Dual Nature of (Phenylseleno)cobaloxime in the Reaction with 2-Propynyl Derivatives

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Photolysis or thermolysis of (phenylseleno)cobaloxime gives a pair of radicals: phenylseleno radical and cobaloxime radical, which are considered to be equilibrated with the ion pair by a single electron transfer. The radical addition on the acetylenic moiety takes place when the 2-propynyl derivatives have weak leaving groups (OH, OPh, OAc). On the other hand, the ionic substitution with phenylseleno anion takes place on bromides and tosylates.

Alkylcobaloxime has been widely used as a versatile and easily obtainable model of alkylcobalamin, alkyl(coenzyme-B_{12}).$^{1)}$ The alkyl–cobalt bond of alkylcobaloxime cleaves easily in a homolytic manner on photolysis or thermolysis.$^{2)}$ The radical pair thus formed mimics the B_{12}-mediated radical process$^{3)}$ which has been proved by a magnetic field effect.$^{4)}$

We have been studying the radical reactions of sulfur compound with alkylcobaloximes and we have suggested the possible involvement of cobalt–sulfur interaction during the radical process.$^{3f,3g,3h,5)}$ As an extension of these studies we were prompted to investigate the reaction of (phenylseleno)cobaloxime to clarify the chemical behavior of selenocobaloxime (Fig. 1). Back and Krishna$^{6)}$ and Sonoda et al.$^{7)}$ showed that the radical addition of diselenide to an acetylenic compound gives a vicinal bis(seleno)ethylene (Eq. 1). In these reactions, the intermediate 2-(phenylseleno)vinyl radical attacks diselenide to cause a homolytic substitution reaction on selenium.$^{8)}$ (Phenylseleno)cobaloxime is expected to yield a phenylseleno radical and a cobaloxime(II) with a radical nature on photolysis or thermolysis (Eq. 2), and the addition of phenylseleno radical to an acetylene gives 2-(phenylseleno)vinyl radical as a reaction intermediate (Eq. 3). The selenovinyl radical thus formed can couple with the coexisting cobaloxime radical (route a) or its allylic hydrogen can be abstracted by the cobaloxime radical (route b) (Scheme 1).

$$\mathrm{RC{\equiv}CH} + \mathrm{(PhSe)_2} \rightarrow \mathrm{RC(SePh){=}CH(SePh)} \qquad (1)$$

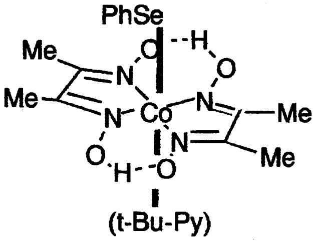


Fig. 1. Structure of (Phenylseleno)cobaloxime (**1**).

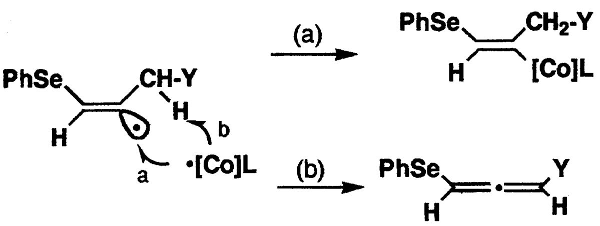
$$\mathrm{PhSe[Co]L} \rightarrow \mathrm{PhSe\cdot} + \mathrm{\cdot[Co]L} \qquad (2)$$

$$\mathrm{PhSe\cdot} + \mathrm{HC{\equiv}CR} \rightarrow \mathrm{PhSe(H)C{=}C(R)\cdot} \qquad (3)$$

With those expectations, a mixture of an acetylene derivative and (4-*t*-butylpyridine)bis(dimethylglyoximato)(phenylseleno)cobalt(III) (**1**),$^{9)}$ hereafter (phenylseleno)cobaloxime or PhSe[Co]L, was irradiated or heated in the presence of 2-propynyl acetate.

Results and Discussion

The reaction with 2-propyn-1-ol (**2a**) gave [(*E*)-2-phenylseleno-1-(hydroxymethyl)vinyl]cobaloxime (**3a**), (*E*)- and (*Z*)-3-(phenylseleno)-2-propenal (**6**),$^{10)}$ and diphenyl diselenide (**5**) (Scheme 2 and Table 1). The structure of **3a** was deduced from its ^{1}H NMR spectrum and the reductive demetalation of **3a** by zinc–acetic acid to give (*Z*)-3-phenylseleno-2-propen-1-ol (Eq. 4). The *E*-configuration of **3a** is shown by the exclusive formation of this less stable *Z*-isomer on the reductive cleavage of the vinyl–cobalt bond.

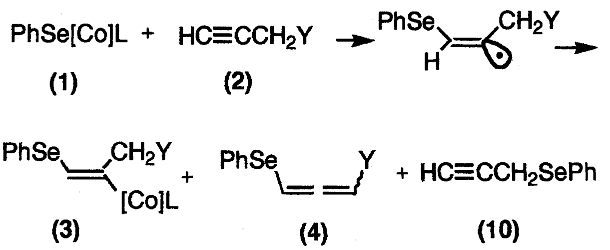


Scheme 1.

Table 1. Reaction of (Phenylseleno)cobaloxime (**1**) with 2-Propynyl Derivatives under Photolysis ($h\nu$)[a] or Thermolysis (Δ)[b]

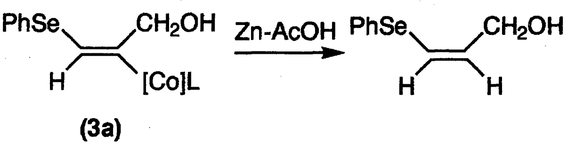
Substrate	Solvent	Activation method[a,b]	Reaction time/h	Product (yield/%)	
2a[c]	Neat	$h\nu$	48	**3a** (45) **6** (5)	**5** (trace)
2a[c]	Neat	Δ	2	**3a** (40) **6** (trace)	**5** (trace)
2b[d]	CH_3CN	$h\nu$	96	**3b** (32)	**5** (trace)
2b[d]	CH_3CN	Δ	9.5	**3b** (67)	
2c[d]	CH_3CN	$h\nu$	51[f]	**5** (trace)	**7** (12)
2c[d]	CH_3CN	Δ	6.5[g]	**3c** (55)	**7** (12)
8a[e]	CH_3CN	Δ	10 min	**10a** (78)	
8b[e]	CH_3CN	Δ	23	**10a** (55)	
9a[e]	CH_3CN	Δ	3	**10b** (58)	
9b[e]	CH_3CN	Δ	39	**10b** (23)	

a) Irradiation by Rayonett 350 nm lamps at ca. 25 °C. b) Heated to 80 °C. c) [**2**]/[**1**]=(10 mol dm^{-3})/(0.2 mol dm^{-3}). d) [**2**]/[**1**]=(2.0 mol dm^{-3})/(0.2 mol dm^{-3}). e) [**8** or **9**]/[**1**]=(0.2 mol dm^{-3})/(0.2 mol dm^{-3}). f) Selenocobaloxime **1** was recovered in 53% yield. g) Selenocobaloxime **1** was recovered in 35% yield.



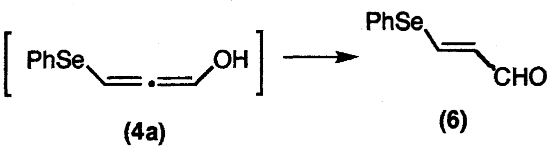
2a,3a,4a: Y=OH ; **2b,3b,4b**: Y=OPh; **2c,3c,4c**: Y=OAc

Scheme 2.

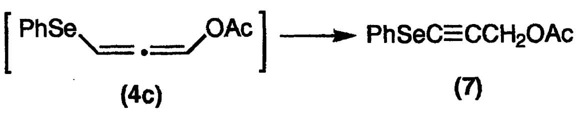


(4)

Product **6** is the photoequilibrated cis–trans mixture which derived from the initial product, 3-phenylseleno-1,2-propadien-1-ol (**4a**), formed by route (b) (Scheme 2 and Eq. 5). Thus the first attack of the phenylseleno radical on 2-propyn-1-ol (**2a**) gives a vinyl radical and the second attack by the cobaloxime radical occurs competitively at the radical center (route a) or the allylic hydrogen of the intermediate (route b) (Scheme 1). Both processes are characteristic properties of cobaloxime. In fact, the radical coupling of this type is important in the formation of organocobaloxime by a single electron transfer mechanism.[11] A typical mode of the decomposition of organocobaloxime on photolysis or thermolysis involves abstraction of the β-hydrogen of alkyl radical by cobaloxime(II) radical.[12] The relative importance of those two processes is controlled by the activation of the allylic hydrogen and the steric hindrance is controlled by another allylic residue (Y). We can not specify the relative importance of these two routes but the allylic interaction of the carbon–oxygen bond and the allylic hydrogen with the radical center must be taken into account.



(5)



(6)

The reaction of (phenylseleno)cobaloxime **1** with 3-phenoxy-1-propyne (**2b**) and 2-propynyl acetate (**2c**) in acetonitrile gave (selenovinyl)cobaloximes **3b**, **3c**, and 3-acetoxy-1-phenylseleno-1-propyne (**7**). The product **7** may be formed through an acetylenic radical intermediate (•C≡CCH_2OAc), but the abstraction of acetylenic hydrogen should be much less probable than the abstraction of 2-propynyl hydrogen. Irradiation of (vinyl)-cobaloxime **3c** did not give the selenoacetylene derivative **7**. The product **7**, therefore, is considered to be derived from the allenic intermediate **4c** by the shift of the double bond (Eq. 6). This type of isomerization has been reported to occur under the influence of a seleno anion.[13] This kind of π-bond migration is also catalyzed by the hydridecobaloxime, H[Co]L,[12b] which formed together with **4c**, this is another possible mechanism for the formation of **7**.

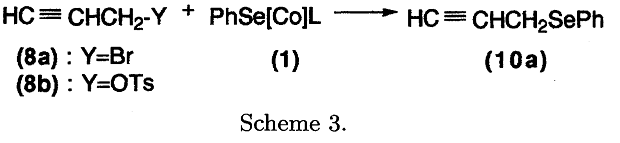
Formations of **3**'s and **6**'s can be considered as secondary processes from 2-propynyl derivatives **2**'s and diphenyl diselenide (**5**), which derives from (phenylseleno)cobaloxime (**1**). Indeed, the diselenide **5** is formed in considerable amounts when the molar ratio (**2**'s/**1**) in the reaction mixture is low; we used the molar ratio (**2**'s/**1**) of ten or more. However, bis(phenylseleno)ethylene, which is the expected product from the diselenide,[6,7] was not found in the product mixture. The reactions of **2b** and **2c** under thermolysis of (phenylseleno)cobaloxime (**1**) gave the phenylseleno-adducts in better yields than the reactions under photolyses. These considerations diminish the possibility of the adduct formation by the photolysis of the diphenyl diselenide (**5**).

In these reactions, ten molar equivalents of 2-propynyl ether (**2b**) or 2-propynyl acetate (**2c**) were reacted in acetonitrile, and the reactions were slow in comparison to the reaction in neat 2-propyn-1-ol (**2a**) (ca. 50 equivalents).

The photochemical reactions with **2a**—**2c** are rather sluggish probably due to the fast recombination of the phenylseleno radical and cobaloxime(II) radical. Facile thermal reactions, on the other hand, are considered to be a consequence of the fast diffusion of the radical pair at the elevated temperature. Thus, a considerable amount of the starting (phenylseleno)cobaloxime (**1**) was recovered intact after the reaction, though its recovery yields was not determined in most cases. In the reaction with ester **2c**, **1** was recovered in 53% yield after the photolysis and 35% yield after the thermal reaction.

The formations of (selenovinyl)cobaloximes **3a**—**3c** can be explained by an anionic mechanism as well as a radical mechanism. However, the formations of diselenide **5**, aldehyde **6**, and a selenoacetylene derivative **7** are hard to understand by ionic mechanisms. If the formations of **6** and **7** are triggered by the addition of a phenylseleno anion, a hydride elimination from the intermediate vinyl anion is required, but it is not a practical process without an extremely strong acid.

To our surprise, an equimolar mixture of (phenylseleno)cobaloxime **1** with 2-propynyl bromide (**8a**) or 2-propynyl tosylate (**8b**) gave phenyl 2-propynyl selenide (**10a**) on the thermolysis at 80 °C (Scheme 3). Further, the reaction of selenocobaloxime **1** with hexyl bromide (**9a**) and hexyl tosylate (**9b**) gave phenyl hexyl selenide (**10b**). These substitution reactions of the bromides and tosylates are explained more reasonably by an S_N2 mechanism. Thus (phenylseleno)cobaloxime (**1**) behaves in a dual manner, radical and ionic, depending on substrate. In the addition reaction to the acetylenic moiety, selenocobaloxime **1** behaves more likely as a radical source. On the other hand, it behaves as an ionic source in the reaction with bromide and tosylate.



Scheme 3.

Thus, the 2-propynyl derivatives having a weak leaving group (OH, OPh, and OAc) react at acetylenic moiety in a radical mechanism, whereas the 2-propynyl and alkyl derivatives having a strong leaving group (Br and OTs) react in an ionic mechanism. This dual nature of (phenylseleno)cobaloxime **1** is understood as an electron transfer equilibrium (Eq. 7). This type of equilibrium between a thioradical and a transition metal complex is well documented.[14] Thus the electron transfer between phenylseleno radical and cobaloxime(II) radical generates a nucleophile, phenylseleno anion, and its reactions with **8**'s and **9**'s in S_N2 give the ionic reaction products **10a** and **10b**, respectively (Eq. 8).

$$\mathrm{PhSe}\cdot + \mathrm{L[Co]}\cdot \rightarrow \mathrm{PhSe}^- + \mathrm{L[Co]}^+ \tag{7}$$

$$\mathrm{PhSe}^- + \mathrm{HC{\equiv}CCH_2Y} \xrightarrow[\mathrm{Y=OTs,Br}]{} \mathrm{HC{=}CCH_2SePh} + \mathrm{Y}^- \tag{8}$$

In conclusion, (phenylseleno)cobaloxime **1** has a dual nature as a radical source and an ionic source depending on the nature of the substrate.

Experimental

General and Starting Materials. ^{1}H NMR (90 MHz) spectra were recorded with a Hitachi R-90H spectrometer in $CDCl_3$ and mass spectra were recorded with a JEOL JMS-Automass-150 spectrometer. Chemical shifts are recorded in δ-values using TMS as an internal standard. Coupling constants are given in Hz.

Acetonitrile was purified with the standard method and stored under argon. 2-Propyn-1-ol (**2a**), 2-propynyl bromide (**8a**), and hexyl bromide (**9a**) are commercially available and used after distillation. Phenyl 2-propynyl ether (**2b**),[15] 2-propynyl acetate (**2c**),[16] 2-propynyl tosylate (**8b**),[17] and hexyl tosylate (**9b**)[17] were prepared by the reported method. (Phenylseleno)cobaloxime (**1**) was prepared from diphenyl diselenide and the cobaloxime(II)-complex which was synthesized from the ligands and cobalt(II) chloride. A mixture of cobalt(II) chloride hexahydrate (2.44 g, 10 mmol), dimethylglyoxime (2.46 g, 21 mmol), and sodium hydroxide (0.82 g, 20 mmol) in 40 ml of degassed methanol was agitated by bubbling argon for 5 min and the mixture was further stirred for 10 min after the addition of 4-*t*-butylpyridine (1.45 ml, 9.9 mmol). The mixture was added with diphenyl diselenide (1.51 g, 4.8 mmol) in 5 ml of benzene and stirred in the dark for 2 h. Pure (phenylseleno)cobaloxime (**1**) (4.40 g, 78%) was obtained by the removal of insoluble residue by filtration, concentration of the mixture in vacuo, chromatography on Florisil (ethyl acetate), and recrystallization from dichloromethane–ethyl ether by diffusional mixing of ethyl ether. **1**, mp 206—208 °C (decomp); ^{1}H NMR δ=1.23 (s, 9H, *t*-Bu), 2.01 (s, 12H, dimethylglyoxime), 6.96—7.53 (m, 7H, Ph and 3,4-hydrogens of Py), 8.19—8.34 (m, 2H, 2,6-hydrogens of Py), and 18.50 (br s, 2H, hydroxyls). UV-vis (EtOH) 250 (ε 20300), 362 (12100) nm. Found: C, 47.60; H, 5.46; N, 11.97%. Calcd for $C_{23}H_{32}CoN_5O_4Se$: C, 47.59; H, 5.56; N, 12.07%.

General Procedure for the Photoreaction of (Phenylseleno)cobaloxime 1 with 2-Propynyl Derivatives. In a Pyrex reaction tube (ϕ, 7 mm) was placed 1 ml of acetonitrile solution of cobaloxime **1** (0.2 mmol) and one of the 2-propynyl derivatives (2.0 mmol). In the case of 2-propyn-1-ol (**2a**), no solvent was used, and the cobaloxime **1** was dissolved in 1 ml of 2-propyn-1-ol. The reaction tube capped with a rubber septum was degassed by bubbling argon through a syringe needle in an ultrasonic bath. The reaction tube was placed on a rotary type Rayonet Photochemical Reactor RPR-100 equipped with 350 nm lamps (Southern New England Ultraviolet Co.), and irradiated for a determined period at ca. 25 °C (Table 1). After irradiation, the mixture was concentrated and subjected to chromatography on silica gel, eluted first with benzene and then with ethyl acetate to give the cobaloximes (**3**'s), diphenyl diselenide (**5**), and 3-(phenylseleno)-2-propanal (**6**). The last two products **5** and **6**[10)] were identified with the known compounds by the comparison of ^{1}H NMR spectra.

Cobaloxime **3a**, mp 154 °C (decomp); ^{1}H NMR $\delta=1.27$ (s, 9H, *t*-Bu), 2.15 (s, 12H, dimethylglyoxime), 4.27 (s, 2H, methylene), 6.25 (s, 1H, vinyl), 7.13—7.32 (m, 7H, Ph and 3,5-hydrogens of Py), 8.40—8.50 (m, 2H, 2,6-hydrogens of Py), and 13.10 (br. s, 2H, hydroxyls). Found: C, 49.10; H, 5.56; N, 10.80%. Calcd for $C_{26}H_{36}CoN_5O_5Se$: C, 49.06; H, 5.70; N, 11.00%.

Cobaloxime **3b**, mp 186—187 °C (decomp); ^{1}H NMR $\delta=$ 1.26 (s, 9H), 2.12 (s, 12H), 4.44 (s, 2H), 6.36 (s, 1H), 7.14—7.30 (m, 7H), 8.42—8.49 (m, 2H), 18.00 (br s, 2H). Found: C, 57.22; H, 5.55; N, 9.72%. Calcd for $C_{32}H_{40}CoN_5O_5Se$: C, 53.94; H, 5.66; N, 9.83%.

3-Acetoxy-1-phenylseleno-1-propyne (**7**), oil, ^{1}H NMR $\delta=$ 2.10 (s, 3H), 4.88 (s, 2H), and 7.25—7.58 (m, 5H). High resolution MS (70 eV), Found: *m/z* 253.9844. Calcd for $C_{11}H_{10}O_2Se$: M, 253.9845.

General Procedure for the Thermal Reaction of (Phenylseleno)cobaloxime 1. Cobaloxime **1** (0.2 mmol) and one of the 2-propynyl derivatives (**2b** or **2c**) (2.0 mmol) were dissolved in 1 ml of acetonitrile and the solution was degassed by bubbling argon through a syringe needle in an ultrasonic bath. In the case of bromides (**8a** and **9a**) and tosylates (**8b** and **9b**), a 1 : 1 mixture of the cobaloxime **1** (0.2 mmol) and the bromide or tosylate (0.2 mmol) was treated in the same manner. In the case of 2-propyn-1-ol (**2a**), 1 ml of **2a** was used instead of acetonitrile. The solution was heated to 80 °C for a period as recorded in Table 1 and then concentrated in vacuo. The residue was subjected to chromatography on silica gel, eluted first with benzene and then with ethyl acetate. New products other than the photolysis products were cobaloxime **3c**, phenyl 2-propynyl selenide (**10a**), and hexyl phenyl selenide (**10b**). The last two selenides were identified with the authentic samples[18—20)] by gas chromato-mass spectra and ^{1}H NMR.

Cobaloxime **3c**, mp 185—186 °C (decomp); ^{1}H NMR $\delta=$ 1.26 (s, 9H), 1.96 (s, 3H), 2.14 (s, 12H), 4.50 (s, 2H), 6.33 (s, 1H), 7.14—7.35 (m, 7H), 8.40—8.47 (m, 2H), and 18.20 (br s, 2H). Found: C, 49.38; H, 5.75; N, 10.45%. Calcd for $C_{28}H_{38}CoN_5O_6Se$: C, 49.56; H, 5.64; N, 10.32%.

Reductive Elimination of Cobaloxime Moiety from Product 3a. A mixture of cobaloxime **3a** (1.0 mmol), activated zinc (10 mmol), and 2.5 ml of 10%-acetic acid in 6 ml of methanol was stirred for 4 h at room temperature. The mixture was filtered through Celite, concentrated in vacuo, and subjected to the chromatography on silica gel eluted with ethylacetate. The oily product thus obtained in 90% yield was determined to be (*Z*)-3-phenylseleno-2-propen-1-ol by ^{1}H NMR and MS-spectra.

(*Z*)-3-Phenylseleno-2-propenol, oil, ^{1}H NMR $\delta=2.00$ (br s, 1H), 4.30 (dd, $J=1.0$ and 5.9 Hz, 2H), 6.23 (dt, $J=5.9$ and 9.2(*cis*-olefin) Hz, 1H), 6.64 (dt, $J=9.2$(*cis*-olefin) and 1.0 Hz, 1H), and 7.24—7.55 (m, 5H). High resolution MS (70 eV), Found: *m/z* 213.9875. Calcd for $C_9H_{10}OSe$: M, 213.9896.

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