164. Oxidative Cyclopropanol Opening by Cob(III)alamin[1]

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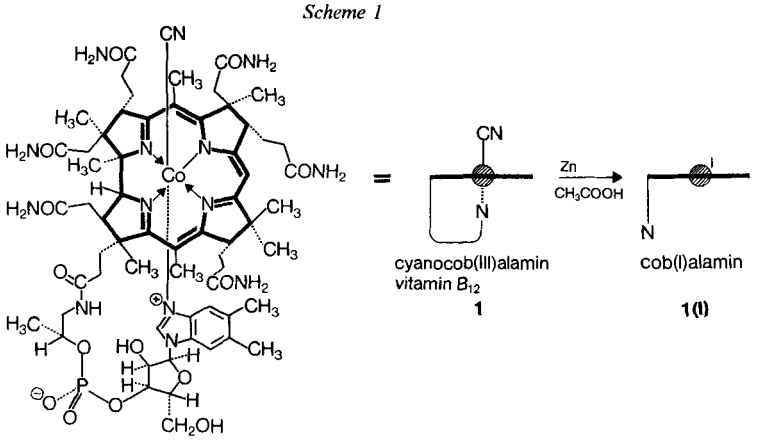
(14.XII.83)

Summary

Starting from the cyclopropanol **2,** the isomeric cyclopropanol **4** and the β,γ-unsaturated aldehydes **7** and **8** have been produced by a cobalamin-dependant transformation. In traces, the two acetoxycyclopropanes **3** and **6,** the saturated aldehydes **5** and **11** and the β,γ-unsaturated aldehyde **9** could be detected *(cf. Structural Formulae* and *Table)*. Starting from **4** the same products in a rather similar distribution were obtained. The isomerization **2**⇄**4** as well as the transformations leading to **7, 8,** and **9** are shown to be mediated by cob(III)alamin (**1(III)**). The results are explained on the basis of rearranging Co-complexes. The migrations might be driven by the electrophilic nature of the central Co(d^6)-atom.

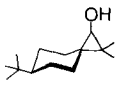
1. Cob(II)- or Cob(III)alamin Oxidizing 2. – When treated with cob(I)alamin (**1(I)**) (see *Scheme 1*) and granular Zn using glacial AcOH as solvent the crystalline cyclopropanol **2**[2]) revealed to be rather stable for 7 d at room temperature under Ar (see *Table,*

Scheme 1



[1]) 13th Communication in the series 'Cob(I)alamin as Catalyst'; for the 12th communication, see [1a].

[2]) For the preparation and the data of **2** and **4**, see [1a].



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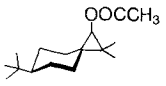

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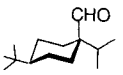

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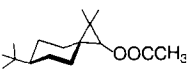

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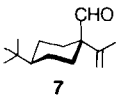

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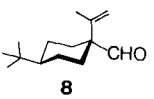

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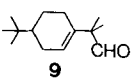

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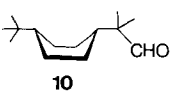

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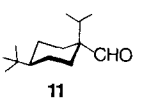

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Table. *Cobalamin-dependant Oxidations of* **2** *and* **4**, *and Blank Experiments with* **2**–**4** *and* **6**

Exper. No.	Starting Material	Reaction Conditions[a])	Reaction Time [days]	Products Yield [%]									
				2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	**2**	A	7	88	4.5	0.8	2.5	–	–	–	–	–	–
2	**2**	B	12	25	19	18.5	4.5	1.5	17	5	0.8	–	–
3	**2**	B	18	–	22	–	8	1.8	47.5	13	1	–	–
4	**2**	C	3	96	0.5	0.3	0.2	–	–	–	–	–	–
5	**2**	C	7	81	10	2	2.5	–	–	–	–	–	–
6	**2**	D	7	39.5	42.5	–	10	–	–	–	–	2	–
7	**2**	E	3	57	1.5	28.5	0.7	0.3	6.5	2.5	0.2	–	–
8	**2**	E	7	16	3.7	8.5	1.5	1.5	42.5	16	0.5	–	0.1
9	**4**	E	3	29	0.5	51	0.2	2.5	10	3.5	0.3	–	0.1
10	**4**	E	7	14.5	1.2	7.5	0.6	3.5	47	19	0.5	–	0.2
11	**3**	E	7	–	98.3	–	–	–	–	–	–	–	–
12	**6**	E	7	–	–	–	–	99.5	–	–	–	–	–

[a]) A: Cob(I)alamin (**1(I)**) from 0.5 mol.-equiv. of **1**, Zn, AcOH, Ar, r.t., green solution. B: Cob(II)alamin (**1(II)**)/acetatocob(III)alamin (**1(III)**) from 0.5 mol.-equiv. of **1**, $Zn(OAc)_2$, AcOH, Ar, r.t., slow O_2-invasion. C: Cob(II)alamin (**1(II)**) from 0.5 mol.-equiv. of **1**, $SnCl_2 \cdot 2H_2O$ (10 mol.-equiv.), AcOH, Ar, r.t., solid residue. D: Cob(II)alamin (**1(II)**) from 0.5 mol.-equiv. of **1**, $SnCl_2 \cdot 2H_2O$ (10 mol.-equiv.), AcOH-H_2O, Ar, r.t., solution. E: Acetatocob(III)alamin (**1(III)**) from 0.5 mol.-equiv. of **1**, AcOH, Ar, r.t., slow O_2-invasion.

Exper. 1). In minor amounts, the corresponding acetate **3**[3])[4]) and the saturated aldehyde **5**[5]), the major product obtained after protonolysis, were formed. The isomerized cyclopropanol **4**[2]) could be detected in traces only. After 7 d the initial green color, indicating the presence of cob(I)alamin (**1(I)**), gradually turned to pink. After 12 d Zn was consumed, a white precipitate, probably anhydrous $Zn(OAc)_2$, was formed and the reaction mixture showed the presence of four aldehydes (**5**[5]), **7**[5]), **8**[4]), **9**[5])), two cyclopropanols (**2**[2]) and **4**[2])), and two acetoxycyclopropanes (**3**[3])[4]) and **6**[3])[4]); *Table, Exper. 2*). As shown in *Exper. 1* cob(I)alamin does not lead to the unsaturated aldehydes **7**, **8** and **9**. The oxidized species cob(II)alamin **1(II)** and acetatocob(III)alamin **1(III)**, formed after Zn-consumption under conditions allowing a slow invasion of O_2 *(cf. Table, Exper. 2)*, seem to produce the isomerization **2**⇄**4** as well as an oxidative transformation with and without skeletal rearrangement leading to **7**–**9**. The same experiment running for additional 6 d under conditions allowing slow O_2-invasion *(cf. Exper. 3)* led to consumption of the two cyclopropanols **2** and **4**. As main products were isolated the two β,γ-unsaturated aldehydes **7** and **8** as well as the acetoxycyclopropane **3**. The acetoxy

[3]) The esterification is probably catalyzed by anh. $Zn(OAc)_2$.

[4]) For analytical data, *cf.* the *Exper. Part.*

[5]) For the preparation and the data, *cf.* [1b].

derivative **6,** the product of protonolytic cyclopropanol ring-opening **5** (see *below*), and the isomerized aldehyde **9** could be isolated in minor amounts.

2. Blank Experiments. – Blank experiments using weakly reductive conditions, in order to exclude the presence of a cob(III)alamin as well as cob(I)alamin, should reveal which of the two oxidized cobalamin species **1(II)** or **1(III)** is accounting for the oxidative transformations indicated in *Exper. 2* and *3*. $SnCl_2$ in acidic solution has been shown to reduce cob(III)alamin to cob(II)- but not to cob(I)alamin [2]. The cyclopropanol **2** was, therefore, treated at room temperature under Ar with 0.5 mol.-equiv. of acetatocob(III)alamin in the presence of an excess of $SnCl_2 \cdot 2\ H_2O$ (10 mol.-equiv.) using glacial AcOH as solvent (see *Exper. 4*). After 18 h, a colorless solution containing a yellow precipitate was formed. After 3 d the starting material **2,** the corresponding ester **3**, the isomerized cyclopropanol **4**, and the saturated aldehyde **5** could be detected in 96, 0.5, 0.3 and 0.2% yield, respectively. Stirring under the same conditions for 4 additional days led to a mixture showing the starting material **2** to be present in 81% yield *(Exper. 5)*. The acetate **3** could be detected in 10%, the isomeric cyclopropanol **4** in 2%, and the saturated aldehyde **5** in 2.5% yield. This experiment shows the starting material **2** to be rather stable in the presence of cob(II)alamin. Due to the fact that under these conditions a colorless solution and a yellow precipitate were formed, indicating the absence of the corrin chromophore from solution, this blank experiment might not be valid. Therefore, an additional control experiment was performed. In aqueous AcOH the colored **1(II)** remained in solution. Hence, cyclopropanol **2** was treated during 7 d with 0.5 mol.-equiv. of acetatocob(III)alamin in the presence of 10 mol.-equiv. of $SnCl_2 \cdot 2\ H_2O$ in glacial $AcOH/H_2O$ 2:1 *(Exper. 6)*. After extraction, the starting material **2**, the acetate **3**, the aldehyde **5**, and the aldehyde **10** were present in a 39.5, 42.5, 10 and 2% yield, respectively. More esterified starting material (**3**) was produced than in the previous blank experiment, probably due to the larger quantity of *Lewis* acid in solution. Both products obtained after protonolytic opening (**5** and **10**, *cf.* [1a]) were present. On the other hand, no derivatives generated by an isomerization and/or an oxidative ring-opening could be detected. These blank experiments show that cob(II)alamin (**1(II)**) is neither accounting for the formation of **4**[6]) nor for the oxidative cyclopropanol opening leading to the β,γ-unsaturated aldehydes **7**–**9**. *Exper. 1* illustrates that, in presence of cob(I)alamin (**1(I)**), cyclopropanol isomerization is resulting in traces only, and oxidative ring-opening could not be detected. Therefore, cob(III)alamin has to account for the isomerization of the cyclopropanol **2** as well as for the transformations leading to **7**–**9.**

3. Oxidations Using cob(III)alamin 1(III). – The cyclopropanol **2** was subjected to a treatment with 0.5 mol.-equiv. of acetatocob(III)alamin in glacial AcOH at room temperature under conditions not excluding a slow O_2-invasion[7]). After 3 d, the starting material was still present in 57% yield, and a substantial amount (28.5%) of isomerized cyclopropanol (**4**) could be detected *(Table, Exper. 7)*; in minor quantities were formed the acetates **3** and **6**, the β,γ-unsaturated aldehydes **7**–**9** as well as the aldehyde **5**. After 4 additional days under the same conditions, the cyclopropanols **2** and **4** were

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[6]) Only traces of **4** were formed in the perhaps invalid blank *Exper. 4* and *5*. In the control *Exper. 6* the isomerized cyclopropanol **4** was not detected.

[7]) An Ar-balloon was used, joints were not greased.

present in 16 and 8.5% yield, respectively, and the β,γ-unsaturated aldehyde **7** (42.5%) was the main product *(Exper. 8)*. In substantial amounts the isomerized unsaturated aldehyde **8** (16%) had been formed, and traces of the acetates **3** (3.7%) and **6** (1.5%), the unsaturated aldehyde **9** (0.5%), and the two saturated aldehydes **5** (1.5%) and **11** (0.1%) could be detected. The generation of **5** and **11** can be ascribed to protonolysis of **2** and **4**, *cf.* [1a]. Acetatocob(III)alamin clearly shows to cause an isomerization of the cyclopropanol **2** to **4**, and the same Co(d^6)-complex is also accounting for the generation of **7–9**.

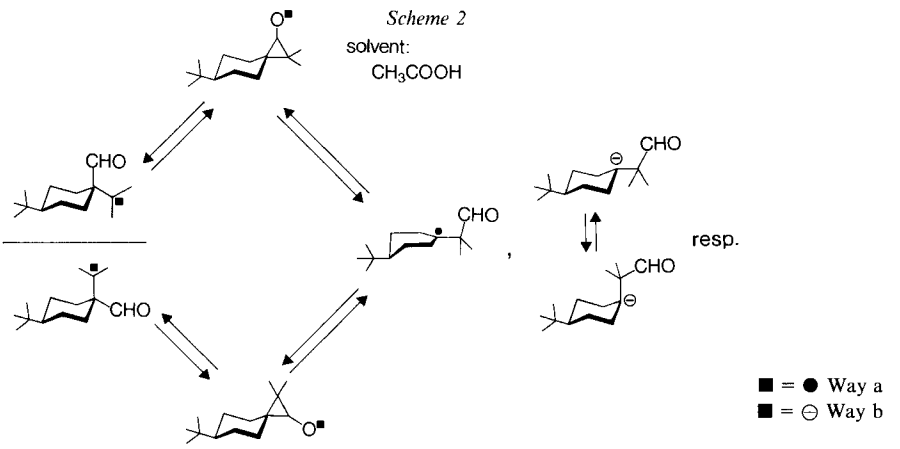
In an identical study using the cyclopropanol **4** as starting material acetatocob(III)alamin also led to isomerization of the cyclopropanol as well as to oxidative ring-opening with and without skeletal rearrangement. After 3 d, the starting material was still present in 51% and the isomerized cyclopropanol **2**, the acetates **3** and **6**, the unsaturated aldehydes **7–9** and the saturated aldehydes **5** and **11** were detected in a 29, 0.5, 2.5, 10, 3.5, 0.3, 0.2, and 0.1% yield, respectively *(Table, Exper. 9)*. After 4 additional days the cyclopropanols **2** (14.5%) and **4** (7.5%), the acetates **3** (1.2%) and **6** (3.5%), the unsaturated aldehydes **7** (47%), **8** (19%), and **9** (0.5%) as well as the saturated aldehydes **5** (0.6%) and **11** (0.2%) could be detected in the crude product mixture *(Exper. 10)*.

It is interesting to recognize that starting from both cyclopropanols **2** and **4** the interaction of acetatocob(III)alamin is generating a similar product distribution after 7 d. After 3 d a substantial cyclopropanol isomerization was observed. The products **7** and **8** were present in small amounts only. After 7 d, most of the cyclopropanols were consumed. In both cases, *i.e.* starting from **2** or **4**, higher amounts of the cyclopropanol **2** and less of **4** have been detected, the relationship **2**/**4** being *ca.* 1.9:1. Very clearly, the cyclopropanols **2** and **4** are consumed and the β,γ-unsaturated aldehydes **7** and **8** are the products of these reactions. The reaction starting from **4** led to a somewhat higher product generation and cyclopropanol consumption than the one starting from **2**.

4. Stability Studies Starting from 3 and 6. – The reactions shown in *Exper. 1–3* and *7–10* reveal the cyclopropanols **2** and **4** to be transformed by acetatocob(III)alamin, but they also illustrate an accumulation of the acetoxycyclopropanes **3** and **6** under the same conditions. It was, therefore, necessary to test the reactivity of acetatocob(III)alamin towards **3** and **6** in appropriate control experiments. Under the conditions used for oxidative transformation of **2** and **4**, the acetoxycyclopropanes **3** and **6** revealed to be inert *(Exper. 11* and *12)*. Therefore a free cyclopropanol is needed for the acetatocob(III)alamin-dependant cyclopropanol isomerization as well as for the oxidative transformations leading to **7–9**.

5. Discussion. – Taking into account that a free cyclopropanol and acetatocob(III)alamin are needed for the transformations given in the *Table (Exper. 1–3* and *7–10)*, we postulate the formation of an intermediate cyclopropanolatocob(III)alamin *(cf. e.g.* **B** in *Scheme 3)*. From this intermediate, products could be generated after rearrangement of the complex. Alternatively, the Co,O-bond could be ruptured in a nucleofugal way [1e] leading to an oxene and cob(I)alamin. As for such a transformation the energy demand would be very high, we don't consider this way to be a rationale for the formation of the products observed. Homolytic fission of **B** could produce an O-radical and cob(II)alamin *(Way a)*, and electrofugal cleavage [1e] might lead to a cyclopropanolate and cob(III)alamin (*Way b;* see *Scheme 2*).

Scheme 2

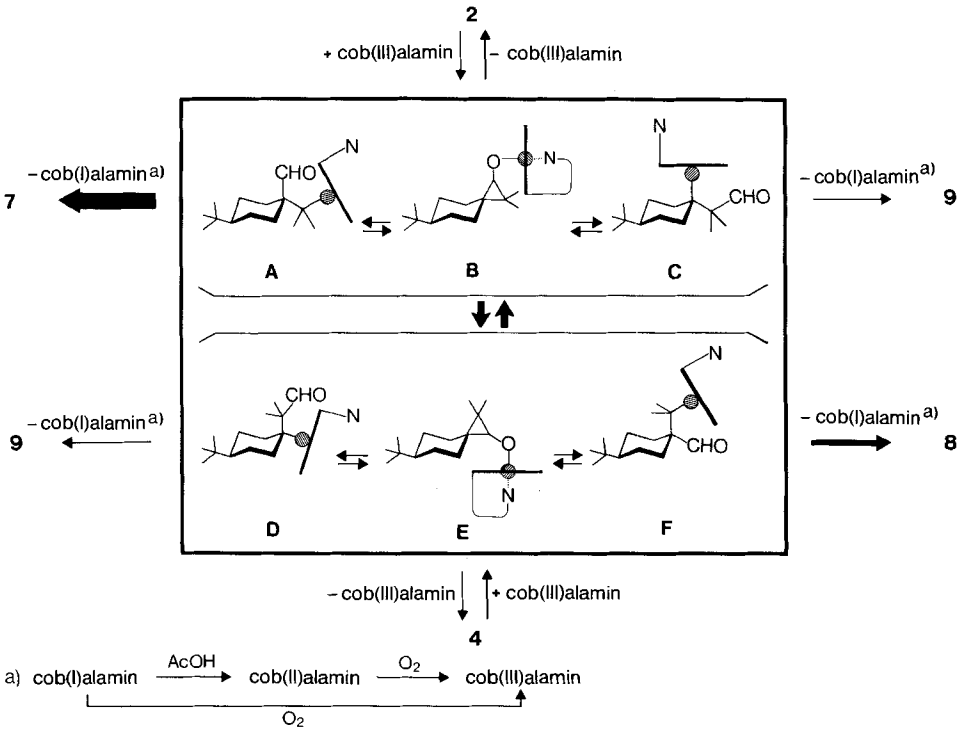


Considering *Way a*, the O-radical might undergo ring-opening reactions generating two tertiary C-radicals. An attack of the C-radicals on the carbonyl dipole might then lead back to the starting O-radical and to a new cyclopropyloxy radical showing inversed configuration at the spiro C-atom. From this new O-radical, a similar ring-opening might again lead to two tertiary C-radicals *(Scheme 2)*. All of the five radicals produced after such a homoallylic migration could abstract an H-atom from the CH_3-group of AcOH, the solvent used for the transformations. By such a pathway, the almost exclusive formation of the β,γ-unsaturated aldehydes **7**–**9** is, therefore, difficult to explain. It is nevertheless interesting to recognize that such a simple homoallylic radical migration permits the formulation of all the C-skeletons observed after cob(III)alamin-mediated transformation of **2** and **4**.

In *Scheme 2*, a similar homoallylic migration is shown starting from a cyclopropanolate *(Way b)*. Following such a rearrangement, four carbanionic species and two cyclopropanolates are produced. These anions would rapidly abstract a proton from AcOH leading to cyclopropanols and saturated aldehydes. Therefore, the generation of the three β,γ-unsaturated aldehydes **7**–**9** can not be explained by a transformation following *Way b*. Interestingly, once again the homoallylic migration allows the formulation of all the skeletons observed. But following this mechanism, the aldehydes would be generated in a wrong oxidation state.

Scheme 3 shows a similar homoallylic rearrangement to explain the transformations of **2** *(Way c)*. In this case, the whole cobalamin moiety is shown to migrate from the cyclopropanolato O-atom (*cf.* **B**) to the two tetrasubstituted C-atoms of the cyclopropane ring generating the tertiary alkylcobalamins **A** and **C**. A reductive elimination from **A** and **C** would then lead to the β,γ-unsaturated aldehydes **7** and **9**. After such a reductive elimination, the cobalamin moiety is released in the d^8-oxidation state, *i.e.* in the form of cob(I)alamin. Under acidic conditions cob(I)alamin is known to be metastable [2–4]; the d^8-complex is transformed to cob(II)alamin and H_2. O_2, present in our experiments in small amounts, oxidizes not only cob(I)alamin but also cob(II)alamin generating the d^6-complex cob(III)alamin. This complex would then lead, after interaction with **2**, to the cyclopropanolatocob(III)alamin **B** catalyzing thereby an oxidative transformation characterized by consumption of **2** and generation of **7** and **9**. O_2 is the ultimate oxidant. The part of the mechanism discussed up to now does not present an explanation for the formation of the isomeric cyclopropanol **4** and the β,γ-unsaturated aldehyde **8**. As shown in the *Table*, the isomeric cyclopropanol **4**, transformed under identical conditions, led to the same products as isolated from **2** in a similar distribution. An analogous mechanism starting from **4** and cob(III)alamin *(cf. Scheme 3)* presents a rationale for the generation of **8** and **9**, but not for **2** and **7**.

Scheme 3 (Way c)

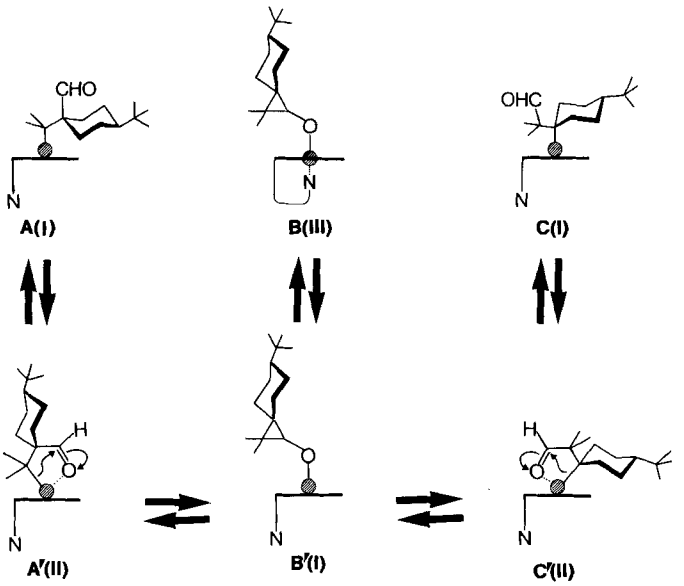


Exper. 8 and *10* starting from **2** and **4** *(Table)* lead to identical products in a rather similar distribution. We assume, therefore, that the products observed are formed under equilibrium conditions. To establish an equilibrium between the top row (**A**⇄**B**⇄**C**) and the bottom row (**D**⇄**E**⇄**F**) shown in *Scheme 3* within the black frame, it is necessary to postulate at least one connection between these two rows. By such a connection an equilibrium between the four alkylcobalamins **A, C, D,** and **F** and the two cyclopropanolatocobalamins **B** and **E** could be established. Reductive elimination from **A, C, D,** and **F** and ligand dissociation from **B** and **E** would not only present a rationale for all the products observed but would also explain the rather similar product distribution obtained after cob(III)alamin-mediated oxydation of **2** and **4**.

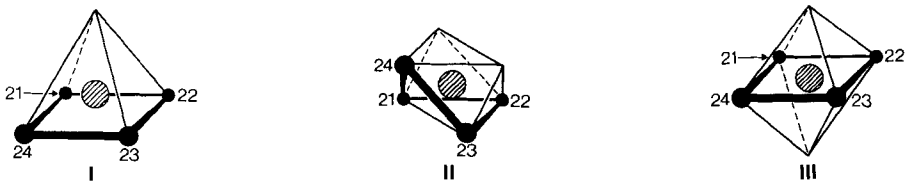
Based on earlier studies [1e] [5–9], we assume that tertiary alkylcobalamins, like *e.g.* **A**, exist as pentacoordinated complexes in basic and acidic solution. Tertiary alkylcob(III)alamins are, therefore, coordinatively unsaturated[8]) and isolobal with $CH_3^{\oplus}$ [10] *(cf. Scheme 4)*. They show an electrophilic central Co-atom, and tetragonal-pyramidal geometry (**I**) can tentatively be ascribed to these pentacoordinated complexes (see *Schemes 4* and *5*). The electron demand of the central Co-atom can principally be satisfied from either apical direction. Under conditions guaranteeing an unprotonated benzimidazole, literature data [9] show that the ribonucleotide from secondary alkylcobalamins does not coordinate the Co-atom. According to this evidence, we assume that

[8]) Co(d^6), over all 16 electrons.

Scheme 4



Scheme 5



this is also valid for tertiary alkylcobalamins. As shown in *Scheme 4*, the electrophilic Co-atom might satisfy its electron demand by formation of a linkage to the O-atom of the formyl group. The resulting complex (**A'(II)**) is coordinatively saturated[9]), isolobal with CH_4, showing two substituents on the β-face of the corrin nucleus. Such a hexacoordinated complex might show distorted octahedral geometry (**II**). The nature of the corrin ring might offer a possibility to arrange the four N-atoms in positions approaching the four corners marked 21–24 in the distorted octahedron **II** *(Scheme 5)*. By shifting electrons from the Co,C-bond to the C-atom of the formyl group, **A'(II)** might be transformed to **B'(I)** *(cf. Scheme 4)*. This complex is once again coordinatively unsaturated[8]) and isolobal with $CH_3^{\oplus}$. The electrophilic Co-atom can now acquire the coordinatively saturated state by closing the ribonucleotide loop (*cf.*[5] [7]) to give **B(III)** *(cf.* **III**, *Scheme 5)*. On the other hand, the electrophilic Co-atom in **B'(I)** could also attack one of the two cyclopropane C,C-bonds directly linked to the carbinol C-atom, leading to **C'(II)** or back to **A'(II)**, *i.e.* in both cases to coordinatively saturated[9]) complexes. Thus, based on the electrophilic character of Co (d^6, overall 16 electrons) and on the possibilities to satisfy its electron demand within the given complexes, a mechanistic formulation of homoallylic migration **A**⇄**C** or **D**⇄**F** is possible[10]).

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[9]) Co(d^6), over all 18 electrons.

[10]) For a review of the mechanisms of action of the B_{12} coenzyme *cf.* [11].

The authors would like to thank Prof. *J. Baldwin*, The *Dyson Perrins Laboratory*, Oxford U.K., for his assistance in this project. We would also like to express our gratitude to our colleagues from the Central Research Units and in particular to Dr. *A. Dirscherl* (microanalysis), Dr. *M. Vecchi* (GC), Drs. *Englert* and *Arnold* (NMR), *G. Oesterheld* (GC/MS) and *W. Meister* (MS) for analytical and spectroscopical data.

Experimental Part

General. See [1b]. The cob(I)alamin catalyst was prepared according to the procedure in [1c].

A. Oxidations with Cob(III)alamin. – a) *Exper. 1–3* (see the *Table*). From 0.33 g of cyanocob(III)alamin (**1**, 0.5 mol.-equiv.) the catalyst was prepared according to the procedure in [1c]. To the suspension of the catalyst, dissolved in 8 ml of AcOH and 1.85 g of activated granular Zn (60 mol.-equiv.) were added 100 mg of crystalline **2** in 2 ml of AcOH. The suspension was stirred in the dark at r.t. for 7 d under Ar using a balloon. From the still green solution, an aliquot (15% of the volume) was withdrawn using a syringe. After aq. workup of this material (Et_2O), 14.1 mg of a mixture (94% of the weight of starting material initially present in this aliquot recovered) were obtained. This mixture was analyzed by TLC, NMR, and GC. GC: **2** (88%), **3** (4,5%), **4** (0.8%), **5** (2.5%). Experiments along these lines [1d] showed that the yield calculated from the GC analysis of the crude product and the yield based on the products obtained after chromatography display comparable figures.

On further stirring of the mixture in the dark at r.t. for 5 d under Ar (balloon), the color of the solution gradually turned to pink. The granules of Zn were absent, and a white precipitate of $Zn(OAc)_2$ was present. A second aliquot (15% of the initial volume) gave 12.5 mg of a mixture (83.5% by weight, see *above*). GC: **2** (25%), **3** (19%), **4** (18.5%), **6** (1.5%), **7** (17%), **8** (5%), **9** (0.8%), **5** (4.5%).

The pink mixture containing solid $Zn(OAc)_2$ was stirred in the dark at r.t. for 6 additional days under Ar (balloon). The final aq. workup of the remaining mixture gave 65.5 mg of a mixture (93.5% by weight, see *above*). GC: **3** (22%), **6** (1.8%), **7** (47.5), **8** (13%), **9** (1%), **5** (8%). For the data of **2, 4** *cf.* [1a]. For the data of **7, 9,** and **5** *cf.* [1b].

An ordinary acetylation (CH_2Cl_2, Et_3N, AcCl, r.t.) of **2** and **4** led to **3** and **6**, respectively. During the chromatography of the nitrile precursor of **7** [1b], a slower running minor fraction could be isolated containing 4β-(*tert*-butyl)-1β-(1-methylvinyl)-1α-cyclohexanecarbonitrile. This derivative was reduced to **8** using diisobutylaluminumhydride in hexane [1b].

cis-*6-(*tert-*Butyl)-2,2-dimethylspiro[2.5]oct-1-yl Acetate* (**3**). R_f 0.63 (Et_2O/hexane 1:10), t_R (GC, 50→350°) 21 min. IR (liq.): 1742 (C=O), 1365, 1238, 1093, 1071. ^{1}H-NMR: 0.85 (*s*, 9H, $C(CH_3)_3$); 0.85–1.90 (*m*, 9H, 4 CH_2, CH); 0.95 (*s*, 3H, CH_3–C(2)); 1.06 (*s*, 3H, CH_3–C(2)); 2.07 (*s*, 3H, CH_3COO); 3.51 (*s*, 1H, H–C(1)). ^{13}C-NMR (100.6 MHz): 15.05, 20.86 (2*q*, $C(CH_3)_2$); 20.22 (*q*, CH_3COO); 22.24, 28.05 (2*s*, C(1) and C(3)); 26.00, 26.12, 26.36, 30.99 (4*t*, C(4), C(5), C(7), C(8)); 27.59 (3*q*, $C(CH_3)_3$); 32.25 (*s*, $C(CH_3)_3$); 47.88 (*d*, C(6)); 65.01 (*d*, C(1)); 171.89 (*s*, CH_3COO). MS: 252 (3, M^+), 236 (1), 221 (2), 210 (60, M^+-CH_2CO), 192 (45, M^+-CH_3COOH), 177 (6), 149 (8), 135 (36), 121 (30), 111 (55), 108 (23), 107 (12), 93 (44), 79 (15), 69 (47), 67 (19), 57 (100, $(CH_3)_3C^+$), 43 (98, CH_3CO^+), 41 (46), 29 (21).

trans-*6-(*tert-*Butyl)-2,2-dimethylspiro[2.5]oct-1-yl Acetate* (**6**). R_f 0.53 (Et_2O/hexane 1:10), t_R (GC, 50→350°) 21.65 min. IR (liq.): 1740 (C=O), 1363, 1235, 1069. ^{1}H-NMR: 0.85 (*s*, 9H, $C(CH_3)_3$); 0.85–1.90 (*m*, 9H, 4 CH_2, CH); 1.06 (*s*, 3H, CH_3–C(2)); 1.14 (*s*, 3H, CH_3–C(2)); 2.05 (*s*, 3H, CH_3COO); 3.43 (*s*, 1H, H–C(1)). ^{13}C-NMR (100.6 MHz): 15.49, (*q*, CH_3–C(2)); 20.67 (2*q*, CH_3–C(2) and CH_3COO); 22.28, 28.65 (2*s*, C(1) and C(3)); 26.42, 26.75, 26,86, 31.55 (4*t*, C(4), C(5), C(7), C(8)); 27.57 (3*q*, $C(CH_3)_3$); 32.44 (*s*, $C(CH_3)_3$); 48.48 (*d*, C(6)); 65.59 (*d*, C(1)); 71.89 (*s*, CH_3COO). MS: 252 (1, M^+), 210 (7, M^+-CH_2CO), 192 (38, M^+-CH_3COOH), 177 (6), 149 (8), 135 (32), 121 (25), 111 (46), 108 (19), 93 (30), 79 (12), 69 (42), 67 (18), 57 (100, $(CH_3)_3C^+$), 43 (94, CH_3CO^+), 41 (45), 29 (19).

*4β-(*tert-*Butyl)-β-(1-methylvinyl-1α-cyclohexanecarboxaldehyde* (**8**). R_f 0.27 (Et_2O/hexane 1:20), t_R (GC, 50→300°) 17.28 min. IR (liq.): 1722 (C=O), 1632 (C=C), 1461, 1372; 917 (C=CH_2). ^{1}H-NMR: 0.89 (*s*, 9H, $C(CH_3)_3$); 0.9–2.4 (*m*, 9H, 4 CH_2, CH); 1.72 (*s*, 3H, CH_3); 5.06 (*s*, 1H, HCH=C); 5.30 (*s*, 1H, HCH=C); 9.17 (*s*, 1H, CHO). MS: 208 (3, M^+), 179 (12, M^+-CHO), 123 (41, $M^+-CHO-CH_2=C(CH_3)_2$), 109 (62), 95 (24), 91 (5), 81 (28), 77 (6), 67 (22), 57 (100, $(CH_3)_3C^+$), 55 (27), 53 (11), 41 (46), 33 (13), 29 (22), 27 (10).

b) *Oxidation Starting from* **2** *(cf. Exper. 7 and 8).* To 0.33 g of cyanocob(III)alamin (**1**; 0.5 mol.-equiv.), dissolved in 10 ml of AcOH, 3.1 g of activated Zn (*cf.* [1c]) were added. The suspension was stirred at 70° for 30 min under Ar. After cooling, half of the solvent was removed at 15 Torr. After filtration, the remaining Zn was

washed with 5 ml of AcOH. The red filtrate was evaporated to yield the catalyst, mainly acetatocob(III)alamin. To the catalyst, dissolved in 7 ml of AcOH, were added 100 mg of crystalline **2** in 2 ml of AcOH. The red solution was stirred in the dark at r.t. for 3 d under Ar (balloon)[11]). From the red solution an aliquot (20% of the volume) was withdrawn and worked up as in *Sect. A.a* giving 17.2 mg of a mixture (86% by weight). GC: **2** (57%), **3** (1.5%) **4** (28.5%), **6** (0.3%), **7** (6.5%), **8** (2.5%), **9** (0.2)), **5** (0.7%).

The remaining red solution was stirred in the dark at r.t. for 4 additional days under Ar (balloon). After aq. extraction (Et_2O), 71.3 mg of a mixture (89% by weight) was obtained. GC: **2** (16%), **3** (3.7%), **4** (8.5%), **6** (1.5%), **7** (42.5%), **8** (16%), **9** (0.5%), **5** (1.5%), **11** (0.1%). Data of **11** see [1a].

c) *Oxidation Starting from* **4** *(Exper. 9 and 10).* Crystalline **4** (100 mg) was treated in the same manner as **2** *(Sect. A.b).* The aliquot (after 3 d) yielded 18.1 mg of a mixture (90.5% by weight). GC: **2** (29%), **3** (0.5%), **4** (51%), **6** (2.5%), **7** (10%), **8** (3.5%), **9** (0.3%), **5** (0.2%), **11** (0.1%). The remaining solution was stirred in the dark at r.t. for 4 additional d under Ar (balloon). After aq. extraction (Et_2O), 77.6 mg of a mixture (97% by weight) was obtained. GC: **2** (14.5%), **3** (1.2%), **4** (7.5%), **6** (3.5%), **7** (47%), **8** (19%), **9** (0.5%), **5** (0.6%), **11** (0.2%).

B. Experiments with Cob(II)alamin. – a) *$SnCl_2 \cdot 2\ H_2O$ as Solid Residue (Exper. 4 and 5).* From 330 mg of cyanocob(III)alamin (**1**; 0.5 mol.-equiv.) the acetatocob(III)alamin catalyst was prepared according to *Sect. A.b.* To the catalyst, dissolved in 7 ml of AcOH, 1.07 g of $SnCl_2 \cdot 2\ H_2O$ (10 mol.-equiv.) were added. After stirring at r.t. for 30 min under Ar, 100 mg of crystalline **2** in 2 ml of AcOH were added. On stirring over night, a colorless solution and a yellow precipitate was formed. After stirring in the dark at r.t. for 3 d under Ar, an aliquot (20% of the volume) yielded *(cf. Sect. A.a)* 20 mg (100% by weight) of a mixture. GC: **2** (96%), **3** (0.5%), **4** (0.3%), **5** (0.2%).

The remaining suspension was stirred in the dark at r.t. for 4 additional d under Ar. After aq. extraction (Et_2O), 74 mg of a mixture (92.5% by weight) was obtained. GC: **2** (81%), **3** (10%), **4** (2%), **5** (2.5%).

b) *$SnCl_2 \cdot 2\ H_2O$ in Solution (Exper. 6).* From 330 mg of cyanocob(III)alamin (**1**; 0.5 mol.-equiv.), the acetatocob(III)alamin catalyst was prepared according to *Sect. A.b.* To the catalyst, dissolved in 9 ml of AcOH/H_2O 2:1, were added 1.07 g of $SnCl_2 \cdot 2\ H_2O$ (10 mol.-equiv.). After stirring at r.t. for 30 min, under Ar, 100 mg of crystalline **2** in 6 ml of AcOH were added to the red-brown solution. This solution, containing small amounts of a yellow precipitate, was stirred in the dark at r.t. for 7 d under Ar. After aq. extraction (Et_2O) 109 mg (quant.), of a solid residue was obtained. GC: **2** (39.5%), **3** (42.5%), **5** (10%), **10** (2%).

C. Stability Studies Using 3 and 6. – a) *Starting from* **3** *(Exper. 11).* From 54 mg of cyanocob(III)alamin (**1**; 0.5 mol.-equiv.) the acetatocob(III)alamin catalyst was prepared according to *Sect. A.b.* To the catalyst, dissolved in 2 ml of AcOH, were added 20 mg of **3** in 1 ml of AcOH. The solution was stirred in the dark at r.t. for 7 d under Ar (balloon). After aq. extraction (Et_2O) 15.4 mg (77% recovery (volatility of **3**)) of product were obtained. GC: **3** (98.3%).

b) *Starting from* **6** *(Exper. 12).* An experiment parallel to *Sect. C.a*, but starting from **6**, led to recovered **6** (81% crude yield). GC: **6** (99.5%).

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