190. The Photooxygenation of Heptamethyl *Coα, Coβ*-Dicyanocobyrinate

by **Bernhard Kräutler**

Laboratorium für Organische Chemie der Eidgenössischen Technischen Hochschule, Universitätstrasse 16, CH-8092 Zürich

(7.VI.82)

Summary

Irradiation with visible light of an oxygen-saturated methanolic solution of heptamethyl *Coα, Coβ*-dicyanocobyrinate and of the sensitizer methylene blue causes the efficient photooxygenation of this vitamin B_{12} derivative. Use of CD_3OD instead of CH_3OH strongly accelerates the reaction. This solvent H/D-isotope effect is consistent with a mechanism involving 'singlet oxygen' and is exploited preparatively. Two photooxygenation products can be isolated from such preparative experiments. One of these, isolated in 47% yield, has NMR.-spectral characteristics identical with those of *Inhoffen*'s heptamethyl *Coα, Coβ*-dicyano-5,6-dioxo-5,6-secocobyrinate (**2a**). To the other photoproduct, isolated in 25% yield, the structure of the unknown isomeric heptamethyl *Coα, Coβ*-dicyano-14,15-dioxo-14,15-secocobyrinate (**3a**) is assigned.

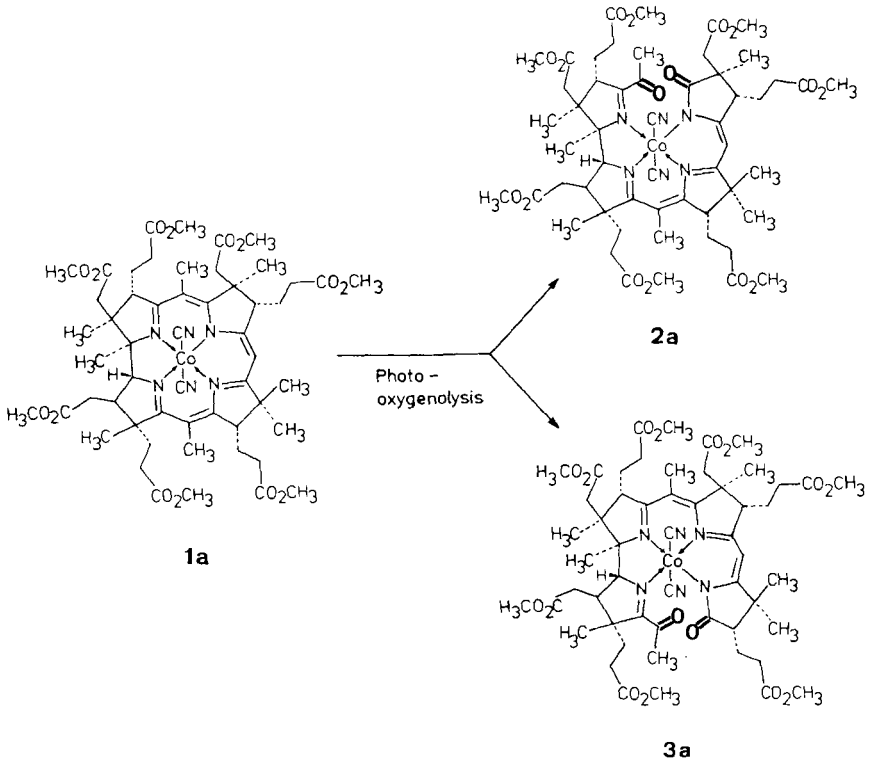
Surprisingly, it appears that the action of singlet oxygen on vitamin B_{12} derivatives has not yet been the subject of chemical investigations. However, we would like to demonstrate here, that photooxygenation reactions of such corrinoid cobalt(III) complexes can be conducted quite cleanly and (even) efficiently, resulting in the cleavage of the corrinoid macrocycle.

Vitamin B_{12} and many of its derivatives have indeed been submitted to chemical degradation for several purposes, *e.g.* elucidation of structural and reactivity patterns [1] [2] [3a–d], and, more recently, in the context of biosynthetic studies [3e]. In the latter respect, low-temperature ozonolysis of the lipophilic heptamethyl *Coα, Coβ*-dicyanocobyrinate [4] (**1a**) proved to be a particularly valuable method of degradation [5] [6]. The corrin macrocycle is cleaved into three major fragments allowing, *e.g.* identification of (radioactive) markers in biosynthetic investigations [6]. Increased control on the ozonolysis reaction was found to result from the introduction of a 'blocking' substituent at the 10-position of the corrin ring, as in heptamethyl *Coα, Coβ*-dicyano-10-bromocobyrinate (**1b**) [7] whose cleavage by ozone at the 5,6-position gave the 5,6-secocorrinoid dicyanocobalt(III) complex **2b** [8] (from which, in turn, the corrinoid **1a** could be reconstituted chemically [8])[1]).

[1]) The structure of **1b** and **2b** is given by the formula of **1a** and **2a**, respectively, in which H–C(10) is replaced by Br–C(10).

0018-019X/82/6/1941-08$01.00/0

Scheme



We have now been able to achieve the corresponding cleavage reaction by the photosensitized oxygenation of cobester **1a**[2]): irradiation with visible light of an oxygen-saturated methanolic solution of **1a** containing the sensitizer methylene blue (MB) leads to the consumption of the deep red corrinoid cobalt(III) complex **1a** and to the formation of two bright orange compounds (as easily checked by TLC. and/or analysis by UV./VIS. spectroscopy). At the earlier stages the photolysis proceeds very cleanly (as indicated by 'isosbestic points' in the UV./VIS. spectra of the reaction mixture; see *Fig. 1*), but decomposition of the orange secocorrinoid oxygenation products becomes important at high conversions (> 80%) of **1a**[3]).

The more polar of the two photooxygenation products of **1a** can be identified (based on its ^{1}H-NMR. and ^{13}C-NMR. spectra) with the 5,6-secocorrinoid heptamethyl *Coα, Coβ*-dicyano-5,6-dioxo-5,6-secocobyrinate (**2a**; s. *Scheme*), obtained recently by *Inhoffen et al.* [8] upon reductive removal of the bromine substituent at the 10-position of the ozonolysis product **2b**. The new, less polar oxygenation

[2]) These studies were induced by our finding that 'pyrocobester' (a B-didehydro-corrin obtained by thermolysis of **1a** [9]) efficiently undergoes a photooxygenation with specific cleavage at the 5,6-position (presented in preliminary form at the Herbstversammlung der Schweizerischen Chemischen Gesellschaft, Bern 1981).

Taken in part from the diploma theses of *R. Stepanek* (ETH Zürich, 1982) and of *H.-P. Jutzi* (ETH Zürich, in progress).

[3]) In preparative experiments a conversion of only about 85–90% was desired.

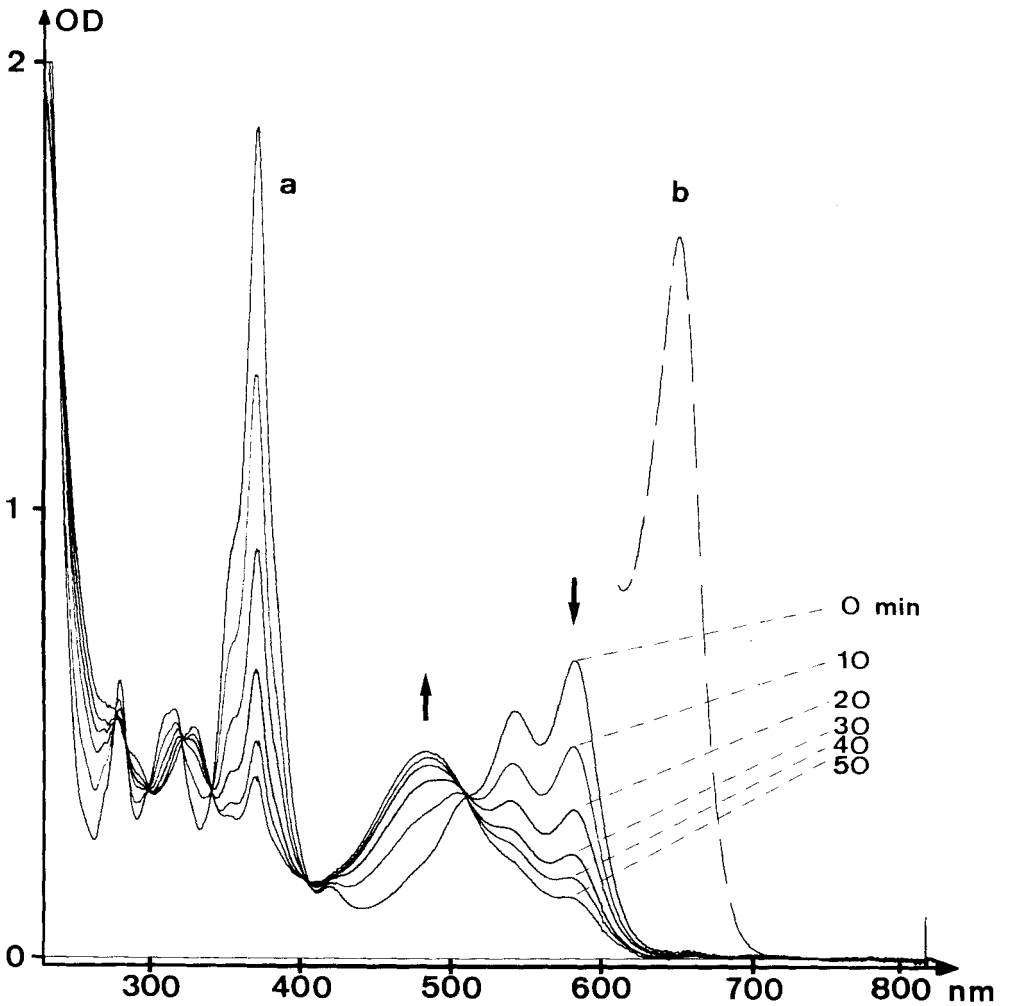


Fig. 1. *Changes in the UV./VIS. spectrum during the MB-sensitized photooxygenation of cobester* **1a** *in* CD_3OD (exciting wavelength: 650 nm; initial concentration of **1a**: $(6.7 \cdot 10^{-4}$ mol/l; O_2 (1 atm); RT.). a) Net spectrum in which the absorption due to the sensitizer is substracted (obtained by placing a MB-solution in CH_3OH into the reference compartment). b) Long wavelength portion of the uncorrected spectrum (showing the long wavelength band of MB).

product **3a**, isolated as orange-brown needles, is the previously unknown[4]) hepta-methyl *Coα, Coβ*-dicyano-14,15-dioxo-14,15-secocobyrinate, an isomer of **2a** whose structure is assigned on the basis of its spectral and analytical data.

The structure of **3a** can be deduced by the following sequence of arguments, and making use of the structural assignment for **2a** [8]: **2a** and **3a** are isomers containing the same kind and number of functional groups (microanalysis, IR. and

[4]) Apparently, a secocorrinoid free ligand corresponding to **3a** can be obtained (in low yield) by treating **1a** with H_2S and oxygen (Dr. *G. Bartels*, private communication, 13.6.1980).

NMR. spectra, mass spectra) including a similar chromophore and (presumably) coordination pattern around the cobalt(III) center (UV./VIS., CD., IR., and ^{13}C-NMR. spectra).

The site of cleavage in **3a** at the 14,15-position is indicated by the ^{13}C-NMR. spectra[5]) and also by the FAB-mass spectra [10]. The mass spectra of **2a** and **3a** exhibit characteristic fragmentation patterns[6]) specific for secocorrinoid (metal)-complexes containing the saturated A/D-ring junction [11]. The FAB-mass spectrum of **3a** shows a base peak at *m/z* 1069 (corresponding to the $(M+1-2\,CN)^+$-ion), accompanied by a less intensive fragment at *m/z* 1067, and pronounced fragments at *m/z* 785 and *m/z* 713 (indicative of a degradation with loss of ring D). The corresponding fragments in the spectrum of **2a** appear as intense signals shifted by 14 units to smaller mass numbers (at *m/z* 771 and *m/z* 699, compatible with a fragmentation involving loss of ring A[7])).

The characteristics of the preparative MB-sensitized photooxygenation of cobester **1a** indicate this reaction to involve molecular oxygen in its singlet excited ($^1\Delta$g) state[8]): the reaction proceeds only in the presence of both light and molecular oxygen, and methylene blue functions as an efficient sensitizer[9]). Of several organic solvents tested (CH_3OH, $CHCl_3$, CH_2Cl_2, CCl_4, and CS_2), methanol promotes by far the cleanest reaction[11]).

Table. *Effect of isotopic composition of methanol on the MB-sensitized photooxygenation of cobester*[a])

Solvent	Reaction time (min)	% of **1a** reacted	Rel. rate[b])	Yield[c])	Ratio **2a/3a**
CH_3OH	160	80	1	60	1.9:1
CH_3OD	50	95	2.5	80	2.0:1
CD_3OD	25	> 95	6.5	73	1.5:1

[a]) Conditions as described in the *Exper. Part* for the MB-sensitized photooxygenation of **1a** in CH_3OD, with suitable reaction time as listed in the *Table*. [b]) Rough estimates based on a (first-order) plot of disappearance of **1a** (using OD. at 583 nm). [c]) Actual total yield of **2a** and **3a** determined spectrophotometrically.

[5]) The ^{13}C-NMR. spectrum of **3a** shows several unique ^{13}C-signals, that are assignable with high confidence. The resonances due to C(19) and C(17) are shifted downfield by 7.3 and 4.3 ppm (while in **2a** they remain nearly unchanged), respectively, relative to their position in the spectrum of **1a**. The signal due to the 12β-methyl group (appearing at a characteristically low field for **1a**) is not found in the spectrum of **3a** at the same position, but instead a new methyl signal arises at higher field (shift *ca.* 5.5 ppm).

[6]) From electron impact mass spectra [11].

[7]) This is comparable to a fragmentation pattern in the mass spectrum of the secocorrinoid metal-free ligand corresponding to **2a** (s. [8]).

[8]) This interpretation is supported by a kinetic investigation (unpublished).

[9]) In the absence of MB, the photooxygenation of **1a** is about 5 times slower, but gives **2a** and **3a** in similar ratios as in the MB-sensitized reactions[10]).

[10]) In 1971 *Rüttimann* [14] tested (various) metal complexes of a synthetic corrin ligand (1,2,2,7,7,12,12-heptamethylcorrin-15-carbonitril) for their activity as photosensitizers (for singlet oxygen) and found that the corresponding corrinatodicyanocobalt(III) showed hardly any activity.

[11]) In the aprotic solvent systems unspecific decomposition of **1a**, **2a** and **3a** is indicated (by TLC.); a function of methanol might be its known enhanced dismutation of superoxide ion, formed in dye sensitized photooxygenations [15].

An increased degree of deuteriation of the solvent ($CH_3OH \rightarrow CH_3OD \rightarrow CD_3OD$) raises the efficiency of the photooxygenation in preparative experiments (with relative apparent rates of about 1:2.5:6.5, respectively)[12]), but has only little effect on the overall yield (based on consumption of **1a**) and the composition of the oxidation products. This is illustrated by the data in the *Table*. In general, such solvent H/D-isotope effects, known for other solvents from mechanistic work [12], should also be taken into consideration when preparative experiments involving singlet oxygen seem inefficient.

The photooxygenation leads to a substantial total yield of the secocorrinoid photooxygenation products **2a** and **3a**[3])[13]). Thus it should be a convenient alternative method for preparing such cleavage products of cobyrinic acid derivatives (which are only partly accessible *via* ozonolysis reactions [8] [13]).

The photooxygenation of cobester, where singlet excited molecular oxygen presumably acts as the attacking electrophile on the corrinoid π-system, allows an alternative evaluation of the reactivity of the corrinoid ligand towards such an attack[14]). In these experiments the 5,6- and the 14,15-positions seem to display a comparable reactivity, not unexpected on the basis of simple model considerations, *i.e.* taking into account the approximate C_2-symmetry of the π-system of the corrin ligand in corrinoid metal complexes [3f,g]. This contrasts somewhat the recent report on the ozonolysis of the 10-bromo-cobester **1b**, where only the 5,6-cleavage product **2b** is found [8].

I am grateful to Prof. Dr. *A. Eschenmoser* for his support of this work. I would like to thank also Dr. *J. Schreiber* for his valuable contribution to the construction of the photolysis cell and Prof. Dr. *J. Seibl* and Dr. *J. Meili* for their help with the FAB-mass spectra.

Experimental Part

(With assistance of *R. Stepanek*[2]) and *H.-P. Jutzi*[2]))

General. Abbreviations: RV. rotatory evaporator; RT. room temperature; V. and HV. water aspirator and high vacuum; OD. optical density; MB methylene blue; AcOMe methyl acetate; TLC. thin layer chromatography. – TLC.: On plates coated with silica gel 60, *Merck* Art. *5721.* – Solvents and reagents: CH_3OH: *Fluka puriss p.a.*; CH_3OD: *Fluka purum*, >99.5% D; CD_3OD: *Fluka purum*, >99.5% D; CH_2Cl_2, AcOMe, benzene: all practical grade and redistilled; silica gel: *Merck* Kieselgel *60* Nr. *9385;* cobester **1a** [4]: purified by column chromatography and crystallization; MB: see Ph. Hv.; $Na_2Cr_2O_7$: techn. grade. – UV./VIS.: *Perkin-Elmer PE 555* or *Uvikon 810;* citation of λ_{max} ($\log\varepsilon$) in nm, min. = λ_{min}, *S* denotes shoulder. – CD.: *Jobin-Yvon* Mark *III;* wavelength of the extrema and of the zero passages λ_0 in nm (molar decadic circular dichroism [$\Delta\varepsilon$]), *S* denotes shoulder; UV./VIS. and CD. in CH_3OH containing 0.02% of HCN. – IR.: *Perkin-Elmer PE 127;* in $CHCl_3$; cm^{-1}, relative intensities, where *s*, *m*, and *w* denote strong, medium, and weak, respectively. – ^{1}H-NMR.: *Bruker WM-300;* in $CDCl_3$; 300.14 MHz; TMS internal reference, chemical shifts in ppm with

---

12) The solvent H/D-isotope effect is found to be a function of the substrate concentration (unpublished result).

13) The lower yield of **3a** from the experiments in CH_3OH and CH_3OD, compared to CD_3OD, possibly arises from further (preferential) degradation of **3a**.

14) The 'cationic' heptamethyl *Coα*-aqua-*Coβ*-cyanocobyrinate (as perchlorate) [4b] is found to react slower by at least a factor of 10.

δ(TMS) = 0; *s, d, t, qa, m* denote singlet, doublet, *etc.*; coupling constants J in Hz. – ^{13}C-NMR.: *Bruker WM-300;* in $CDCl_3$; 75.47 MHz; TMS internal reference, chemical shift in ppm with δ(TMS) = 0; *s, d, t, qa, m* denote singlet, doublet, *etc.* as displayed in the off-resonance decoupled spectrum. Fast-Atom-Bombardment (FAB). – MS.: *Kratos AEI MS-50* fitted with M-scan FAB-system; argon bombardment at 8–10 kV; glycerol matrix.

Apparatus and experimental set-up. The photolysis cell used here *(Fig. 2)*, designed[15]) especially for the purpose of achieving optimal use of incident light for the irradiation of small solution volumes, consists basically of a flat stainless steel body. A thick glass window allows broad external illumination under slight pressure (up to several atm of gas). In the experiments described here, an oxygen pressure of 1 atm was continuously maintained by a slow stream of O_2 through the reaction solution.

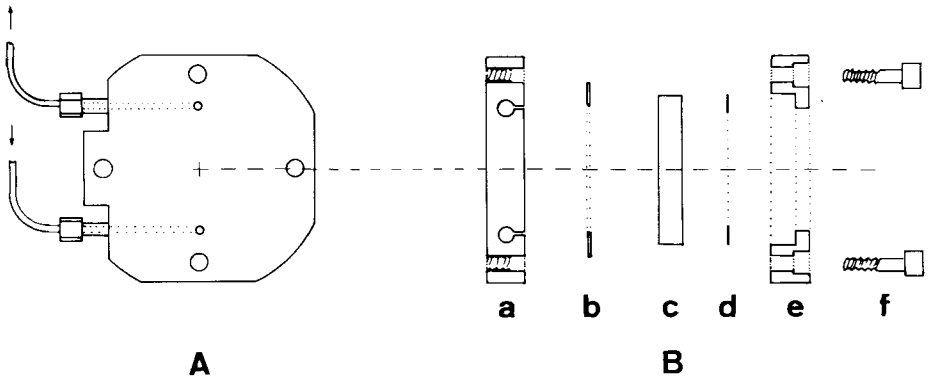


Fig. 2. *Schematic drawing of the dissembled photolysis cell*[15]). A) View from the rear; arrows indicate gas flow during experiment. B) Side view of dissembled parts (a: rear plate (stainless steel); b: *Teflon* ring as spacer; c: glass window; d: seal; e: front plate (stainless steel); f: (four) screws).

During irradiation, the photolysis cell was immersed into a filter/cooling system consisting of two concentrically arranged *Pyrex* beakers (3 and 2 l) the inner one of which was filled at constant level with running water as cooling solution (15°), while the space between the two beakers was filled with a filter solution of sodium dichromate (0.5 M) in distilled water[16]), to cut off light of $\lambda < 550$ nm. A 15 V/150 W halogen lamp (type *EFR, General Electric*) with ellipsoidal mirror was placed in front of the photolysis cell (at twice the focal length of the mirror) so as to illuminate the photolysis solution horizontally and evenly through the *Pyrex* window of the cell (and through the filter/cooling solutions). The concentration of MB was chosen to give an OD. of 1.5 (at 650 nm) initially (degradation of MB was insignificant).

Sensitized photooxygenation of cobester **1a**. A solution of 118 mg (108 µmol) of crystalline cobester **1a** and of 0.11 mg (0.34 µmol) of MB in 3.1 ml of CH_3OD was introduced into the photolysis cell under oxygen. A slow stream of oxygen was maintained through the cell, while the position of the cell was adjusted in the filter/cooling bath to ensure a homogeneous illumination of the solution with the 150 W halogen lamp[17]). After the reaction solution had been purged with oxygen for several min, the photolysis was started and the oxygen flow continued during the reaction. Samples of equal volume were withdrawn at regular intervals to monitor the progress of the reaction (by TLC. and UV./VIS.). After 90 min of irradiation, the consumption of **1a** was estimated to be about 90%, and the photolysis was stopped. The content of the reactor was transferred and the solvent evaporated (RV., $\leq$40°/V.). The residue was then chromatographed on a column ($\varnothing$ = 3 cm; 15 cm length) of 50 g of silica gel with AcOMe/benzene 4:1 (containing 0,2% acetone-cyanohydrin). Separation of **1a**, **2a**, and **3a** was

[15]) The photolysis cell was designed and constructed by Dr. *J. Schreiber.*

[16]) Regular checks ensured the relevant optical properties to be constant: OD. > 1.5 for $\lambda < 543$ nm and OD. < 0.01 for $\lambda > 600$ nm (1 cm path length); no noticeable change was observed over weeks.

[17]) In this experiment a 15 V/150 W halogen lamp (BLV *Licht und Vakuum Technik*, W. Germany, type *EFR*) was used.

not complete, and a small fraction containing **1a** and **3a** (*ca.* 10 μmol) was purified by TLC. with the same solvent mixture[18]). The combined fractions of **1a**, **2a**, and **3a** were evaporated to dryness (RV., ≤40°/V.), the individual residues taken up in CH_2Cl_2, filtered through a plug of dried cotton (in a pipette), and dried. Then the raw yields were determined spectroscopically in methanol[19]), **1a**: 13.2 μmol; **2a**: 53.0 μmol; **3a**: 29.0 μmol.

The individual fractions were then taken to dryness, dissolved in about 20 ml of CH_2Cl_2 and shaken with *ca.* 20 ml of satd. aq. $NaHCO_3$-solution (in which 20 mg of KCN had been dissolved). The organic layer was separated, dried by filtration through cotton, and the solvent was evaporated (RV., RT./V.).

From the fraction of raw **1a** 12.9 mg (11.8 μmol) of crystalline cobester was reisolated. Fraction **2a** was taken up in *ca.* 0.5 ml of CH_2Cl_2 and 1 ml of benzene and precipitated by adding it to 25 ml of cyclohexane, giving 56.5 mg (50.5 μmol; 47%) of **2a** as powdery orange-brown solid. Fraction **3a** was dissolved in *ca.* 2 ml of AcOMe and 3 ml cyclohexane and crystallized (after seeding) by keeping the solution (in a stoppered flask) in the refrigerator overnight: 26.1 mg of orange-brown crystals of **3a**. Chromatography (TLC.) of the mother-liquor and workup as above gave further 4.6 mg of crystalline **3a**; total yield of **3a**: 30.7 mg (27.4 μmol; 25%). Total yield of **2a**/**3a**: 72% (or 81%, if corrected for the reisolated **1a**). The oxygenation products isolated this way were pure by TLC. and identified (TLC., UV./VIS. and ^{1}H-NMR.) with the material characterized earlier.

Samples of **2a** and **3a** from several (smaller scale) photooxygenations, performed under similar conditions, identified by TLC., UV./VIS. and ^{1}H-NMR., were combined, precipitated (for **2a**) and crystallized (for **3a**) as described above, and dried (RT./HV., 48 h). *Heptamethyl* Coα,Coβ*-dicyano-5,6-dioxo-5,6-secocobyrinate* (**2a**) [8]: TLC. (AcOMe/benzene/acetone-cyanohydrin 4:1:0.01): Rf 0.18. M.p. 109–110° ([8]: 111°). – UV./VIS. ($c = 5.7 \cdot 10^{-5}$mol/l): 270 *S* (3.99), 290 *S* (3.90), 326 (3.96), 364 *S* (3.45), 481 (3.92); min. 302, 390 br.[20]). – CD. ($c = 5.7 \cdot 10^{-5}$ mol/l): 269 (−8.4), 297 *S* (3.5), 329 (32.4), 354 (14.8), 424 (−22.2), 467 (−25.7), 551 (6.35); λ_0 at 258, 287, 379, 526. – IR. (4.3%)[21]): 2126*w*, 1734*s*, 1555*m*, 1525*m*, 1498*m*, 1438*s*, 1400*m*, 1370*m*, 1105*s*, *etc.* – ^{1}H-NMR. and ^{13}C-NMR.: chemical shift values coincide with those reported in [8][22]). – FAB-MS.[23]): 1072 (33), 1071 (61), 1070 (100, $(M+1)^+ - 51$); 1069 (22), 1068 (28, $(M+1)^+ - 53$), 1056 (12), 771 (5, $(M+1)^+ - 2CN - H_2 - 296$)[24]), 699 (17, $(M+1)^+ - 2CN - 370$)[24]), 685 (16, $(M+1)^+ - 2CN - 384$)[24]), 613 (14, $(M+1)^+ - 2CN - 456$), *etc.*

Heptamethyl Coα,Coβ*-dicyano-14,15-dioxo-14,15-secocobyrinate* (**3a**): TLC. (AcOMe/benzene/acetone-cyanohydrin 4:1:0.01): Rf 0.28. M.p. 126–128° (darkens at 120°). – UV./VIS. ($c = 1.16 \cdot 10^{-4}$ mol/l): 270 *S* (3.99), 286 *S* (3.88), 326 (4.02), 364 *S* (3.31), 481 (3.99), 564 *S* (3.31); min. 299, 382. – CD. ($c = 1.16 \cdot 10^{-4}$ mol/l): 272 (−6.0), 294 *S* (3.0), 329 (47.8), 358 *S* (14.7), 418 (−18.5), 482 (−37.1), 561 (8.6); λ_0 at 262, 286, 375, 532. – IR. (4%): 2126*w*, 1734*s*, 1566*m*, 1534*m*, 1500*m*, 1438*s*, 1401*m*, 1380*m*, *etc.* – ^{1}H-NMR.: 1.25, 1.31 (double int.), 1.32, 1.33 and 1.50 (5 *s*, 18 H, 6 CH_3); 2.10 (*s*, $H_3C(5')$) and 2.82 (*s*, $H_3C(15')$) overlapped by 1.6–3.0 (*m*), 2.34/3.34 (*AB*-system, $J_{AB} = 15$) and 3.22 (*d*×*d*, 1 H), in total 31 H; 3.63, 3.66, 3.67, 3.69 (double int.), 3.72 and 3.74 (6 *s*, 22 H, 7 $COOCH_3$)[26]); 3.85 (*d*-like, 1 H); 4.96 (*d*, $J = 8$, 1 H, H–C(19)); 5.54 (*s*, 1 H, H–C(10)). – ^{13}C-NMR.: 15.7 (*qa*, C(5));

---

[18]) The fractions corresponding to **1a** and **2a** were scraped and eluted with CH_2Cl_2/CH_3OH 10:1 (containing 1% HCN).

[19]) **1a** ($\varepsilon_{583} = 10{,}900$).

[20]) λ_{max} and relative intensities as in [8], but extinction coefficients larger by 1.5.

[21]) These values deviate noticeably from those given in [8].

[22]) Maximal deviations: ^{1}H-NMR.: 0 to +0.02 ppm; ^{13}C-NMR.: 0 to −0.1 ppm.

[23]) The spectra[25]) of noncrystalline samples of both **2a** and **3a** showed a base peak at *m/z* 1070 (one mass number larger than expected for a fragment by loss of axial cyanide ligands), without apparent effect on the fragment ion mass numbers. ^{1}H-NMR. and ^{13}C-NMR. do not indicate specific deuteriation.

[24]) Interpretation of fragments: 296 = ring A; 370 = 296 + 74 ($CH_3CO_2CH_3$); 384 = 296 + 88 ($C_4H_8O_2$).

[25]) We thank *M-Scan, Ltd.*, Iver, U.K., for collecting FAB-mass spectra of (noncrystalline samples of) **2a** and **3a**.

[26]) The H–C(8) signal is presumably hidden by the $COOCH_3$ signals: a 300.14-MHz-NMR. spectrum in C_6D_6 (TMS int. standard) shows these signals shifted to higher field (3.24–3.44 ppm), and a *m* due to two oberlapping signals appears at 3.8–4 ppm (presumably H–C(3) and H–C(8)); a *d* at 5.18 (1 H, $J = 8$) and a *s* at 5.65 (1 H) again can be assigned to H–C(19) and H–C(10), respectively.

16.6, 19.5, 19.6 and 20.2 (4 *qa*, 4 CH_3); 20.7 (*t*, $H_2C(13')$?); 24.1 (*qa*); 24.9, 25.3 (2 *t*); 25.5 (*qa*, $H_3C_\beta(12')$?); 29.9, 31.4, 31.5 and 31.8 (4 *t*); 32.9 (*qa*, $H_3C(15')$); 32.9 and 33.5 (2 *t*); 38.1 (*d*, HC(18)); 41.1 and 41.9 (2 *t*); 45.8, 46.4 and 49.5 (3 *s*, C(2), C(7), C(12)); 50.2 (*d*); 51.5, 51.7, 51.8, 51.9 (double int.), 52.1 and 52.5 (6 *qa*, 7 $COOCH_3$); 54.4 and 56.3 (2 *d*, HC(3), HC(8)?); 62.6 (*s*, C(17)); 82.0 (*d*, HC(19)); 84.4 (*s*, C(1)); 94.7 (*d*, HC(10)); 105.8 (*s*, C(5)); 131.4 and 135.3 (2 *s*, *C*N); 162.7 (*s*, C(6)); 170.8, 171.7, 172.1, 172.3, 172.8, 173.6, 174.3, 175.3 and 176.4 (9 *s*, 7 *C*$OOCH_3$ and 2 imine C-atoms); 183.8, 183.9 and 190.8 (3 *s*, lactam–*C*O(C(15)) and 2 imine C-atoms); 197.9 (*s*, acetyl–*C*O(C(14))). – FAB-MS.[23]): 1072 (14), 1071 (31), 1070 (61), 1069 (100, $(M+1)^+-2CN$); 1068 (39), 1067 (55, $(M+1)^+-2CN-H_2$); 1055 (15), 1039 (11), 1025 (13), 1011 (11), 995 (10), 785 (11, $(M+1)^+-2CN-H_2-282$)[27]); 714 (15), 713 (34, $(M+1)^+-2CN-356$)[27]); 699 (8, $(M+1)^+-2CN-370$)[27]); 627 (9), 625 (8, $(M+1)^+-2CN-444$)[27]); *etc.*

$C_{54}H_{73}CoN_6O_{16}$ Calc. C 57.85 H 6.56 N 7.50% Found C 57.98 H 6.63 N 7.37%

REFERENCES

[1] *D.C. Hodgkin, A.W. Johnson & A.R. Todd*, Chem. Soc., London, Spec. Publ. *3*, 109 (1955).

[2] *K. Folkers & D.E. Wolf*, Vitamins and Hormones *12*, 1 (1954).

[3] a) *E.L. Smith*, 'Vitamin B_{12}', 3rd ed., Methuen & Co., London 1965; b) *J.M. Pratt*, 'Inorganic Chemistry of Vitamin B_{12}', Acad. Press, London 1972; c) *W. Friedrich*, «Vitamin B_{12} und verwandte Corrinoide», Vol. III/2, «Fermente, Hormone und Vitamine», eds. R. Ammon & W. Dirscherl, G. Thieme, Stuttgart 1975; d) *R. Bonnett*, in 'B_{12}', ed. D. Dolphin, Vol. I, J. Wiley & Sons, New York 1982, p. 201; e) *A.R. Battersby & E. McDonald*, in 'B_{12}', ed. D. Dolphin, Vol. I, J. Wiley & Sons, New York 1982, p. 107; f) *J. Pickworth-Glusker*, in 'B_{12}', ed. D. Dolphin, Vol. I, J. Wiley & Sons, New York 1982, p. 23; g) *R. Keese*, Tetrahedron Lett. *1969*, 149.

[4] a) *R. Keese, L. Werthemann & A. Eschenmoser* (1965), unpublished; b) *L. Werthemann*, Dissertation ETH Zürich, No. 4097 (1968).

[5] a) *T.L. Bogard & A. Eschenmoser*, unpublished work, cited in [6a]; b) *P. Löliger*, Dissertation ETH Zürich, No. 4074 (1968).

[6] a) *A.R. Battersby, M. Ihara, E. McDonald, J.R. Stephenson & B.T. Golding*, J. Chem. Soc., Chem. Commun. *1973*, 404; b) *C. Nussbaumer, M. Imfeld, G. Wörner, G. Müller & D. Arigoni*, Proc. Natl. Acad. Sci. USA *78*, 9 (1981); c) *D. Arigoni*, Ciba Foundation Symposium No. 60, 'Molecular Interactions and Activity in Proteins', Excerpta Medica, Amsterdam 1978, p. 243.

[7] *A. Gossauer, K.-P. Heise, H. Götze & H.H. Inhoffen*, Justus Liebigs Ann. Chem. *1977*, 1480.

[8] *R.-P. Hinze, H.M. Schiebel, H. Laas, K.-P. Heise, A. Gossauer, H.H. Inhoffen, L. Ernst & H.-R. Schulten*, Liebigs Ann. Chem. *1979*, 811.

[9] *L. Ernst, G. Holze & H.H. Inhoffen*, Liebigs Ann. Chem. *1981*, 198.

[10] a) *M. Barber, R.S. Bordoli, R.D. Sedgwick & A. Tyler*, J. Chem. Soc., Chem. Commun. *1981*, 325; b) *D.J. Surman & J.C. Vickerman*, J. Chem. Soc., Chem. Commun. *1981*, 324; c) *D.H. Williams, C. Bradley, G. Bojesen, S. Santikarn & L.C.E. Taylor*, J. Am. Chem. Soc. *103*, 5700 (1981).

[11] *J. Seibl*, Org. Mass Spectrom. *1*, 215 (1968).

[12] a) *P.B. Merkel, R. Nilsson & D.R. Kearns*, J. Am. Chem. Soc. *93*, 1030 (1971); b) *D.R. Kearns*, in 'Singlet Oxygen', eds. H.H. Wasserman & R.W. Murray, Acad. Press, New York 1979, p. 115.

[13] *G. Bartels, R.-P. Hinze, H.H. Inhoffen & L. Ernst*, Liebigs Ann. Chem. *1979*, 1440.

[14] *A. Rüttimann*, Dissertation ETH Zürich, No. 5186 (1973).

[15] a) *G.S. Cox, D.G. Whitten & C. Gianotti*, Chem. Phys. Lett. *67*, 511 (1979); b) *J.A. Tee & J.S. Valentine*, in 'Superoxide and Superoxide Dismutase, eds. A.M. Michelson, J.M. McCord & I. Fridovich, Acad. Press, London 1977.

---

[27]) Interpretation of fragments: 282 = ring D; 356 = 282 + 74 ($CH_3CO_2CH_3$); 370 = 282 + 88 ($C_4H_8O_2$); 444 = 282 + 74 + 88.