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Cyanide-Coordination Effect on Photochemical Carbon-Skeleton Rearrangements of Alkyl Ligands Coordinated to Vitamin B_{12} Model Complexes

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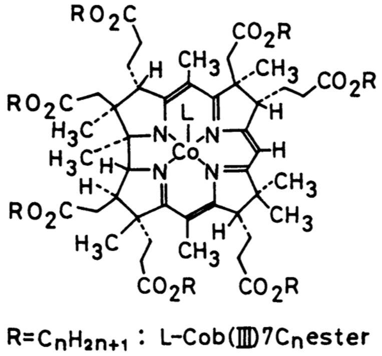
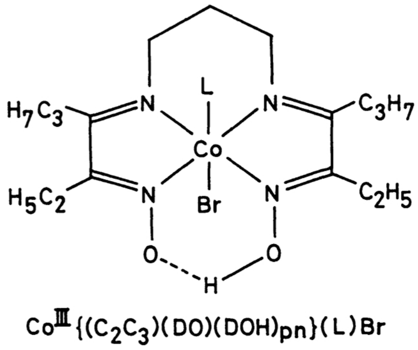
The cyanide ion induced the heterolytic cleavage of the cobalt-carbon bond involved in vitamin B_{12} model complexes by its coordination to the central cobalt atom and enhanced the carbon-skeleton rearrangements via formation of anionic intermediates under anaerobic irradiation with the visible light.

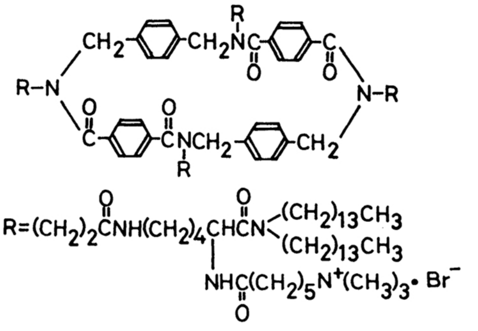
Vitamin B_{12}-dependent enzymes catalyze various carbon-skeleton rearrangement reactions which are not explained clearly from the viewpoints of organometallic and organic chemistry so far studied. Thus, clarification of reaction mechanisms involved therein has become a fascinating research target in bioinorganic chemistry. We have been dealing with vitamin B_{12} model chemistry in connection with microenvironmental effects on the catalytic activity in two different manners as follows. (i) Holoenzyme model systems are composed of a hydrophobic vitamin B_{12} and an apoenzyme model such as an octopus azaparacyclophane, APC[C_2Lys(C_5N^+)2C_{14}]$_4$, or the single-compartment vesicle of N^+C_5Ala2C_{16}, and the catalytic reactions are carried out in aqueous media under photolysis conditions.[1)] (ii) Electrochemical reactions catalyzed by a hydrophobic vitamin B_{12} or a relevant model complex are carried out in organic solvents.[2)] In the light of our previous studies, it has become apparent that the rearrangement reactions of model substrates proceed much readily via formation of anionic intermediates as compared with those via formation of radical ones, even though the reaction is generally considered to proceed via radical mechanisms in vivo. In this work, we found that cyanide ions enhanced the formation of anionic species from alkylated vitamin B_{12} model complexes and the rearrangement reactions proceeded readily under photolysis conditions.



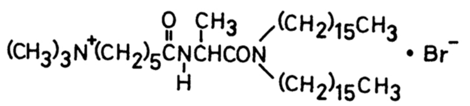
R=C_nH_{2n+1} : L-Cob(III)7$C_n$ester



Co^{III}\{(C_2C_3)(DO)(DOH)pn\}(L)Br



APC[C$_2$Lys(C$_5$N$^+$)2C$_{14}$]$_4$



$$(CH_3)_3\overset{+}{N}(CH_2)_5\overset{O}{\overset{\|}{C}}\underset{H}{N}\overset{CH_3}{\overset{|}{C}}HCON\begin{matrix}(CH_2)_{15}CH_3\\(CH_2)_{15}CH_3\end{matrix}\cdot Br^-$$

N$^+$C$_5$Ala2C$_{16}$

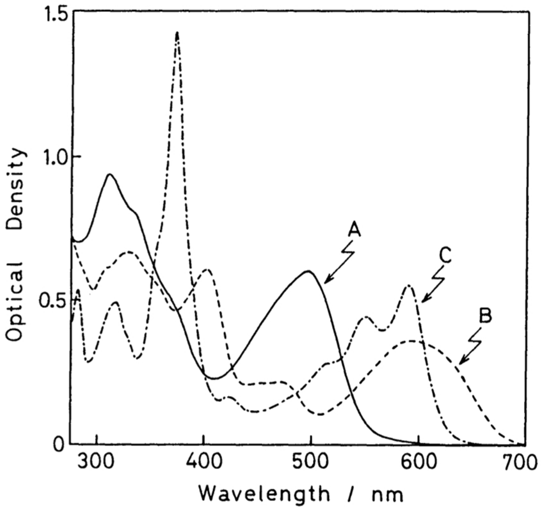


Fig. 1. Electronic spectra for anaerobic photolysis of CH_3-Cob(III)-7C$_1$ester in DMF at 20.5 ± 0.1 °C: A, the methylated complex (5.0×10^{-5} mol dm^{-3}) alone; B, after addition of TBA-CN (1.0×10^{-2} mol dm^{-3}) to A; C, B being irradiated with a 200-W tungsten lamp from a distance of 90 cm for 5 min under nitrogen atmosphere.

The coordination of cyanide ions to methylcobalamin or methylcobaloxime at the cobalt atom has been claimed to result in an increase in electron density at the metal atom and enhanced reduction of the methyl group to the corresponding carbanion species upon photolysis.$^{3)}$ We confirmed such a heterolytic cleavage by means of spectroscopic measurements. When CH_3-Cob(III)7C$_1$ester in N,N-dimethylformamide (DMF) was irradiated with the visible light in the presence of cyanide ions under anaerobic conditions, spectral changes were observed as shown in Fig. 1. CH_3-Cob(III)7C$_1$ester was converted first into (CH_3)(CN)Cob(III)7C$_1$ester upon addition of tetra-n-butylammonium cyanide (TBA-CN) (B in Fig. 1) and then transformed into $(CN)_2$Cob(III)7C$_1$ester under anaerobic irradiation conditions (C in Fig. 1). This reaction was also examined by the spin-trapping technique with α-phenyl-N-(t-butyl)nitrone (PBN). ESR spectra for the PBN spin adduct formed in the course of photolysis are shown in Fig. 2. ESR signals attributable to the PBN spin adduct were clearly observed (A in Fig. 2), while the signal intensities became much weaker upon addition of the cyanide ion under otherwise identical conditions (B in Fig. 2). The Co^{II} species was clearly observed without the cyanide ion (A in Fig. 3), but the corresponding signal intensities became markedly weaker upon addition of the cyanide ion (B in Fig. 3). These ESR spectra clearly indicate that CH_3-Cob(III)7C$_1$ester is cleaved to the Co^{II} species and the methyl radical under anaerobic irradiation conditions, and then an electron is transferred from the cobalt atom to the methyl radical when the cyanide ion is coordinated to the central cobalt atom (Eq. 1). The rate constant for the spin-trapping reaction with PBN was reported to be 4×10^6 mol^{-1} dm^3 s^{-1} for the methyl radical.$^{4)}$ On the basis of the above ESR experiments, the rate for the electron transfer seems to be comparable to that for the spin-trapping reaction.

Since the above results prove that the cobalt-carbon bond undergoes heteroly-

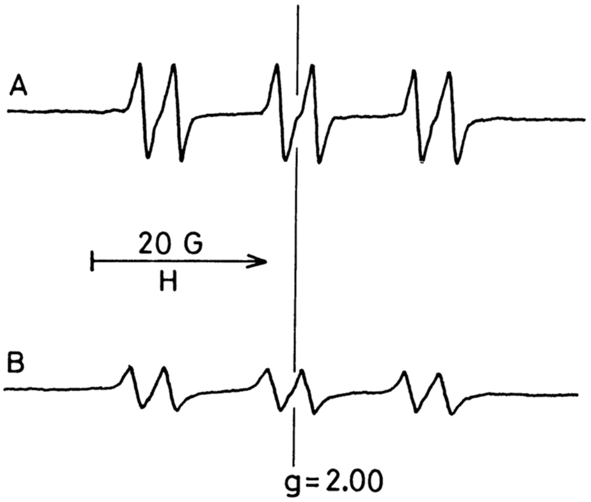


Fig. 2. ESR spectra for a system containing CH_3-Cob(III)7C_1ester (8.5×10^{-3} mol dm^{-3}) and PBN (9.5×10^{-2} mol dm^{-3}) in methanol under anaerobic irradiation with a 500-W tungsten lamp from a distance of 30 cm for 2 h: A, without KCN; B, in the presence of KCN (0.19 mol dm^{-3}).

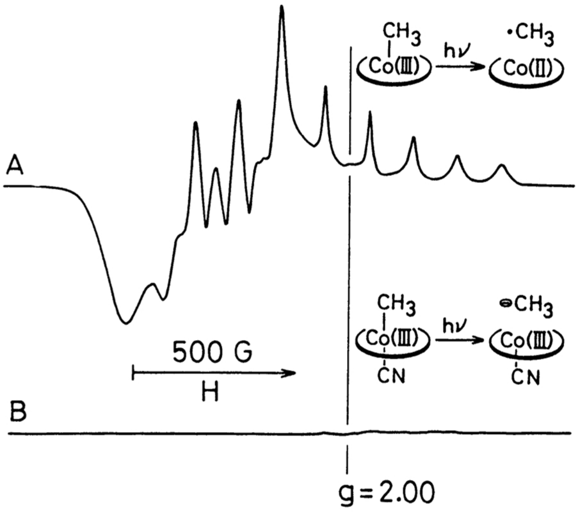
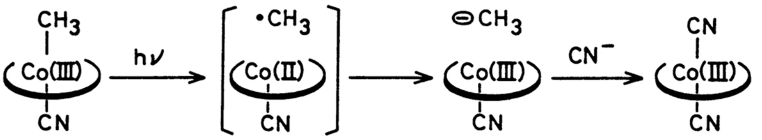


Fig. 3. ESR spectra for CH_3-Cob(III)7C_1ester (8.5×10^{-3} mol dm^{-3}) in methanol at 77 K, anaerobic irradiation being performed with a 500-W tungsten lamp from a distance of 30 cm for 100 h at room temperature before the measurements: A, without KCN; B, in the presence of KCN (0.19 mol dm^{-3}).



(1)

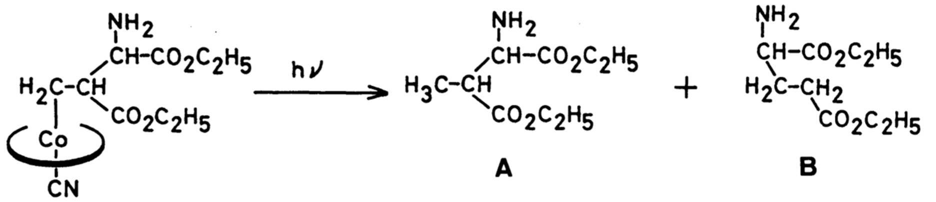
sis under the specified conditions, we investigated the cyanide-coordination effect on the photochemical carbon-skeleton rearrangements of substituted alkyl ligands coordinated to a hydrophobic vitamin B_{12}. Various solutions containing $(CO_2C_2H_5)$-$(NH_2)CHCH(CO_2C_2H_5)CH_2$-Cob(III)7$C_3$ester and TBACN were irradiated with the visible light under anaerobic conditions in a manner as described previously,[1)] and the products were analyzed by GLC (Table 1; refer to Eq. 2). The ratio of the rearrangement product, **B**/**A** in Table 1, for the glutamate mutase-like reaction in the presence of TBACN was large as compared with that for the reaction without cyanide ions. In particular, the rearrangement reaction was the major one in apoenzyme models, APC[C_2Lys(C_5N^+)2C_{14}]$_4$ and the N^+C_5Ala2C_{16} vesicle. The similar cyanide effect as regards acceleration of carbon-skeleton rearrangements was observed for other substrates having carboxylic ester, acetyl, and cyano groups. These reactions are now consistent with a mechanism involving formation of an anionic intermediate derived from the corresponding coordinated alkyl ligand by the heterolytic cleavage of the cobalt-carbon bond as enhanced via cyanide-ion coordination to the cobalt atom.

The cyanide-coordination effect on the photochemical carbon-skeleton rearrangement was also observed for an alkylated vitamin B_{12} model, Co^{III}\{$(C_2C_3)(DO)$-

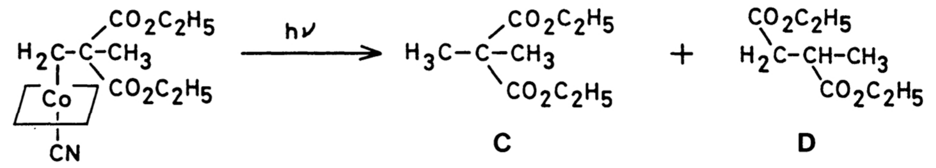
Table 1. Product analyses for photolysis of $(CO_2C_2H_5)(NH_2)CHCH(CO_2C_2H_5)CH_2$-Cob(III)7$C_3$ester in various media at 20 °C[a)]

	Yield/%					
	In the presence of TBACN[b)]			Without TBACN		
Medium	**A**	**B**	**B/A**	**A**	**B**	**B/A**
Methanol	63 ± 4	15 ± 5	0.25	83 ± 5[e)]	0	0
Benzene	60 ± 3	21 ± 4	0.35	78 ± 2[e)]	Trace[e)]	~0
APC[C_2Lys(C_5N^+)2C_{14}]$_4$[c)]	36 ± 4	45 ± 3	1.25	68 ± 4	15 ± 4	0.22
N^+C_5Ala2C_{16}[d)]	36 ± 5	42 ± 4	1.17	66 ± 5[e)]	14 ± 3[e)]	0.21

a) A solution containing the alkylated complex (5.0×10^{-5} mol dm^{-3}) was irradiated with a 500-W tungsten lamp for 1 h from a distance of 30 cm under anaerobic conditions. Products were analyzed by GLC. b) TBACN, 6.0×10^{-4} mol dm^{-3}. c) APC[C_2-Lys(C_5N^+)2C_{14}]$_4$ (5.0×10^{-5} mol dm^{-3}) in phosphate—borate buffer (0.05 mol dm^{-3}, pH 9.2). d) N^+C_5Ala2C_{16} (5.0×10^{-3} mol dm^{-3}), as single-compartment vesicles, in phosphate—borate buffer (0.05 mol dm^{-3}, pH 9.2). e) Reference 1.



(2)



(3)

$(DOH)_{pn}\}\{(C_2H_5CO_2)_2(CH_3)CH_2\}Br$. When the alkylated complex (7.7×10^{-2} mol dm^{-3}) was irradiated with the visible light in DMF under anaerobic conditions in the presence of TBACN (0.77 mol dm^{-3}), 1,2-bis(ethoxycarbonyl)propane (**D**), the ester-migrated product, was obtained in a yield greater than 90% (refer to Eq. 3).

In conclusion, the cyanide ion induces the heterolytic cleavage of the cobalt-carbon bond involved in vitamin B_{12} model complexes under anaerobic irradiation conditions, and the photochemical carbon-skeleton rearrangement reactions proceed via formation of anionic intermediates.

References

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