269. Aspects of the Reduction of Double Bonds Using Cob(I)alamin as Catalyst[1])

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Dedicated to Prof. Dr. *A. Hürlimann* on the occasion of his 60th birthday

(14.X.82)

Summary

The olefinic system in 3β-methoxy-4-cholesten-6α-ol (**2**) is reduced using cob(I)alamin (**1(I)**; see *Scheme 1*) as catalyst, aqueous acetic acid as solvent and metallic zinc as electron source (*cf. Schemes 2* and *3*). Experimental evidence for an attack of **1(I)** on both faces of the double bond is presented. By the same catalyst (1*R*)-10,10-dimethyl-2-pinene-10-carbonitrile (**9**) is first transformed to the menthene derivative **11** (see *Schemes 4* and *5*). The ring opening is then followed by a fast saturation of the disubstituted olefinic system in **11**, and ultimately the remaining double bond is reduced in a slow reaction. The *cis*-configurated saturated menthane derivative **16** is the main final product (**16/17** $\approx$ 10:1).

1. Introduction. – The accessibility of alkylcobalamins from isolated olefins and cob(I)alamin (**1(I)**; see *Scheme 1*) under acidic conditions has been published [1] [2]. The attack of cob(I)alamin (**1(I)**) and a proton on a non-activated double bond has been shown to follow '*Markownikoff*'s' rule leading to a tertiary alkylcobalamin starting from a trisubstituted olefinic system [2b]. The reductive cleavage[2]) of the Co, C-bond in an alkylcobalamin has been studied [1] [2b] [2c] [3], and experimental evidence for a pathway following retention of configuration has been presented [2c] [3b].

2. Reduction of 3β-methoxy-4-cholesten-6α-ol (*2*). – The attempt to reduce the olefinic function in 3β-methoxy-4-cholesten-6α-ol (**2**) using catalytic amounts of cob(I)alamin (**1(I)**) in aqueous acetic acid led, after transesterification with sodium ethoxide in ethanol, to a mixture of the starting material and the four products **3**–**6** (see *Scheme 2*). The transformation revealed to be slow requiring 93 h under the conditions applied for the conversion of about 40% of the starting material **2**. Prior to chromatographic separation of the crude product mixture, the corresponding

[1]) 10th Communication in the series Cob(I)alamin as Catalyst; for the 9th communication see [1].

[2]) Compare *Scheme 2* in [1].

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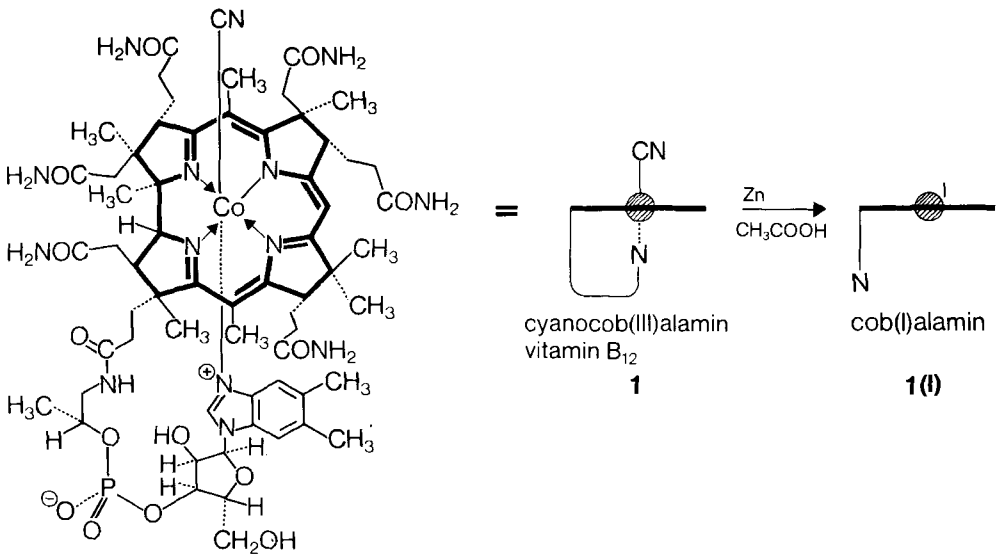
Scheme 1



acetates, also formed under these conditions, have been transformed to the appropriate alcohols by transesterification. After separation, the starting material **2** showed to be present in 64% yield together with the ketone **4** (13%) and the two epimeric alcohols **3** (2.5%) and **5** (4.5%). In addition 4-cholesten-3α,6α-diol (**6**; 5%) could be isolated. This derivative was also detected in a corresponding blank experiment without cobalamin as single product (15%) revealing the generation of **3**–**5** by cob(I)alamin (**1(I)**) in the catalyzed transformation.

From the two intermediate tertiary alkylcobalamins[3]) **7** and **8** (see *Scheme 3*), accessible after the normal [2b] [2c] *'Markownikoff'* attack at the Δ^4-double bond, the formation of the three products **3**–**5** can be explained. A reductive cleavage[4]) of the Co, C-bond, which has been shown to follow retention of configuration [2c] [3b], leads to **3** from **7** and to **5** from **8**. The ketone **4** can be generated from both intermediates **7** and **8** by electrofugal fission of the Co, C-bond[2]) [2b] leading to the corresponding intermediate enol[5]). It is interesting to recognize that the bulky cobalamin attacks on both faces of the Δ^4-double bond. This might be due to the long Co, C-bond[6]) diminishing the steric interactions between the cobalamin and the carbon framework of the steroid.

3. Reduction of (1*R*)-10,10-dimethyl-2-pinene-10-carbonitrile (*9*). – The saturation of the trisubstituted double bond in the pinene derivative **9** led, after 72 h at room temperature, to a mixture containing 5.5% of the starting material, 80% of

[3]) The equilibrium of alkylcobalamins in solution is indicated by the lateral arrows. See footnote 2 in [1].

[4]) Compare *Scheme 2* in [1], and [2c].

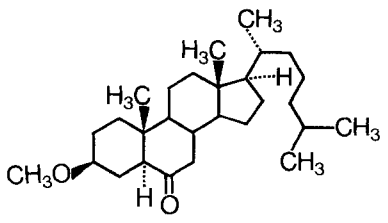
[5]) Not shown in *Scheme 3*.

[6]) In coenzyme B_{12} this bond amounts to 2.05 Å [4].

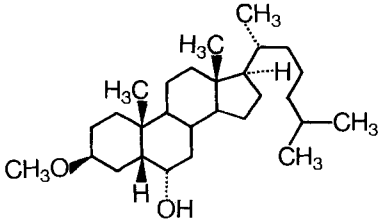
Scheme 2

with
without
generated by
cobalamin
64%
71%
–
2.5%
–
2.5%
cat.
Zn (20 Mol-equiv.)
CH_3COOH-H_2O
RT, 93h
dark, Ar
after extraction and
$NaOC_2H_5$/
C_2H_5OH
treatment
2
2
3

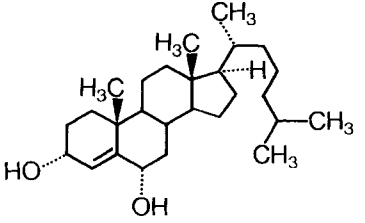
Scheme 2 (continued)



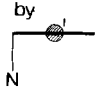
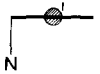
4



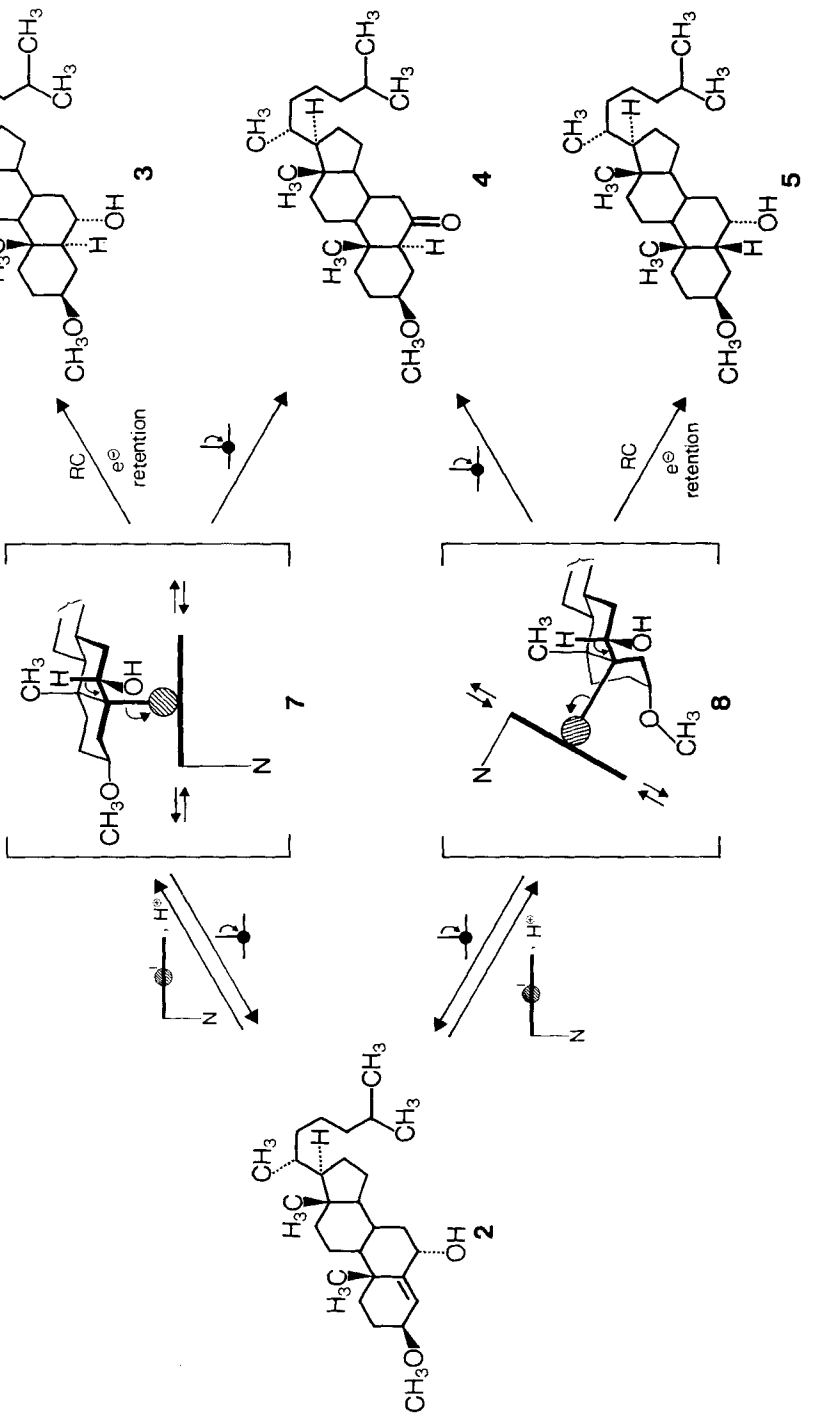
5



6

with	without	generated by 
	cobalamin	
13%	–	13%
4.5%	–	4.5%
5%	15%	–
89%	86%	

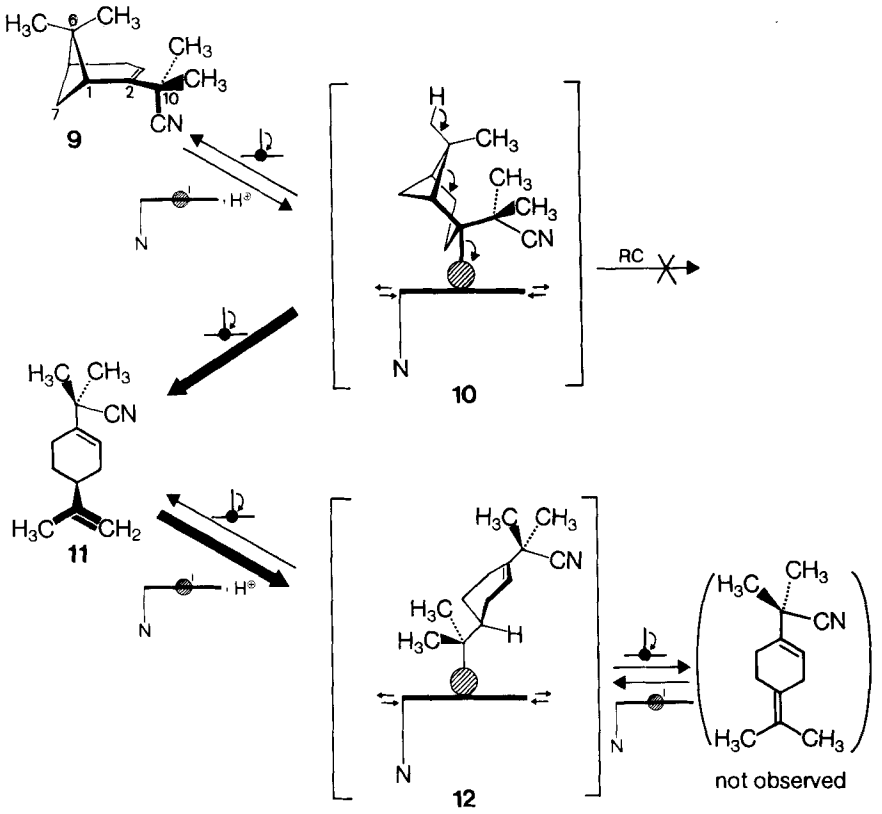
Scheme 3



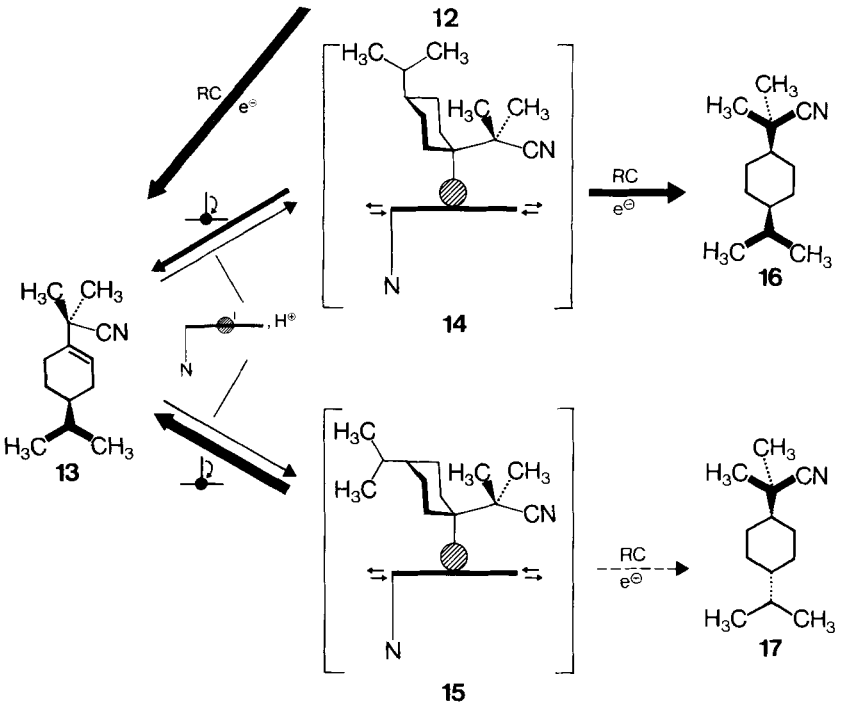
the menthene derivative **13** and 10.5% of the *cis*-configurated saturated nitrile **16**[7]) (see *Schemes 4* and *5*). The unsaturated nitrile **13** was optically active. After three additional reductions (see *Scheme 5*), the product mixture contained 31% of **13**, 57.5% of **16** and 6% of saturated *trans*-derivative **17**.

Once again the trisubstituted olefinic system in **9** is attacked by **1(I)** leading slowly to the intermediate alkylcobalamin **10** (see *Scheme 4*) from which the monocyclic intermediate **11** becomes accessible after nucleofugal fragmentation[2]). No saturated pinane derivatives have been detected illustrating a rapid fragmentation of **10** and the absence of a reductive cleavage of the Co, C-bond in the same intermediate alkylcobalamin. In the cascade of additional reductions the intermediate **11** has never been detected. It is assumed that a new and rapid attack of cob(I)alamin (**1(I)**) on the disubstituted double bond of **11** generates the alkylcobalamin **12** producing the monounsaturated **13** after reductive cleavage. The fact that, after the first re-

Scheme 4



[7]) A similar reduction starting from 2-(4-*t*-butyl-1-cyclohexenyl)-2-methylpropanenitril led to a 13:1 mixture of the two corresponding saturated products. In the X-ray analysis a derivative from the major product showed *cis*-substitution at the cyclohexane ring. Full experimental data will be published in a subsequent paper.

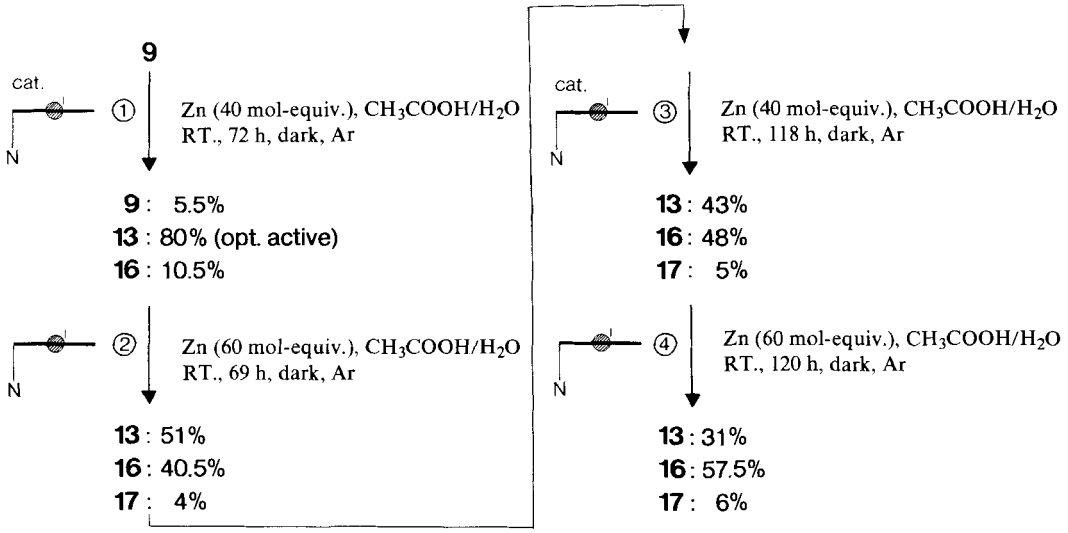


duction, **13** has been isolated as an optically active compound is an indication for rapid formation of **12** and for a distinctly slower attack of **1(I)** at the trisubstituted double bond in **11**. Interestingly the product showing a totally substituted olefin, theoretically accessible from **12** after nucleofugal fission, has never been observed. The tertiary alkylcobalamin **12**, in contrast to the sterically more hindered alkylcobalamin **10**, seems to be more stable and less prone to decay by a nucleofugal pathway. As both faces of the remaining double bond in **13** are accessible to **1(I)**, two additional alkylcobalamins **14** and **15** can be generated under the conditions applied. A nucleofugal fission from these intermediates leads back to **13** allowing the establishment of an equilibrium between these two stereoisomers **14** and **15** (*cf.* [2b]).

Cobalamin is considered to be sterically more demanding in comparison to the 1-cyano-1-methylethyl substituent also bound to the same C-atom in **14**. In this intermediate the cyclohexane ring adopts a conformation displaying the two 'large'[8]) substituents both in an equatorial arrangement. In the epimer **15** at least one of the two 'large' substituents occupies an axial position. Therefore **14** should be favored in the equilibrium between **14** and **15** leading to the *cis*-substituted saturated system **16** as major product after retentive reductive cleavage. Experimental data endorsing this view have been obtained. The relation of the *cis*-configurated saturated nitrile **16** to the corresponding *trans*-stereoisomer **17** showed to be 10:1.

[8]) Cobalamin and isopropyl.

Scheme 5



4. Kinetic aspects of the reduction of olefins. – Comparing kinetic aspects of the reduction of several isolated double bonds using **1(I)** as catalyst in the presence of acetic acid, the following data can be discussed (see *Scheme 6*). The reduction of 10-undecenyl acetate (**18**) showed to be completed after 15 h using **1(I)** as catalyst, glacial acetic acid as solvent and metallic zinc as electron source [1]. From the experimental work presented in *Chapt. 3*, evidence is emerging that in **11** the disubstituted and sterically more accessible olefinic system is preferentially reduced.

The trisubstituted double bond in **19** is saturated in a slow reaction (52 h) generating *cis*- (**20**) and *trans-p*-menthane (**21**) in a ratio of about 5:2 [2b]. As in the case discussed above, the catalyst attacks both faces of the double bond generating the two alkylcobalamins **22** and **23**. Reductive cleavage with retention of the configuration from the more stable intermediate **22** showing the two 'large'[8]) substituents in equatorial positions requires the formation of *cis-p*-menthane (**20**). In the experiment, data paralleling this view have been obtained.

In the cyclohexene derivative **13** the sterically protected double bond is slowly saturated (to 63.5% after 379 h) despite the presence of large amounts of cobalamin (0.5–1.0 mol-equiv.). The *cis*-configurated derivative **16** again shows to be the major product as discussed in *Chapt. 3*. The steric bulk of the substituents protecting the olefinic system in the starting material **13** is not only influencing the rate of the saturation of the double bond but also the ratio between the two saturated products (**16/17** $\approx$ 10:1).

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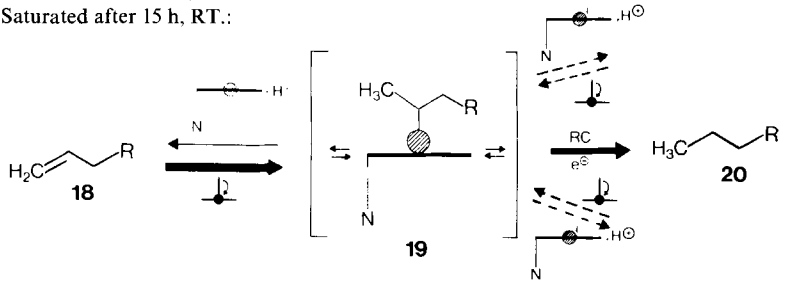
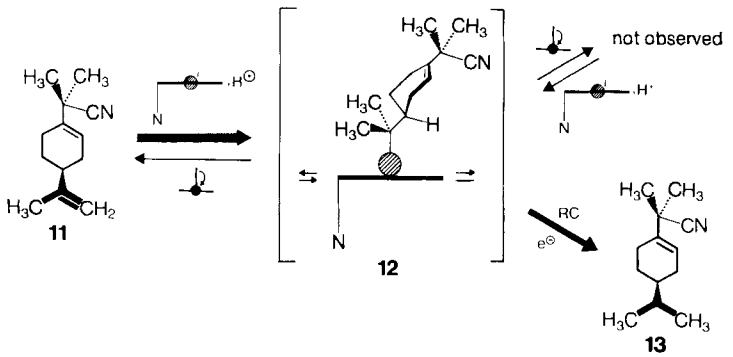
Scheme 6

a) Saturated after 15 h, RT.:

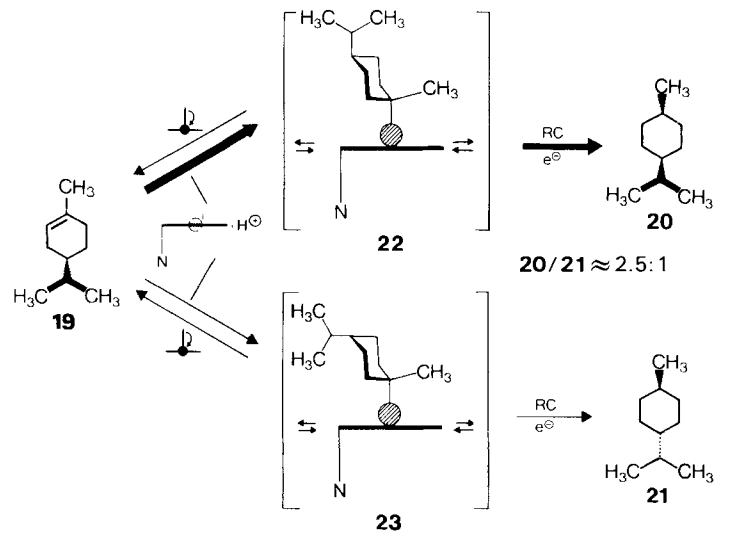


R: $(CH_2)_8OOCCH_3$

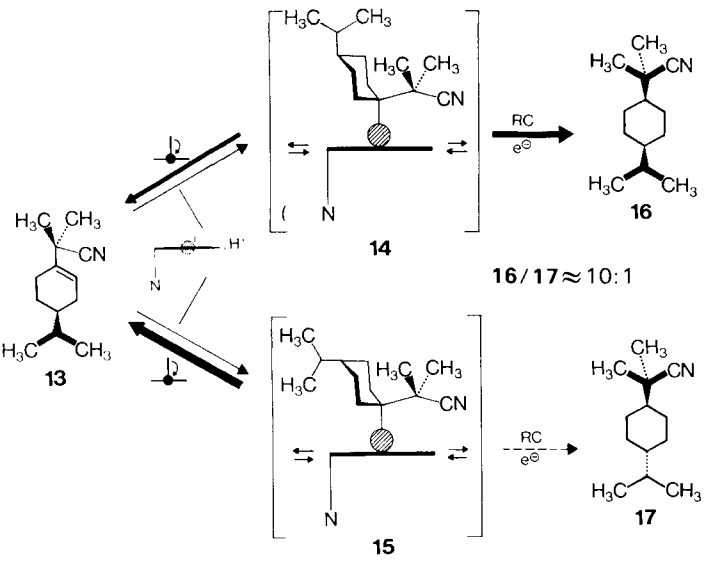
b) Preferential saturation of the disubstituted double bond:



c) Saturated after 52 h, RT.:



d) Saturated to 63.5% after 379 h, RT.:



Experimental Part

(collaborators: *D. Süss* and *R. Unger*)

General remarks. S. [2b] [5]. The procedure followed during a 'usual' or 'normal' extraction is described in [2b]. The catalyst was prepared as described in [1].

Synthesis of 3β-methoxy-4-cholesten-6α-ol (**2**). From 3β-methoxy-4-cholestene the 3β-methoxy-4-cholesten-6-one was obtained in analogy to the procedure leading to 3β-acetoxy-4-cholesten-6-one, see [6] [7]. Subsequent $LiAlH_4$ reduction gave **2**, m.p. 123–124° (ether/hexane), Rf 0.01 (ether/hexane 1:1), t_R (GC., 200→300°) 15.0 min, $[\alpha]_{589}^{RT} = +0.296°$ ($c = 0.01$ g/ml, C_2H_5OH). – IR. (KBr): 3470 (OH); 1662 (C=C); 1098, 1070 (C–O–C, C–O (alcohol)). – ^{1}H-NMR.: 0.68 (*s*, 3 H, $H_3C(18)$); 0.7–2.2 (*m*, 36 H, CH_3, CH_2, CH, OH); 1.07 (*s*, 3 H, $H_3C(19)$); 3.39 (*s*, 3 H, CH_3O); 3.6–3.95 (*m*, 1 H, H_α–C(3)); 3.95–4.35 (*m*, 1 H, H_β–C(6)); 5.65–5.78 (*m*, 1 H, H–C(4)). – MS.: 416 (13, M^+), 398 (56, $M^+ - H_2O$), 384 (71, $M^+ - CH_3OH$), 369 (67, $M^+ - CH_3 - CH_3OH$), 366 (54, $M^+ - CH_3OH - H_2O$), 355 (29), 331 (23), 247 (31), 135 (71), 95 (92), 81 (73), 55 (79), 43 (100).

Reduction of 3β-methoxy-4-cholesten-6α-ol (**2**). Following the procedure described earlier [1], 2.5 g (0.4 mol-equiv.) of cyanocob(III)alamin (**1**) was transformed into the catalyst using 6.3 g (20 mol-equiv.) of activated zinc[9]). Prior to the complete elimination of acetic acid, the metallic zinc was removed by filtration, and the red filtrate was evaporated to dryness at 50°. The residue was dissolved in 21 ml of aq. acetic acid (CH_3COOH/H_2O 20:1) and 6.3 g of activated metallic zinc[9]) was added to the red solution. The suspension was stirred at r.t. under Ar until[10]) a dark green colour revealed the presence of cob(I)alamin (**1(I)**). To the suspension of the soluble catalyst and the electron source was added 2 g of **2** dissolved in 79 ml of acetic acid/water 20:1[11]). The mixture was stirred in the dark at r.t. under Ar for 93 h. After addition of water and filtration, the mixture was extracted with CH_2Cl_2, the org. layer neutralized with aq. $NaHCO_3$-solution and dried with

[9]) For the procedure used to activate zinc, see [5].

[10]) To obtain the green color of **1(I)**, a period of 5 to 10 min was usually required.

[11]) Due to the access of air after opening of the flask, the color turned back to red.

$MgSO_4$. After evaporation of the solvent, the residue (2 g) was dissolved in 50 ml of alcohol, and 10 ml of a 0.25 M solution of C_2H_5ONa in ethanol was added. The solution was stirred at r.t. under N_2 for 21 h then water was added, and the products of the transesterification were extracted with CH_2Cl_2. After drying and evaporation of the solvents, the crude mixture (1.95 g) was separated by chromatography (SiO_2, ether/hexane mixtures and ethyl acetate): 1280 mg (64%) of **2**, 49 mg (2.5%) of **3**, 264 mg (13%) of **4**, 89 mg (4.5%) of **5** and 93 mg (5%) of **6**.

Data of 3β-methoxy-5α-cholestan-6α-ol (**3**). Rf 0.14 (ether/hexane 1:1). – IR. (KBr): 3502 (OH); 1650 (C=C); 1101, 1088, 1049 (C–O–C, C–O). – ^{1}H-NMR.: 0.65 (*s*, 3 H, $H_3C(18)$); 0.6–2.5 (*m*, 39 H, CH_3, CH_2, CH, OH); 0.82 (*s*, 3 H, $H_3C(19)$); 3.0–3.35 (*m*, 1 H, H_β–C(6)); 3.35–3.6 (*m*, 1 H, H_α–C(3)); 3.36 (*s*, 3 H, CH_3O). – MS.: 418 (26, M^+), 400 (36, $M^+ - H_2O$), 368 (17, $M^+ - H_2O - CH_3OH$), 353 (22, $M^+ - H_2O - CH_3OH - CH_3$), 263 (14), 246 (24), 231 (28), 213 (26), 155 (29), 123 (41), 95 (100), 81 (33), 55 (36), 43 (31).

Data of 3β-methoxy-5α-cholestan-6-one (**4**). M.p. 89–91° (ether/hexane), Rf 0.26 (ether/hexane 1:1), t_R (GC., 200→300°) 18.2 min, $[\alpha]_{589}^{RT} = -0.17$ ($c = 0.01$ g/ml, C_2H_5OH). – IR. (KBr): 1712 (C=O); 1385, 1373 (CH_3); 1106 (C–O–C). – ^{1}H-NMR.: 0.68 (*s*, 3 H, $H_3C(18)$); 0.6–2.5 (*m*, 38 H, CH_3, CH_2, CH); 0.77 (*s*, 3 H, $H_3C(19)$); 2.85–3.35 (*m*, 1 H, H_α–C(3)); 3.35 (*s*, 3 H, CH_3O). – MS.: 416 (85, M^+), 387 (100), 384 (28, $M^+ - CH_3OH$), 369 (17), 331 (20), 261 (30), 247 (35), 123 (90).

Data of 3β-methoxy-5β-cholestan-6α-ol (**5**). Rf 0.21 (ether/hexane 1:1). – IR. (KBr): 3520 (OH); 1383, 1375, 1367 (CH_3); 1096, 1088, 1051 (C–O–C, C–O of alcohol). – ^{1}H-NMR.: 0.7 (*s*, 3 H, $H_3C(18)$); 0.7–2.15 (*m*, 39 H, CH_3, CH_2, CH, OH); 1.02 (*s*, 3 H, $H_3C(19)$); 3.0–3.3 (*m*, 1 H, H_β–C(6)); 3.35 (*s*, 3 H, CH_3O); 3.7–3.9 (*m*, 1 H, H_α–C(3)). – MS.: 418 (4, M^+), 400 (100, $M^+ - H_2O$), 385 (6, $M^+ - H_2O - CH_3$), 368 (17, $M^+ - H_2O - CH_3OH$), 353 (11, $M^+ - H_2O - CH_3OH - CH_3$), 260 (23), 246 (35), 228 (23), 213 (27), 147 (29), 95 (95), 81 (36), 55 (43), 43 (39).

Data of 4-cholestene-3α,6α-diol (**6**). Rf 0.05 (ether/hexane 1:1). – IR. (KBr): 3320 (OH); 1739 (C=C); 1130, 1072, 1040 (C–O of alcohol). – ^{1}H-NMR.: 0.7 (*s*, 3 H, $H_3C(18)$); 0.6–2.3 (*m*, 35 H, CH_3, CH_2, CH); 1.02 (*s*, 3 H, $H_3C(19)$); 2.48–2.75 (*m*, 2 H, 2 HO); 3.95–4.4 (*m*, 2 H, H_β–C(3) and H_β–C(6)); 5.55–5.75 (*m*, 1 H, H–C(4)). – MS.: 384 (100, $M^+ - H_2O$), 369 (82, $M^+ - H_2O - CH_3$), 355 (48), 331 (36), 135 (21), 95 (57).

A corresponding blank experiment without cobalamin led, after chromatography, to 1420 mg (71%) of **2** and 287 mg (15%) of **6**.

Synthesis of (1R)-10,10-dimethyl-2-pinene-10-carbonitrile (**9**). Starting from (–)-myrtenol (=(1*R*)-2-pinene-10-ol) using CCl_4/PPh_3 in CH_3CN and subsequently a phase-transfer-catalyzed S_N2 displacement reaction with NaCN (benzene/H_2O–NaCN/$(C_4H_9)_4N^+OH^-$), the (*E*/*Z*, 1*R*)-2(10)-pinene-10-carbonitrile was prepared. From this intermediate the target compound **9** was obtained using an excess of lithium diisopropylamide in THF and adding an appropriate excess of methyl iodide, Rf 0.50 (ether/hexane 1:5), t_R (GC., 100→260°) 6.7 min, $[\alpha]_{589}^{RT} = -0.362$ ($c = 0.01$ g/ml, $CHCl_3$). – IR. (liq.): 2232 (CN); 1650 (C=C); 1386, 1366 ($(CH_3)_2C$); 812 (C=CH). – ^{1}H-NMR.: 0.82 (*s*, 3 H, H_3C_{endo}–C(6)); 1.16 (*d*, $J = 8.5$, 1 H, H_{syn}–C(7)[12]); 1.34 (*s*, 3 H, H_3C_{exo}–C(6)); 1.40 (*s*, 6 H, 2 H_3C–C(10)); 1.5–2.7 (*m*, 5 H, CH_2, 3 CH); 5.55–5.8 (*m*, 1 H, H–C(3)). – ^{13}C-NMR.: 21.10, 25.12, 25.36, 26.17 (4 *qa*, 4 CH_3); 31.77, 31.15 (2 *t*, 2 CH_2); 37.00, 37.92 (2 *s*, C(6), C(10)); 40.69, 43.06 (2 *d*, C(1), C(5)); 117.44 (*d*, C(3)); 123.77 (*s*, CN); 146.67 (*s*, C(2)). – MS.: 189 (4, M^+), 174 (6, $M^+ - CH_3$), 145 (27), 130 (37), 79 (100), 68 (69).

Reduction of (1R)-10,10-dimethyl-2-pinene-10-carbonitrile (**9**). Following the procedure described earlier, 1.43 g (0.1 mol-equiv.) of **1** was transformed into the catalyst using 27.6 g (40 mol-equiv.) of activated zinc[9]. Prior to the complete elimination of acetic acid, the metallic zinc was removed by filtration, and the red filtrate was evaporated to dryness at 50°. The residue was dissolved in 120 ml of aq. acetic acid (CH_3COOH/H_2O 20:1) and 27.6 g of activated metallic zinc[9]) was added to the red solution. The suspension was stirred at r.t. under Ar until[10]) a dark green colour revealed the presence of **1(I)**. To the suspension of the soluble catalyst and the electron source was added 2.0 g of **9** dissolved in 20 ml of acetic acid/water 20:1. The mixture was stirred in the dark at r.t. under Ar for 72 h. After usual extraction, the crude mixture was purified by chromatography (SiO_2 toluene/hexane 1:2, 1.94 g (97%) after chromatography). A separation of the products was obtained using prep. GC. yielding 5.5% of **9**, 80% of **13** and 10.5% of **16**.

[12]) The terms *syn* and *anti* refer to the position of the substituents on the bridge with respect to the longer branch of the main ring.

*Data of 7,7-dimethyl-1-*p*-menthene-7-carbonitrile* (**13**). Rf 0.21 (toluene/hexane 1:1), t_R (GC., 100→280°) 9.14 min, $[\alpha]_{589}^{RT} = -0.13$ ($c = 0.01$ g/ml, C_2H_5OH). – IR. (liq.): 2236 (CN); 1390, 1370 ($(CH_3)_2C$). – ^{1}H-NMR.: 0.91 (*d*, $J = 6$, 6 H, $H_3C(9)$, $H_3C(10)$); 1.05–2.3 (*m*, 8 H, 3 CH_2, 2 CH); 1.44 (*s*, 6 H, 2 $H_3C-C(7)$); 5.75–5.92 (*m*, 1 H, H–C(2)). – ^{13}C-NMR.: 19.65, 19.90 (2 *qa*, C(9), C(10)); 26.26, 26.66 (2 *qa*, $(CH_3)_2C(7)$); 25.31, 26.55, 29.15 (3*t*, 3 CH_2); 32.22, 40.02 (2*d*, 2 CH); 37.83 (*s*, C(7)); 122.97 (*d*, C(2)); 124.51 (*s*, CN); 136.89 (*s*, C(1)). – MS.: 191 (8, M^+), 176 (9), 164 (8), 148 (9), 134 (9), 123 (60), 121 (25), 120 (7), 107 (18), 105 (8), 91 (11), 79 (52), 77 (18), 67 (100), 65 (8), 55 (36), 53 (21), 41 (66), 39 (22), 27 (30).

Data of cis-*7,7-dimethyl-*p*-menthane-7-carbonitrile* (**16**). Rf 0.21 (toluene/hexane 1:1), t_R (GC., 100→280°) 9.52 min. – IR. (liq.): 2240 (CN); 1385, 1368 ($(CH_3)_2C$). – ^{1}H-NMR.: 0.89 (*d*, $J = 7$, 6 H, $H_3C(9)$, $H_3C(10)$); 1.05–1.45 (*m*, 6 H, $H_{ax}-C(2)$, $H_{ax}-C(3)$, $H_{ax}-C(5)$, $H_{ax}-C(6)$, H–C(1), H–C(4)); 1.32 (*s*, 6 H, 2 $H_3C-C(7)$); 1.55–1.70 and 1.85–2.0 (2 *m*, 4 H, $H_{eq}-C(2)$, $H_{eq}-C(3)$, $H_{eq}-C(5)$, $H_{eq}-C(6)$); 1.65–1.85 (*m*, 1 H, H–C(8)). – ^{13}C-NMR.: 21.14 (2 *qa*, C(9), C(10)); 22.86, 28.06 (twice 2 *t*, C(2), C(3), C(5), C(6)); 24.78 (2 *qa*, $(CH_3)_2C(7)$); 25.98, 39.90, 46.11 (3 *d*, 3 CH); 36.47 (*s*, C(7)); 124.91 (*s*, CN). – GC./MS.: 193 (5, M^+), 178 (7, $M^+ - CH_3$), 150 (9, $M^+ - CH(CH_3)_2$), 136 (7), 123 (23), 108 (8), 95 (6), 83 (39), 81 (48), 79 (9), 69 (100), 67 (32), 55 (37), 53 (10), 41 (60), 39 (14), 27 (16).

The product mixture after chromatography (1.2 g), obtained from the reduction of **9** mentioned above, was again reduced under analogous conditions using 8.5 g (1.0 mol-equiv.) of **1**, 24.6 g (60 mol-equiv.) of activated zinc[9]) and aq. acetic acid as solvent (CH_3COOH/H_2O 20:1). The mixture was stirred for 69 h. The GC. of the product after chromatographic purification (1.12 g (93%)) showed the following distribution of compounds: 51% of **13**, 40.5% of **16**, and 4% of **17**. The saturated *trans*-compound **17** was isolated from a parallel experiment using prep. GC.

Data of trans-*7,7-dimethyl-*p*-menthane-7-carbonitrile* (**17**). Rf 0.21 (toluene/hexane 1:1), t_R (GC., 100→280°) 9.64 min. – IR. (liq.): 2240 (CN); 1385, 1365 ($(CH_3)_2C$). – ^{1}H-NMR.: 0.86 (*d*, $J = 7$, 6 H, $H_3C(9)$, $H_3C(10)$); 0.8–1.34 (*m*, 6 H, $H_{ax}-C(2)$, $H_{ax}-C(3)$, $H_{ax}-C(5)$, $H_{ax}-C(6)$, H–C(1), H–C(4)); 1.32 (*s*, 6 H, 2 $H_3C-C(7)$); 1.34–1.5 (*m*, 1 H, H–C(8)); 1.75–1.86 and 1.86–1.98 (2 *m*, 4 H, $H_{eq}-C(2)$, $H_{eq}-C(3)$, $H_{eq}-C(5)$, $H_{eq}-C(6)$). – MS.: 193 (3, M^+), 178 (4, $M^+ - CH_3$), 150 (6, $M^+ - CH(CH_3)_2$), 83 (36), 69 (100).

The material obtained after chromatography of the second reduction (1.12 g) was once more analogously reduced using 4.25 g (0.5 mol-equiv.) of **1**, 16.4 g (40 mol-equiv.) of activated zinc[9]) and aq. acetic acid as solvent (CH_3COOH/H_2O 20:1). The mixture was stirred for 118 h. After chromatography (1.07 g (95%)), the GC. showed the following product distribution: 43% of **13**, 48% of **16**, and 5% of **17**.

The material (1.07 g) obtained after chromatography of the third reduction was reduced once more using the following conditions: 8.5 g (1.0 mol-equiv.) of **1**, 24.6 g (60 mol-equiv.) of activated zinc[9]), acetic acid/water 20:1, 120 h. After chromatography (990 mg (92%)), the GC. showed the following product distribution: 31% of **13**, 57.5% of **16**, and 6% of **17**.

A corresponding blank experiment using 40 mol-equiv. of activated zinc[9]) in aq. acetic acid (acetic acid/water 20:1) led, after 117 h, to a raw product (100%) which showed only the starting material **9** in the GC. (98.8%). Pure starting material **9** was isolated after chromatography in a yield of 82%.

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