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A Novel Color Former Organogel for Radiation Detection Systems

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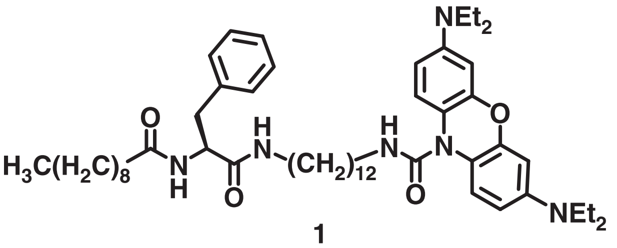
A novel leuco phenoxazine color former containing L-phenylalanine at the protecting group was prepared for radiation detection systems. It forms elongated self-assembled fibers in common organic solvents, leading to that efficient gelation. FE-SEM and FT-IR of the xerogel showed the color former formed a three-dimensional net-like structure. The color former organogel showed sufficient sensitivity to γ rays that it can be used for imaging in heavy particle radiotherapy and has good potential for three-dimensional radiation detection systems.

Radiation has been widely utilized in many fields such as medicine, agriculture, and industry.[1] For example, medical apparatus are sterilized by γ rays without producing hazardous residue. γ Rays are high-energy electromagnetic radiation and the penetration power is very large. As human beings have no ability of directly seeing γ rays, the recognition of γ rays is important by some other method. We have studied the development of the color formers to recognize γ rays easily by visualization.[2]

Recently, many low-molecular-weight organic compounds have been found to be organogelators that can gel various organic solvents. Organogels consist of long nanofibers that are self-assembled as a result of the usual array of noncovalent forces such as hydrogen bonding, van der Waals, and π–π stacking. Noncovalent cross-links among the nanofibers and/or mechanical entanglements create a three-dimensional network. Recent research shows that L-amino acid derivatives had organogelation abilities for most organic solvents.[3]

If organogelation ability is introduced to the color former, the diffusion of the generated dyes could be prevented by intermolecular interaction in the three-dimensional color former networks. The gel could be applied in a heavy particle detector and used for imaging in therapeutic instruments.

Here we report the properties of new compound **1** (Scheme 1) in which the phenoxazine moiety is attached to an L-phenylalanine-based scaffold[4] via a dodecamethylene chain (7.9% yield). The synthesis of **1** was straightforward and was observed by ^{1}H NMR, ^{13}C NMR, FAB-MS, and FT-IR spectra.[5]



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Scheme 1.

Table 1. Gelation properties of color former **1** for common organic solvent[a]

Solvent	
Hexane	I
Toluene	S
$CHCl_3$	S
CH_2Cl_2	G
CCl_4	G
Ethyl acetate	G
CH_3CN	PG
DMF	S

[a] Gelation tests were conducted at 80 g L^{-1}. The following abbreviations are used: P, precipitate; I, insoluble; S, solution; PG, partially gel; and G, gel.

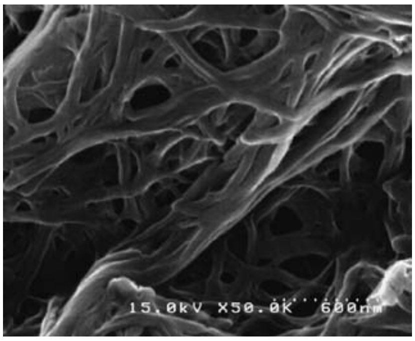

Figure 1. FE-SEM image of xerogel of **1**.

Gelation tests were carried out using common solvents (Table 1). Color former **1** was observed to be insoluble in nonpolar and protic polar solvents, while it was soluble in several less polar solvents such as ethyl acetate, $CHCl_3$, and CH_2Cl_2. On estimating the critical gelation concentration (CGC)[6] of the solvents, the lowest CGC value was obtained: 80 g L^{-1} when CH_2Cl_2 was used. As the color former gel was easily colored by heating, CH_2Cl_2 was used in the following experiment because of its low boiling point.

The morphological analysis of dichloromethane xerogel of **1** obtained from the dichloromethane gels was studied by field-emission scanning electron microscopy (FE-SEM)[7] (Figure 1). This analysis showed that **1** was composed of fibrillar self-assembled nanostructures. In order to evaluate the driving forces for gelation, the FT-IR spectra were measured.[8] The FT-IR spectra of **1** was measured in dichloromethane xerogel. The IR spectra of xerogel of **1** showed bands at 3296 cm^{-1} (amide νN–H), 1640 cm^{-1} (amide νC=O), and 1546 cm^{-1} (amide δN–H), characteristic of hydrogen-bonded amide groups. Such IR shifts indi-

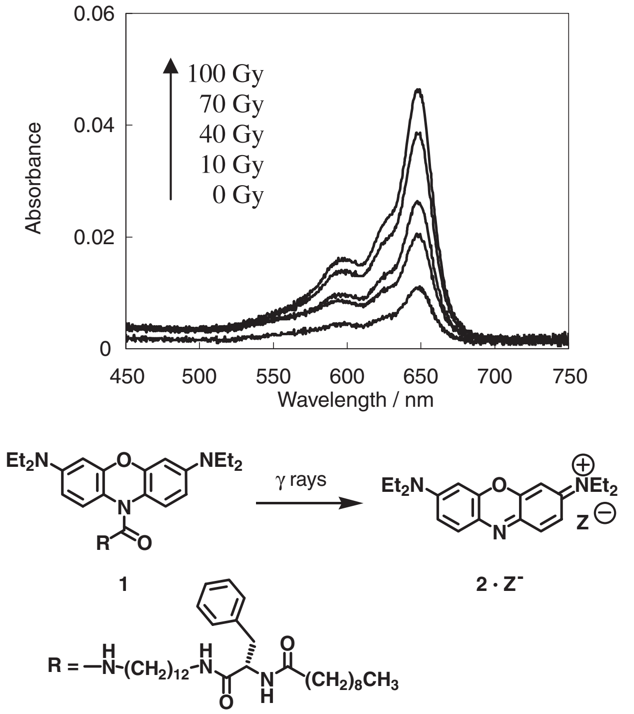

Figure 2. Spectral changes of **1** to give colored form **2** in dry dichloromethane ($[\mathbf{1}]_0 = 0.25\,\text{mM}$) at 4 h after γ irradiation to the dichloromethane gel of **1**.

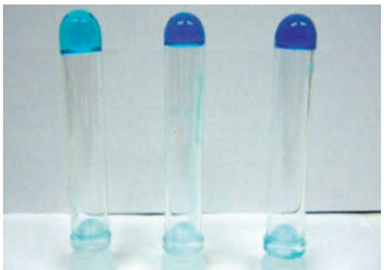

Figure 3. Images of **1** ($[\mathbf{1}]_0 = 80\,\text{g}\,\text{L}^{-1}$) to give colored form **2** after γ irradiation (from left; 0, 40, and 70 Gy).

cate the presence of intermolecular hydrogen-bonding interaction between the amide groups and the carboxyl groups.

UV–vis spectra of the dichloromethane gel of **1** after γ irradiation with ^{60}Co were measured with a solution (0.25 mM) prepared by dilution of the dichloromethane gel of **1** ($[\mathbf{1}]_0 = 80\,\text{g}\,\text{L}^{-1}$) with dichloromethane (Figure 2). The color former gel was slightly colored in the course of preparation. The maximum absorption wavelength increase in the spectra of **1** after γ irradiation coincided with that of **2**•Cl$^-$ (649 nm) to indicate that **1** changed to the dye form **2** under γ irradiation. The color change is easily detectable by the naked eye at less than 40 Gy of irradiation (Figure 3). The color change after γ irradiation of 40 Gy suggests that the gel will be useful in heavy particle radiotherapy with heavy particle beams of 40–70 Gy.

In conclusion, a novel leuco phenoxazine color former **1** was prepared and showed efficient gelation in common organic solvents. The gel structure was determined by FE-SEM and FT-IR. This dichloromethane gel of color former **1** showed sufficient color change that γ irradiation of 40 Gy can be detected by the naked eye. A novel color former organogelator will be applied in heavy particle detectors for three-dimensional color former networks in organogel.

References and Notes

1 a) N. Yamakawa, A. Takahashi, E. Mori, Y. Imai, Y. Furusawa, K. Ohnishi, T. Kirita, T. Ohnishi, *Cancer Sci.* **2008**, *99*, 1455. b) R. Arora, D. Gupta, R. Chawla, R. Sagar, A. Sharma, R. Kumar, J. Prasad, S. Singh, N. Samanta, R. K. Sharma, *Phytother Res.* **2005**, *19*, 1. c) S. M. Glidewell, N. Deighton, B. A. Goodman, J. R. Hillman, *J. Sci. Food Agric.* **1993**, *61*, 281.

2 a) T. Tachikawa, Y. Morinaka, S. Tokita, *J. Photopolym. Sci. Technol.* **2001**, *14*, 245. b) E. Yuya, T. Sumio, *J. Photopolym. Sci. Technol.* **2005**, *18*, 117.

3 a) K. Yabuuchi, Y. Tochigi, N. Mizoshita, K. Hanabusa, T. Kato, *Tetrahedron* **2007**, *63*, 7358. b) M. Suzuki, S. Owa, H. Shirai, K. Hanabusa, *Tetrahedron* **2007**, *63*, 7302. c) S. Debnath, A. Shome, S. Dutta, P. Das, *Chem.—Eur. J.* **2008**, *14*, 6870. d) I. Coates, A. Hirst, D. Smith, *J. Org. Chem.* **2007**, *72*, 3937.

4 X. Fu, Y. Yang, N. Wang, H. Wang, Y. Yang, *J. Mol. Recognit* **2007**, *20*, 238.

5 FAB-MS m/z 853 (M + 1, $C_{52}H_{80}N_6O_4$); IR (NaCl, cm^{-1}) 3296, 1640, 1546, 1510, 1280, 1241, 740, 701; ^{1}H NMR (200 MHz, CDCl$_3$): δ 7.40–7.05 (m, 9H, ArH), 6.51–6.30 (s, 1H, CONH), 6.34–6.13 (s, 2H, ArH), 5.44 (br s, 1H, CONH), 4.70–4.44 (m, 1H, CH$_2$N*H*, $J = 7.8$ Hz), 3.46–2.88 (m, 24H, NC*H*$_2$CH$_3$, NHC*H*$_2$), 2.40–2.05 (s, 2H, NHCOC*H*$_2$), 1.83–1.56 (q, 12H, NCH$_2$C*H*$_3$), 1.56–1.13 (m, 20H, CH$_2$), 1.13–0.80 (t, 3H, CH$_3$); ^{13}C{^{1}H} NMR (126 MHz, (CD$_3$)$_2$CO): δ 9.94 (s, CH$_3$), 11.56 (s, CH$_3$), 20.43 (s, CH$_2$), 23.56 (s, CH$_2$), 24.58 (s, CH$_2$), 24.70 (s, CH$_2$), 26.69–27.71 (m, CH$_2$), 29.71 (s, CH$_2$), 33.70 (s, CH$_2$), 36.03 (s, CH$_2$), 37.03 (s, CH$_2$), 38.53 (s, CH$_2$), 42.17 (s, CH$_2$), 52.49 (s, CH), 97.54 (s, CH), 104.73 (s, CH), 116.23 (s, CH), 123.37 (s, CH), 124.37 (s, CH), 126.15 (s, CH), 127.32 (s, CH), 135.65 (s, CH), 144.47 (m, CH), 154.11 (s, CO), 169.55 (s, CO), 171.38 (m, CO).

6 a) H. Chow, J. Zhang, C. Lo, S. Cheung, K. Wong, *Tetrahedron* **2007**, *63*, 363. b) D. Diaz, J. Cid, P. Vazquez, T. Torres, *Chem.—Eur. J.* **2008**, *14*, 9261.

7 M. Suzuki, T. Sato, A. Kurose, H. Shirai, K. Hanabusa, *Tetrahedron Lett.* **2005**, *46*, 2741.

8 a) I. Jadrnickova, F. Spurny, A. Molokanov, *Radiat. Prot. Dosim.* **2007**, *126*, 657. b) A. Takahashi, T. Onishi, *General Review* **2006**, *41*, 92.

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