# Effect of a cobalt(II) complex on the radical reaction of vinyl type sulfides. A 'radico-catalysis'

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**Vinyl type sulfides show increased radicophilicity at the β-position *via* the coordination to a cobalt(II) complex, and hence the balance between Smiles rearrangement and an *ortho*-substitution, in vinyl type sulfides having an intramolecular alkyl radical, is lost to favor the latter reaction.**

Acid and base catalysis generates a 'paired electron hole' [eqn. (1)] and a 'paired electron pool' [eqn. (2)], respectively. Likewise radical catalysis can be defined as the generation of 'unpaired electron density' at the reaction center [eqn. (3)].

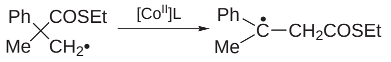
$$\text{Acid catalysis:}\quad RX + \text{Acid} \longrightarrow R^{\delta+}\cdots X\cdots \text{Acid}^{\delta-} \qquad (1)$$

$$\text{Base catalysis:}\quad RX + \text{Base} \longrightarrow R^{\delta-}\cdots X\cdots \text{Base}^{\delta+} \qquad (2)$$

$$\text{Radico-catalysis:}\quad RX + \bullet(\text{Rad}) \longrightarrow R^{\delta\bullet}\cdots X\cdots \text{Rad}^{\delta\bullet} \qquad (3)$$

We have demonstrated that a cobalt(II) complex, cobaloxime(II),[1]† accelerates the radical substitutions on the sulfur of a thioester group [eqn. (4)][2] and the radical 1,2-rearrangement of a thioester group [eqn. (5)].[2,3] Caddick *et al.*,[4] Aldabbagh and

$$\text{Me}\bullet + \text{RCOSAr} \xrightarrow{[\text{Co}^{\text{II}}]\text{L}} \text{MeSAr} + \text{RCO}\bullet \qquad (4)$$



(5)

Bowman,[5] and Tada *et al.*[6] showed the usefulness of the sulfur function in the radical annelation on indole and benzimidazole systems, in which the intramolecular alkyl radicals attack the *ipso*-position to yield indoleno or benzimidazoleno carbocycles by the extrusion of the sulfur function. We have suggested the effect of cobaloxime(II) in the radical annelation of 2-phenylthioindole *via* an intramolecular *N*-alkyl radical.[6]

Here we report another type of radico-catalysis by cobaloxime(II) in the radical annelation of benzothiophene and uracil derivatives. Coordination of a vinyl type sulfide to cobalt(II) generates an unpaired electron (spin) density on the sulfur, which can delocalize to the β-position of the vinyl group as shown in Fig 1. The coordination has been proven *via* an EPR study by us[7] and characterized by back donation from cobalt(II) to sulfur. The bonding force of this back donation makes the unstable two-centered three electron bond feasible.

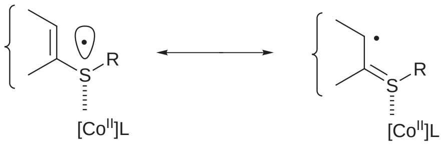


**Fig. 1** Resonance expression of spin delocalization in a sulfur–cobalt(II) complex.

Homolysis of triphenyltin cobaloxime produces a triphenyltin radical and cobaloxime(II) [eqn. (6)] but the former dissipates *via* reaction with a halide to leave an organo radical [eqn. (7)]. Thus the organo radical and cobaloxime(II) coexist in the reaction system and associate by the coordinative interaction discussed above [eqn. (8)]. The interaction of the vinyl type

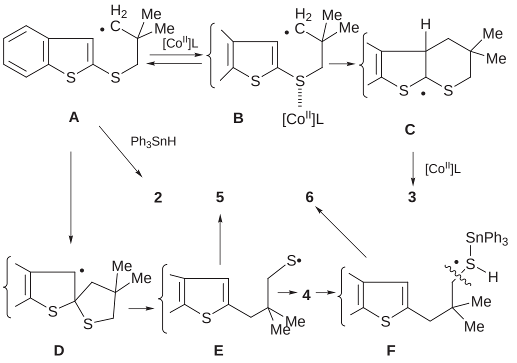
$$\text{Ph}_3\text{Sn[Co]L} \longrightarrow \text{Ph}_3\text{Sn}\bullet + [\text{Co}^{\text{II}}]\text{L} \qquad (6)$$

$$\text{RBr} + \bullet\text{SnPh}_3 \longrightarrow \text{R}\bullet + \text{Ph}_3\text{SnBr} \qquad (7)$$

$$\text{R}\bullet + [\text{CO}^{\text{II}}]\text{L} \longrightarrow (\text{R}\bullet)\cdots[\text{CO}^{\text{II}}]\text{L} \qquad (8)$$

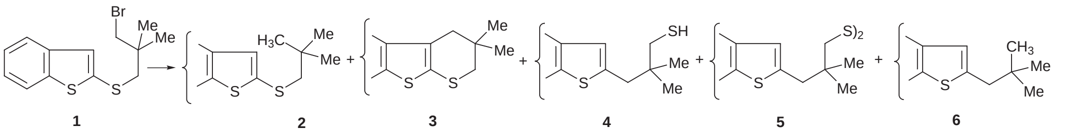
sulfide and the cobalt(II) species may increase the radicophilicity of the vinyl moiety.

Thus 3-(benzothiophen-2-ylthio)-2,2-dimethylpropyl bromide **1** was treated with triphenyltin cobaloxime under heating and the products **3** and **5** were obtained as shown in Scheme 1. The thermolysis gives the cobaloxime(II) radical and the intermediate radical **A** which interact with each other by the coordination discussed above to give radical **B** and thus product **3** (Scheme 2).



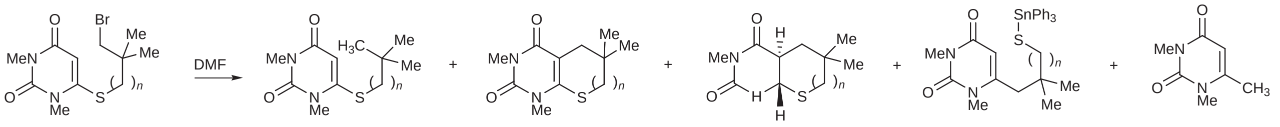
**Scheme 2**

Treatment of bromide **1** with Ph$_3$SnH–AIBN gave the products **4** and **6** after Smiles rearrangement by an addition–elimination mechanism (**A**→**D**→**E** in Scheme 2)[8] and the reduction product **2**. Thus the cobaloxime(II) in the reaction system evidently accelerates the radical attack on the 3-position of benzothiophene and *ortho*-substitution becomes competitive with the radical Smiles rearrangement.[8–10] On the other hand, in



| | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| Ph$_3$Sn[Co]L / 130 °C‡ | — | 17% | — | 70% | — |
| Ph$_3$SnH–AIBN / 80 °C§ | 11% | — | 71% | — | 14% |

**Scheme 1**



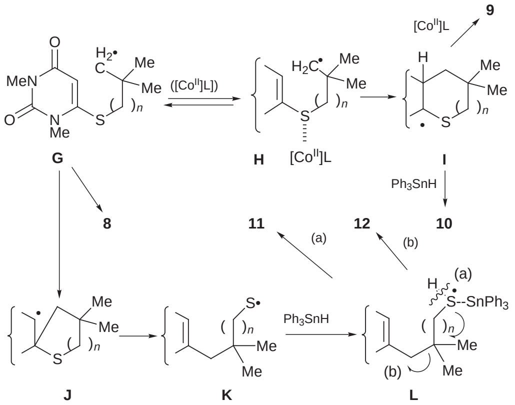
| 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|
| $n = 1$ $Ph_3Sn[Co]L$‡ | — | 73% | — | — | — |
| $n = 1$ $Ph_3SnH$–AIBN§ | — | — | 38% | 45% | 8% |
| $n = 2$ $Ph_3Sn[Co]L$‡ | 28% | 47% | — | — | — |
| $n = 2$ $Ph_3SnH$–AIBN§ | 82% | — | — | — | — |

**Scheme 3**

addition to product **2**, only the products of Smiles rearrangement were obtained without cobaloxime(II). The formation of the product **6** is accounted for by radical substitution on sulfur through the radical intermediate **F**. A reasonable mechanism for formation of these products is shown in Scheme 2.

Next we tested the effect of cobaloxime(II) on the radical from *n*-(1,3-dimethyluracil-5-ylthio)-2,2-dimethylalkyl bromide **7** and a similar acceleration effect was observed for the *ortho*-substitution, as shown in Scheme 3. Bromide **7** ($n = 1$) gave the substitution product **9** in the presence of cobaloxime(II) whereas the reaction with $Ph_3SnH$ gave the addition product **10** and the products **11** and **12** formed *via* Smiles rearrangement (Scheme 4).

Both Smiles rearrangement *via* a six-membered intermediate (**J**) ($n = 2$) and *ortho*-addition *via* a seven-membered intermediate (**I**) ($n = 2$) are slow and the only product from the reaction of $Ph_3SnH$ and bromide **7** ($n = 2$) is the direct reduction product. The reaction with triphenyltin cobaloxime, however, gave the *ortho*-substitution product **9** ($n = 2$) as a major product, however the intramolecular radical addition is still slow and hydrogen abstraction form the solvent to give product **8** ($n = 2$) is the dominant process. A reasonable mechanism for formation of **8–12** is illustrated in Scheme 4. The intermediate radical **I** ($n = 1$) which gives **10** ($n = 1$) is formed even without cobaloxime(II), although with lower efficiency, while radical **I** ($n = 2$) which gives **9** ($n = 2$) is formed only with the assistance by cobaloxime(II). The intermediates **I** ($n = 1,2$) give products **9** ($n = 1,2$) with hydrogen elimination by cobaloxime(II) and the product **10** ($n = 1$) *via* hydrogen abstraction from the tin hydride. Products **11** and **12** derive from the intermadiate **L** ($n = 1$) *via* hydrogen elimination [route (a)] and the fragmentation process [route (b)], respectively, after Smiles rearrangement (Scheme 4).



**Scheme 4**

All the experimental results shown here suggest an acceleration effect of cobalt(II) species on the radical attack of an alkyl radical on a vinyl type sulfide. Thus the coordination of a vinyl sulfide to a paramagnetic cobalt(II) complex generates a spin density at the β-position and makes the β-position more radicophilic. We propose a term ‘radico-catalysis’ for this effect even though the reaction is stoichiometric and not ‘catalytic’ in the correct sense.

Experimental details and structural assignments of the products will be reported in a full paper.

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## Notes and references

† Cobaloxime(II) is bis(dimethylglyoximato)(4-*tert*-butylpyridine)cobalt(II) and denoted here by $[Co^{II}]L$.

‡ *Reaction conditions*: **1** or **7** (0.1 mmol), $Ph_3Sn[Co]L$ (0.3 mmol), DMF (5.0 ml), 130 °C, 24 h.

§ *Reaction conditions*: **1** or **7** (0.1 mmol), $Ph_3SnH$ (0.2 mmol), AIBN (0.1 mmol), benzene (40 ml), 80 °C, 4 h.

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