (film): 2925 (m), 2869 (m), 1719 (s), 1648 (m), 1453 (m), 1366 (m), 1219 (m), 1147 (s), 1042 (m), 970 (w), 859 (w).

Example 11:

Cyclopropanation of *E/Z*-Geranitrile: *E/Z*-5-(2,2-dimethyl-cyclopropyl)-3-methyl-pent-2-enenitrile.

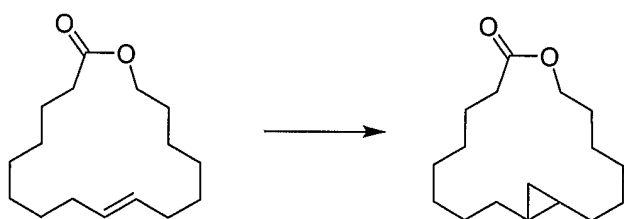


Prepared as described in example 7 but in 2 cycles from *E/Z*-Geranitrile (dr = 1:1) (77 g, 0.52 mol), dibromomethane (2 x 720 ml, 10.3 mol), neat TIBA (2 x 358 g, 1.8 mol) and anhydrous FeCl_3 (2 x 5 g, 30 mmol). Work-up after 17 h at 25°C (per cycle), as described in example 1, and distillation (bp $95^\circ\text{C} / 0.06$ Torr) (after the 2nd cycle) gives 50 g (59%) of the cyclopropanation product (71% GC-purity, 8% aldehyde, 11% alcohol, dr = 1:1) as colorless oil. $^1\text{H-NMR}$ (CDCl_3 , 400 MHz): 5.1 (1 H), 2.5 (m, 1 H), 2.25 (m, 1 H), 2.05 (s, 1.5 H), 1.9 (s, 1.5 H), 1.6 - 1.3 (2 H), 1.05 (6 H), 0.45 (2 H), -0.1 (1 H) ppm. $^{13}\text{C-NMR}$ (CDCl_3 , 400 MHz): 165.43 and 165.4 (2 s), 117.2 and 117.0 (2 s), 95.6 and 95.0 (2 d), 39.1 and 36.7 (2 t), 27.6 and 27.5 (2 t), 27.39 and 27.37 (2 q), 28.9 and 23.8 (2 d), 22.9 and 21.0 (2 q), 19.9 and 19.8 (2 q), 15.6 and 15.5 (2 s) ppm. GC/MS: 162 (20%), 148 (1%, $[\text{M} - 15]^+$), 94 (20%), 81 (55%), 55

(100%). IR (film): 2952 (s), 2867 (m), 2218 (w), 1676 (w), 1632 (w), 1454 (m), 1377 (m), 1365 (m), 1120 (w), 1020 (m), 866 (w), 801 (w). Odour: Hesperidic, powerful, fresh, geranitrile.

5 Example 12:

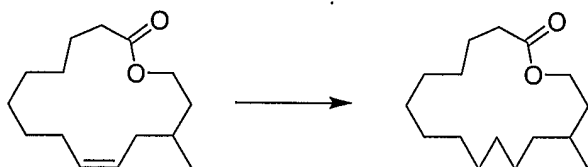
Cyclopropanation of *E*-Ambrettolide: *trans*-8-oxa-bicyclo[15.1.0]octadecan-9-one



Prepared as described in example 7 but in 2 cycles from *E*-Ambrettolide (20 g, 80 mmol),
 10 dibromomethane (2 x 110 ml, 1.6 mol), neat TIBA (2 x 47 g, 0.24 mol) and anhydrous FeCl₃ (2
 x 0.8 g, 5 mmol). Work-up after 6 h at 25°C (per cycle), as described in example 1, and
 distillation (bp 130°C / 0.04 Torr) (after the 2nd cycle) gives 6.6 g (30%) of the
 cyclopropanation product (97% GC-purity) as colorless oil. ¹H-NMR (CDCl₃, 400 MHz): 4.2
 (m, 1 H), 2.35 (m, 2 H), 1.85 (1 H), 1.7 -1.6 (5 H), 1.5 - 1.2 (14 H), 0.8 (m, 1 H), 0.55 (m, 1 H),
 15 0.45 (m, 1 H), 0.35 (1 H), 0.2 (2 H) ppm. ¹³C-NMR (CDCl₃, 400 MHz): 173.9 (s), 63.9 (t),
 34.8 (t), 33.9 (t), 33.5 (t), 29.8 (t), 29.5 (t), 29.5 (t), 29.1 (t), 28.6 (t), 28.31 (t), 28.29 (t), 26.4
 (t), 25.6 (t), 18.63 (d), 18.56 (d), 11.9 (t) ppm. GC/MS: 266 (1%, M⁺), 248 (1%, [M - 18]⁺),
 123 (10%), 109 (22%), 96 (50%), 82 (63%), 67 (75%), 55 (100%). IR (film): 2921 (s), 2851
 (m), 1733 (s), 1460 (m), 1347 (w), 1237 (m), 1161 (m), 1113 (w), 1057 (w), 1022 (w), 720
 20 (w).

Example 13:

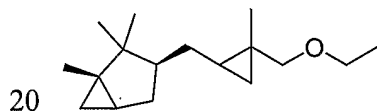
Cyclopropanation of NirvanolideTM: *cis*-3-Methyl-6-oxa-bicyclo[13.1.0]hexadecan-7-one.



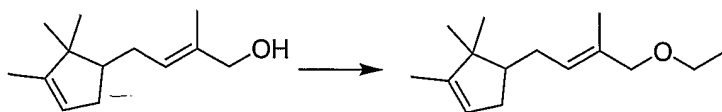
- 5 Prepared as described in example 7 from Nirvanolide (Frater, G.; Helmlinger, D.; Mueller, U. Givaudan-Roure (International) S.A., 1999, EP 908455) (20 g, 84 mmol), dibromomethane (235 ml, 3.35 mol), neat TIBA (100 g, 0.5 mol) and anhydrous FeCl₃ (0.8 g, 5 mmol). Work-up after 5 h at 25°C, as described in example 1, and distillation (bp 100°C / 0.03 Torr) gives 8 g (38%) of the cyclopropanation product as colorless oil. Odour: musky, metal, powdery. ¹H-
- 10 NMR (CDCl₃, 400 MHz): 4.2 (m, 2 H), 2.3 (m, 2 H), 1.7 (1 H), 1.7 - 1.2 (16 H), 1.0 (3 H), 0.8 (m, 1 H), 0.6 (m, 1 H), -0.3 (m, 1 H) ppm. ¹³C-NMR (CDCl₃, 400 MHz): 174.0 (s), 62.1 (t), 37.4 (t), 36.3 (t), 34.6 (t), 30.2 (d), 28.6 (t), 27.6 (t), 27.5 (t), 27.1 (t), 26.8 (t), 24.8 (t), 18.4 (q), 16.1 (d), 13.8 (d), 10.9 (t) ppm. GC/MS: 252 (1%, M⁺), 237 (1%, [M - 15]⁺), 223 (1%), 210 (1%), 195 (1%), 182 (1%), 109 (20%), 95 (35%), 81 (100%). IR (film): 2924 (m), 2855 (m),
- 15 1731 (s), 1458 (m), 1378 (w), 1337 (w), 1248 (m), 1151 (m), 1120 (w), 1091 (w), 1060 (m), 1021 (w), 965 (w), 848 (w).

Example 14:

trans-3-(2-Ethoxymethyl-2-methyl-cyclopropylmethyl)-1,2,2-trimethyl-bicyclo-[3.1.0]hexane.



(i) Preparation of the precursor: *E*-4-(4-Ethoxy-3-methyl-but-2-enyl)-1,5,5-trimethyl-cyclopentene:



25

A solution of Nor-Radjanol (Bajgrowicz, J. A.; Frank, I.; Frater, G.; Hennig, M. *Helv. Chim. Acta* 1998, 81, 1349 - 1358) (60 g, 0.3 mol) and ethyl iodide (73 ml, 0.47 mol) in non-

aqueous tetrahydrofuran (400 ml) is cooled to -50°C , where 50% NaH (20 g, 0.42 mol) is added in one portion. The stirred mixture is slowly warmed up to 25°C and is kept at this temperature under cooling until the exothermy ceases. After dilution with methyl *tert*-butyl ether, water is added carefully. The organic phase is separated, washed with water until pH = 7
 5 and dried over MgSO_4 . Filtration and evaporation of the solvent under reduced pressure gives 76 g of a residue, which is distilled (bp $65^{\circ}\text{C} / 0.03$ Torr) giving 61 g (89%) of a colorless oil. Odour: earthy, agrestic, green. $^1\text{H-NMR}$ (CDCl_3 , 400 MHz): 5.4 (t, 1 H), 5.2 (s, 1 H), 3.85 (s, 1 H), 3.4 (q, 2 H), 2.3 (m, 1 H), 2.2 (m, 1 H), 2 (m, 1 H), 1.8 (2 H), 1.65 (s, 3 H), 1.6 (s, 3 H), 1.2 (t, 3 H), 1.0 (s, 3 H), 0.8 (s, 3 H) ppm. $^{13}\text{C-NMR}$ (CDCl_3 , 400 MHz): 148.4 (s), 132.2 (s),
 10 127.5 (d), 121.6 (d), 76.7 (t), 64.6 (t), 50.2 (d), 46.6 (s), 35.5 (t), 28.1 (t), 25.7 (q), 19.6 (q), 15.1 (q), 13.8 (q), 12.5 (q) ppm. GC/MS: 222 (5%, M^+), 207 (8%, $[\text{M} - 15]^+$), 176 (40%, $[\text{M} - \text{EtOH}]^+$), 161 (100%), 121 (65%), 108 (100%), 93 (95%). IR (film): 2955 (m), 2865 (m), 1444 (m), 1381 (m), 1359 (m), 1090 (s), 1011 (m), 861 (w), 799 (m).

15 (ii) Cyclopropanation of *E*-4-(4-Ethoxy-3-methyl-but-2-enyl)-1,5,5-trimethyl-cyclopentene:
trans-3-(2-Ethoxymethyl-2-methyl-cyclopropylmethyl)-1,2,2-trimethyl-bicyclo-[3.1.0]hexane.



Prepared as described in example 7 from *E*-4-(4-ethoxy-3-methyl-but-2-enyl)-1,5,5-trimethyl-
 20 cyclopentene (1.56 g, 7 mmol), dibromomethane (28 ml, 0.4 mol), neat TIBA (15 ml, 60 mmol) and anhydrous FeCl_3 (0.2 g, 1.2 mmol). Work-up after 1.5 h at 25°C , as described in example 1, and Kugelrohr distillation (bp $100^{\circ}\text{C} / 0.07$ Torr) gives 0.9 g (52%) of the bis-cyclopropanation product as colorless oil (dr = 1:1). $^1\text{H-NMR}$ (CDCl_3 , 400 MHz): 3.45 (q, 2 H), 3.2 - 3.1 (m, 2 H), 1.85 (m, 1 H), 1.6 - 0.8 (6 H), 1.2 (t, 3 H), 1.1 (2s, 3 H), 1.02 (s, 3 H),
 25 0.85 (s, 3 H), 0.75 (2s, 3 H), 0.5 - 0.45 (3 H), $-0.1 - 0.0$ (2 H) ppm. $^{13}\text{C-NMR}$ (CDCl_3 , 400 MHz): 79.93 and 79.90 (2 t), 65.8 and 65.8 (2 t), 45.1 and 44.7 (2 d), 41.4 and 41.1 (2 d), 32.5 and 32.4 (2 t), 31.4 and 31.2 (2 s), 29.6 and 28.9 (2 t), 22.9 and 22.8 (2 s), 22.7 and 22.6 (2 d), 21.3 and 21.1 (2 d), 20.3 (s), 19.7 and 19.6 (2 q), 19.6 (q), 19.1 (s), 17.41 and 17.38 (2 q), 16.0 (2 q), 15.5 (2 q), 15.19 and 15.17 (2 q), 13.92-and-13.88 (2 t) ppm. GC/MS: 250 (1%, M^+),
 30 235 (2%, $[\text{M} - 15]^+$), 204 (4%, $[\text{M} - \text{EtOH}]^+$), 189 (12%), 149 (30%), 121 (60%), 107 (80%), 86 (100%). IR (film): 2952 (m), 2927 (m), 2856 (m), 1451 (m), 1378 (m), 1362 (m), 1297 (m), 1105 (s), 1014 (m), 872 (w), 838 (w).

Example 15:Cyclopropanation of Z-Cyclododecene: *cis*-Bicyclo[10.1.0]tridecane

Prepared as described in example 7 from Z-Cyclododecene (E/Z = 3:1) (1.66 g, 10 mmol),
 5 dibromomethane (14 ml, 0.2 mol), neat TIBA (7.5 ml, 30 mmol) and anhydrous FeCl₃ (0.1 g,
 0.6 mmol). Work-up after 2 h at 25°C, as described in example 1, and Kugelrohr distillation
 (bp. 60°C / 0.07 Torr) gives 1.5 g (83%) of the cyclopropanation product as colorless oil
 (cis/trans = 3:1), whose analytical data (NMR, MS) are consistent with the ones described in
 the literature (O'Connor, E. J.; Brandt, S.; Helquist, P.; *J. Am. Chem. Soc.* **1987**, *109*, 3739 -
 10 3747).

Example 16:

[CpFe(CO)₂]₂-catalyzed cyclopropanation of Nor-Radjanol: *trans*-2-methyl-4-(1,2,2-trimethyl-
 bicyclo-[3.1.0]hex-3-yl)but-2-en-1-ol.

15

Prepared, as described in example 3, from Nor-Radjanol (1.94 g, 10 mmol), dibromomethane
 (14 ml, 0.2 mol), neat TIBA (8.8 ml, 35 mmol), and with cyclopentadienyliron dicarbonyl
 dimer [CpFe(CO)₂]₂ (100 mg, 0.3 mmol) in place of the FeCl₃ of that example. Work-up after
 3 h at 25°C, Silicagel filtration and bulb-to-bulb distillation gives 1.9 g (91%) of a colorless oil
 20 (85% GC-purity), whose analytical data are consistent with the ones described for the same
 product obtained from example 3.

Example 17:

CpTiCl₃-catalyzed cyclopropanation of Nor-Radjanol: *trans*-2-methyl-4-(1,2,2-trimethyl-
 25 bicyclo-[3.1.0]hex-3-yl)but-2-en-1-ol.

Prepared, as described in example 3, from Nor-Radjanol (1.94 g, 10 mmol), dibromomethane
 (14 ml, 0.2 mol), neat TIBA (8.8 ml, 35 mmol), and with cyclopentadienyltitanium trichloride
 CpTiCl₃ (100 mg, 0.3 mmol) in place of the FeCl₃ of that example. Work-up after 3 h at 25°C
 30 and bulb-to-bulb distillation gives 1.8 g (85%) of a colorless oil (77% GC-purity), whose
 analytical data are consistent with the ones described for the same product obtained from
 example 3.

Claims:

1. A process for the cyclopropanation of a substituted alkene, comprising the reaction of the alkene with a carbenoide, generated from dibromomethane and a tri-(C₂ - C₈)-alkyl aluminium compound in the presence of a catalytic amount of a metal compound selected from the group consisting of Lewis acids other than tri-(C₂ - C₈)-alkyl aluminium compounds, metallocenes and metal carbonyl complexes.
5
2. A process according to claim 1, in which the tri-(C₂ - C₈)-alkyl aluminium is triisobutyl aluminium.
10
3. A process according to claim 1, in which there is used from 1 - 5 molar equivalents, preferably 2.5 - 3.5 equivalents, of tri-(C₂ - C₈)-alkyl aluminium reagent.
- 15 4. A process according to claim 1, in which there is used from 5 - 100 molar equivalents, more preferably 25 - 35 equivalents, of dibromomethane.
5. A process according to claim 1, in which the metal compound is a Lewis acid selected from the group consisting of copper and iron halides, preferably FeCl₂ and FeCl₃.
20
6. A process according to claim 1, in which the metal compound is a metallocene containing at least one cyclopentadienyl-ligand.
7. A process according to claim 1 in which the metal compound is used at a concentration of 0.01 - 30%, preferably 1 - 10%, with respect to the alkene to be cyclopropanated.
25
8. A process according to claim 5, in which 10 - 20 molar equivalents of dibromomethane is used.
- 30 9. A process according to claim 1 in which excess dibromomethane is recovered for further use.
10. A process according to claim 9, in which the recovery is carried out by the steps of:

- (i) adding the reaction mixture to aqueous base at a temperature from -10° - 0°C ;
 - (ii) warming slowly the resulting two-phase mixture to room temperature;
 - (iii) separating the phases;
- 5 (iv) adding isopropanol to the organic phase; and
- (v) drying azeotropically and evaporating the dibromomethane under reduced pressure.
11. Manufacture of a flavour or fragrance ingredient, comprising the cyclopropanation of
- 10 an alkene by a process according to claim 1.

INTERNATIONAL SEARCH REPORT

International application No
PCT/CH2005/000763

A. CLASSIFICATION OF SUBJECT MATTER
 C07C29/32 C07C41/30 C07C253/30 C07D313/00 C07C43/115
 C07C43/162 C07C2/42 C07C67/347

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
 Minimum documentation searched (classification system followed by classification symbols)
 C07C C07D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
 EPO-Internal, CHEM ABS Data, BEILSTEIN Data, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KEJI MARUOKA ET AL.: "Trialkylaluminium-Alkylidene Iodide. A Powerful Cyclopropanation Agent with Unique Selectivity" J. ORG. CHEM., vol. 50, 1985, pages 4412-4414, XP002369364 the whole document	1, 11
A	EDWIN C. FRIEDRICH: "Regioselectivity and Solvent Effects in Cyclopropanation of Alkadienes" J. ORG. CHEM., vol. 56, 1991, pages 2202-2205, XP002369365 cited in the application column 2, paragraph 2	1, 11

Further documents are listed in the continuation of Box C.

See patent family annex.

- * Special categories of cited documents :
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 - *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
 - *O* document referring to an oral disclosure, use, exhibition or other means
 - *P* document published prior to the international filing date but later than the priority date claimed
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 - *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
 - *Z* document member of the same patent family

Date of the actual completion of the international search 23 February 2006	Date of mailing of the international search report 13/03/2006
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Diederens, J
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INTERNATIONAL SEARCH REPORT

International application No

PCT/CH2005/000763

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 801 049 A (GIVAUDAN-ROURE S.A; GIVAUDAN SA) 15 October 1997 (1997-10-15) cited in the application page 5, line 59 - page 6, column 2 -----	1,11

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/CH2005/000763

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0801049	A	EP 1008579 A2	14-06-2000