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Preparation of a crown-ether-modified lophine peroxide as a guest-sensitive novel chemiluminophore and modulation of its chemiluminescence by metal cations[†]

Hideki Okamoto,* Makoto Owari, Masaru Kimura and Kyosuke Satake

Graduate School of Natural Science and Technology, Okayama University, Tsushima-Naka 3-1-1, Okayama 700-8530, Japan

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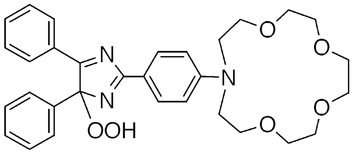
Abstract—A guest-sensitive chemiluminophore, a novel crown-ether-modified lophine peroxide **1**, has been prepared, and its chemiluminescent behavior has been investigated in the presence of alkaline and alkaline earth metal cations. In the presence of Na^+, the λ_{max} of the chemiluminescence of peroxide **1** was blue-shifted (505 nm) compared to the case without a metal cation (566 nm). The chemiluminescent intensity was enhanced by addition of Na^+ while that of Mg^{2+} decreased the intensity. © 2001 Elsevier Science Ltd. All rights reserved.

Molecular photodevices, whose properties can be controlled by specific additives, have been extensively developed[1] since the pioneering studies of Vögtle on chromoionophores.[2] For such chromophores, conventionally, absorption and photoluminescent properties have been controlled through interactions between the host dyes and specific guests.[3]

Chemiluminescent output provides potent highly sensitive analytical tools.[4] Thus, it would be of interest to construct a chemiluminophore possessing a host function, which displays change in its chemiluminescent behavior on addition of a specific guest, since such a chemiluminophore may serve as a novel, highly sensitive luminescent chemosensor.

It has been reported that the chemiluminescent properties of lophine peroxide (2,4,5-triphenyl-4*H*-imidazol-4-ylhydroperoxide) are affected significantly by substitution on its phenyl groups.[5–7] Therefore, it is expected that incorporation of an ionophore function into the phenyl groups of lophine peroxide would enable control of its chemiluminescent properties through fine-tuning of the substituent effects based on the complex formation between the ionophore part and guest ions. On the basis of this molecular design, we have examined the synthesis of a crown-ether-modified lophine peroxide **1** as a novel chemiluminescent ionophore. Herein we would like to report our preliminary results on the preparation of the modified lophine peroxide **1** and its chemiluminescence studies in which the chemiluminescent properties of the peroxide **1** were modulated by metal cations.



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Crown-ether-modified triphenylimidazole **3**, which is the precursor of the peroxide **1**, was synthesized by condensation of benzaldehyde **2**[8] and benzil in the presence of ammonium acetate[9] in good yield (Scheme 1).[10] The imidazole **3** was converted into the desired peroxide **1** through a reaction with singlet oxygen in CH_2Cl_2 at low temperature.[5,11] The resulting solution of the peroxide **1** was poured into a short silica gel column, and subsequent elution with MeCN gave a solution of the peroxide **1** in MeCN.[12] The solution of the peroxide **1** was used for the present chemiluminescence measurements without further purification because the peroxide **1** was not stable enough to be isolated at room temperature: although the peroxide **1** was durable at 0°C for several hours, it underwent

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Keywords: chemiluminescence; chemiluminescent ionophore; lophine peroxide; aza crown ether.

* Corresponding author. Tel.: +81-(0)86-251-7840; fax: +81-(0)86-251-7853; e-mail: hokamoto@cc.okayama-u.ac.jp

[†] Here we describe a chemiluminescent dye as a *chemiluminophore* for convenience, in accordance with the fact that luminescent dyes are called luminophores.

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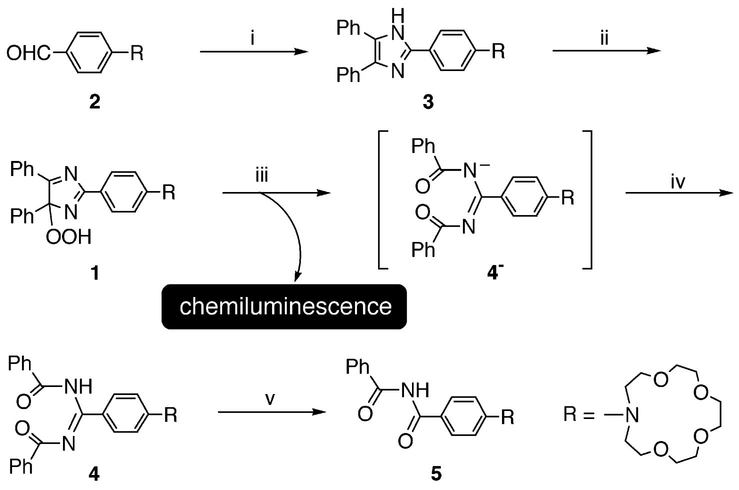

Scheme 1. *Reagents and conditions*: (i) benzil (0.9 equiv.), $AcONH_4$ (10 equiv.), AcOH, reflux, 1 h, 78%; (ii) O_2, methylene blue, *hν*, −78°C, CH_2Cl_2, 30 min; (iii) NBu_4OH, MeCN, rt; (iv) AcOH; (v) NBu_4OH, MeCN, rt.

slowly spontaneous chemiluminescent reaction at room temperature.

When tetrabutylammonium hydroxide was added to the MeCN solution of the peroxide **1**, bright yellow chemiluminescence was observed. After disappearance of the chemiluminescent emission (within 90 s), the resulting reaction mixture was neutralized carefully with acetic acid followed by extraction with CH_2Cl_2 to give a benzamidine derivative **4** as the sole product.[10] For the base-induced chemiluminescent reaction of lophine peroxide, it has been reported[5,11] that lophine peroxide gives *N*,*N*′-dibenzoylbenzamidine as a product. Thus, the fact that the benzamidine **4** was obtained in the present chemiluminescent reaction confirmed that the peroxide **1** was involved as the key intermediate of the chemiluminescence.[11,13]

The effects of metal cations on the chemiluminescence of peroxide **1** were investigated. Fig. 1 shows the chemiluminescence spectra of the peroxide **1**, and in Fig. 2, the relative chemiluminescent intensity observed in the presence of metal cations is summarized. The spectra were observed with a multi-channel photodiode array detector and the intensities were determined by integration of the chemiluminescence spectra in the 430–670 nm region detected during the chemiluminescent reaction (90 s). In the absence of any additive, peroxide **1** showed a broad chemiluminescent emission band between 450 and 670 nm (λ_{max} 566 nm) [Fig. 1, curve (a)]. Addition of Li^+ or K^+ had minimal effect on the chemiluminescence [Fig. 1, curves (b) and (d), Fig. 2]. On the other hand, in the presence of Na^+, the chemiluminescent intensity of the peroxide **1** was enhanced 1.5-fold relative to that observed in the absence of a metal cation (Fig. 2), and the λ_{max} shifted to 505 nm (51 nm blue-shifted compared to the case without Na^+) [Fig. 1, curve (c)]. Effects of alkali earth metal cations on the chemiluminescence were also examined. As shown in Fig. 2, Ca^{2+} and Ba^{2+} displayed no remarkable effect on the intensity. In contrast, Mg^{2+} reduced significantly the chemiluminescent intensity (ca. 0.7 relative to the case without a metal cation). Therefore, by means of the addition of metal cations, the chemiluminescent intensity of the host chemiluminophore **1**

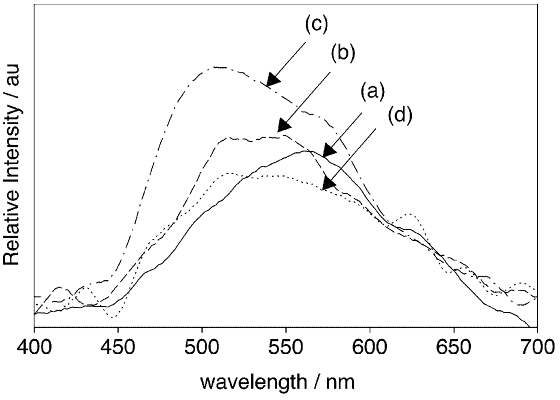

Figure 1. The chemiluminescence spectra of the peroxide **1** (ca. 1.5 mM) in MeCN observed on addition of tetrabutylammonium hydroxide (MeOH soln, excess) at 20°C in the presence of metal cations (25 mM as perchlorate). (a) Without metal cation; (b) Li^+; (c) Na^+; (d) K^+.

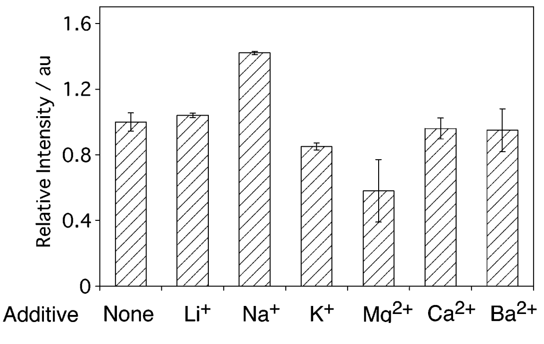

Figure 2. Relative chemiluminescent intensity of the peroxide **1** (ca. 1.5 mM) in MeCN observed on addition of tetrabutylammonium hydroxide (MeOH soln, excess) in the presence of metal cations (25 mM, as perchlorate) at 20°C. The experimental errors were based on at least three independent runs.

could be changed by a factor of 0.7–1.5 relative to that observed without metal cations.

The effect of the metal cations on the chemiluminescent properties could be due to a variety of factors: e.g. the complex formation of the crown-modified peroxide **1** with a metal cation[14] may cause a change in the efficiency of the excited-product-providing step, or a change in the fluorescent efficacy of an emitting species involved in the chemiluminescence. Concerning the reported chemiluminescenct reaction of lophine peroxide,[5,6] the conjugate base of the benzamidine **4**$^-$ has been expected to be the light emitter in the chemiluminescence. However, as the benzamidine **4** underwent rapid hydrolysis to the dibenzamide **5**[10] in alkaline media, the fluorescent properties of the benzamidine **4** have not been studied and thus the exact emitting species in the chemiluminescence of the peroxide **1** has not been specified. Currently, the factor(s), in which metal cations control the chemiluminescent properties of the peroxide **1**, have not been determined and a study to clarify these factors is under way.

The present results first show that modulation of the chemiluminescent output of the chemiluminophore **1** was achieved by addition of metal cations. The molecular design combining a chemiluminophore with an ionophore provides a basis for novel chemosensors displaying guest-sensitive chemiluminescent output.

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10. Physical data for the novel compounds. Compound **3**: colorless fine needles, mp 191–192°C; ^{1}H NMR (500 MHz, acetone-d_6) δ 3.55 (s, 4H), 3.60 (s, 8H), 3.60 (t, 4H, J=6.0 Hz), 3.75 (t, 4H, J=6.0 Hz), 6.77 (m, 2H), 7.25 (brt, 2H, J=7.0 Hz), 7.32 (brt, 4H, J=7.0 Hz), 7.58 (br, 4H), 7.93 (m, 2H); UV (EtOH) $\lambda_{\max}$ (log ε) 324 nm (4.58); IR (KBr) $\nu_{\max}$ 1613, 1118 cm^{-1}. Anal. calcd for $C_{31}H_{35}N_3O_4$: C, 72.49; H, 6.87, N, 8.18. Found: C, 72.26; H, 6.83; N, 8.18%. Compound **4**: yellow needles, mp 212–213°C; ^{1}H NMR (500 MHz, CDCl$_3$) δ 3.63 (s, 4H), 3.64–3.70 (m, 12H), 3.79 (t, 4H, J=6.0 Hz), 6.70 (d, 2H, J=9.0 Hz), 7.49 (bs, 4H), 7.58 (bs, 2H), 7.91 (d, 2H, J=9.0 Hz), 8.05 (bs, 2H), 8.33 (bs, 2H), 12.44 (s, 1H); $\nu_{\max}$ (KBr) 1702, 1598 cm^{-1}; UV (MeCN) $\lambda_{\max}$ (log ε) 369 nm (4.09), 4.27 (4.14). Anal. calcd for $C_{31}H_{35}N_3O_6$: C, 68.24; H, 6.47, N, 7.70. Found: C, 68.18; H, 6.39; N, 8.12%. Compound **5**: colorless prisms, mp 170–171°C; ^{1}H NMR (500 MHz, DMSO-d_6) δ 3.32 (s, 4H), 3.53 (m, 8H), 3.58 (t, 4H, J=5.9 Hz), 3.64 (t, 4H, J=5.9 Hz), 6.69 (m, 2H), 7.48 (t, 4H, J=8.0 Hz), 7.59 (dt, 2H, J=8.0, 1.5 Hz), 7.77 (m, 2H), 7.82 (dd, J=8.0, 1.5 Hz) 10.90 (s, 1H); UV (EtOH) $\lambda_{\max}$ (log ε) 235 nm (4.15), 338 (4.33); IR (KBr) $\nu_{\max}$ 3244, 1692, 1678, 1601, 1118 cm^{-1}. Anal. calcd for $C_{24}H_{30}N_2O_6$: C, 65.14; H, 6.83, N, 6.33. Found: C, 65.44; H, 6.95; N, 6.27%.
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