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Organogelators Derived from [3.3]Metacyclophane Skeleton with a Urea Unit

Akihiko Tsuge,* Ryuichiro Matsushita, Katsuhiko Sakura, Tetsuji Moriguchi, and Koji Araki
Department of Applied Chemistry, Kyushu Institute of Technology,
1-1 Sensui-cho, Tobata-ku, Kitakyushu, Fukuoka 804-8550

(Received February 7, 2012; CL-120100; E-mail: tsuge@che.kyutech.ac.jp)

Dithia[3.3]metacyclophanes with a urea unit having long alkyl chains have been prepared. It has been found out that some of them give stable organogels in some solvents, and their gelating ability depends on structural properties of both aromatic components in the dithia[3.3]metacyclophane.

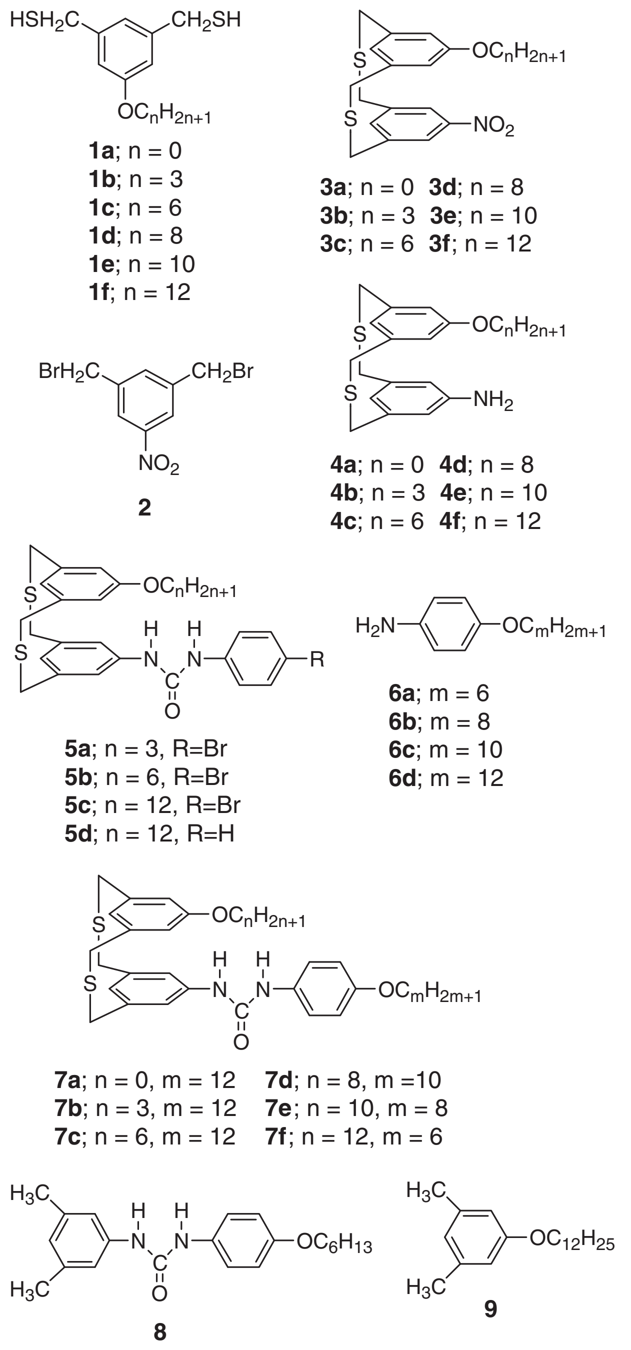
During the past several years, a great deal of research has focused on low-molecular-weight organogelators (LMOGs)[1] because they are not only of fundamental scientific interest but also have promising technological applications in various areas. Large structural diversity has been proposed to fulfill the requirements of the organogelators capable of gelling organic solvents in which gelators consisting of the cyclic component have also been investigated. As those cyclic gelators, macrocyclic compositions such as calixarene,[2] resorcinarene,[3] cucurbit[7]uril,[4] crown ether,[5] cyclodextrin,[6] cyclophane,[7] and dehydrobenzoannulene-based macrocycles[8] have been employed. On the other hand, there has been only one example on an organogelator based on the small-sized cyclic compound reported by Abe[9] to the best of our knowledge; however, in this report [2.2]paracyclophane has been employed as the base to construct the imidazole dimer photochromic organogel.

We have been interested in small-sized cyclophanes, especially [*n*.*n*]metacyclophanes in terms of their specific π systems due to the strong transannular π-electronic interactions between aromatic components in close proximity.[10] These [*n*.*n*]metacyclophanes can also be characterized by their conformational properties like the conversion between the *syn*- and the *anti*-conformers. From the view points of creating novel organogelators the [*n*.*n*]metacyclophane skeleton could be a unique candidate because of two components in the cyclophane compounds arranged in the layered structure. In order to realize the organogelators consisting of the metacyclophane skeleton we focused on the dithia[3.3]metacyclophanes because we have established the synthetic strategy to obtain their derivatives.

Thus, we have designed dithia[3.3]metacyclophanes which carry the appropriate long alkyl chain connected by the urea unit to the aromatic ring.

5-Alkoxy-1,3-bis(sulfanylmethyl)benzenes **1a**–**1f** were obtained by reduction of the corresponding diethyl 5-alkoxyisophthalates with hydrogen gas in the presence of 10% Pd/C, followed by chlorination using thionyl chloride and subsequent reaction with thiourea in yields of 20–35%. Bromination of 1,3-dimethyl-5-nitrobenzene with NBS gave the bis(bromomethyl) compound **2** in a yield of 55%. Cyclization of **1a**–**1f** and **2** using K_2CO_3 as a base under highly dilute conditions[11] afforded the corresponding dithia[3.3]metacyclophanes **3a**–**3f** in yields of 34–57%.

The aminocyclophanes **4a**–**4f** were prepared by reductions of **3a**–**3f** in yields of 73–90% (Scheme 1).



Scheme 1. Chemical structures of [3.3]metacyclophanes and referential compounds.

Table 1. Gelation properties of cyclophanes **5a**–**5d** in various solvents[a]

	Cyclophane			
	5a	**5b**	**5c**	**5d**
Hexane	I	I	I	I
Cyclohexane	I	I	G (0.6)	G (0.2)
Chloroform	S	S	S	S
Benzene	S	S	S	S
Toluene	S	S	S	S

[a] I: insoluble, S: soluble, G: gel. The values given in parentheses are the minimum concentration (mg mL^{-1}) to achieve gelation.

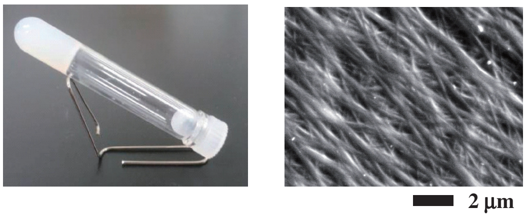


Figure 1. Optical and SEM images of gel from **5d** in cyclohexane.

The treatments of **4b**, **4c**, and **4f** with 4-bromophenyl isocyanate or phenyl isocyanate afforded the desired cyclophanes **5a**–**5d** (Scheme 1).[12] In the reaction of **4a** and **6d** utilizing triphosgene the cyclophane **7a** was obtained in a yield of 34%. Similar reactions between **4b**–**4f** and **6a**–**6d** were carried out to prepare the cyclophanes **7b**–**7f** (Scheme 1).[12]

The gelation behaviors of the cyclophanes **5a**–**5d** were studied in a variety of solvents and some results are summarized in Table 1.

In the series of the cyclophanes **5a**–**5d** the C12 alkyl chain was found necessary to gelate the solvents. Interestingly **5d** can form gels at a lower concentration than **5c**, which could be attributed to the bromine atom reducing the hydrogen bondings of the urea unit. Figure 1 shows the optical image and the SEM analysis of **5d**. Elongated fibers containing slender ones were observed. The C=O stretching at 1654 cm^{-1} was seen for **5d**, indicating formation of the hydrogen-bondings. The other cyclophanes were either too soluble or too insoluble in the solvents examined.

Although we have already clarified the structure of the dithia[3.3]metacyclophane system, the X-ray analysis[13] of the cyclophane **5a** was carried out in order to know the basic cyclophane structure with the urea group.

As expected the *syn* conformation has been confirmed meaning the urea group and the long alkyl chain are located in close proximity in the solid state (Figure 2).

The gelation properties of the cyclophanes **7a**–**7f** carrying two kinds of alkyl chains were also examined (Table 2).

In contrast to **5d** the cyclophane **7a** shows no clear gelation in spite of the C12 alkyl chain. This fact demonstrates the position of a long alkyl spacer could play a critical role for gelation behaviors in this cyclophane system. Formation of organogel was observed in cyclohexane for other cyclophanes **7b**–**7f**. As an example the gel formed from **7f** was shown in Figure 3. **7f** exhibits a network of slender fibers.

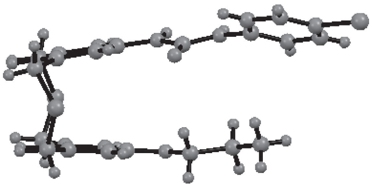


Figure 2. X-ray crystal structure of **5a**.

Table 2. Gelation properties of cyclophanes **7a**–**7f** in various solvents[a]

	Cyclophane					
	7a	**7b**	**7c**	**7d**	**7e**	**7f**
Hexane	I	P	I	I	I	I
Cyclohexane	P	G (1.1)	G (1.1)	G (2.1)	G (1.5)	G (0.6)
Ethanol	P	P	G (2.0)	S	S	S
Chloroform	S	S	S	S	S	S
Benzene	PG	S	S	S	S	S
Toluene	PG	S	S	S	S	S

[a] I: insoluble, S: soluble, P: precipitate, G: gel, PG: partial gel. The values given in parentheses are the minimum concentration (mg mL^{-1}) to achieve gelation.

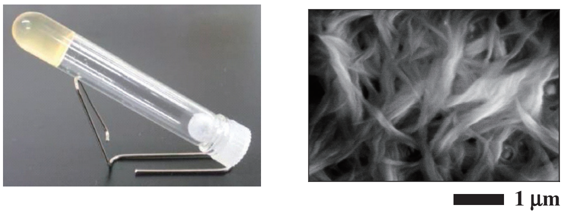


Figure 3. Optical and SEM images of gel from **7f** in cyclohexane.

Quite interestingly, **7c** is the only cyclophane that can gelate ethanol, even though the cyclophane **7f** likewise has the C6 and C12 alkyl chains. The alcohols such as methanol, buthanol, hexanol, and isopropanol were found to be also gelated by **7c**. The cyclophanes **7d** and **7e** having the C8 and C10 alkyl chains exhibit a similar trend for gelation. The minimum concentration to achieve gelation for cyclohexane was observed for the cyclophane **7f**. Considering the cyclophane **7c** with the C6 and C12 alkyl chains, the long C12 alkyl chain on the opposite side of the urea unit should be closely related to the gelation. In order to know the contribution of the cyclophane skeleton to gelation properties we have synthesized the partial units of most powerful gelater **7f**. The 1:1 mixture of **8** and **9** has no ability to gelate any solvents examined, meaning that the cyclophane by which these two long alkyl chain units are connected is essential for the gelator.

In conclusion we have achieved organogelators based on small-sized cyclophanes. This first development should disclose a new aspect of the organogelator because cyclophanes have a unique π-electron system as well as a dynamic structure. Further research according to this concept is in currently underway in our laboratory.

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12 Supporting Information is available electronically on the CSJ-Journal Web site, http://www.csj.jp/journals/chem-lett/index.html.

13 Crystal data for **5a**: $C_{26}H_{27}BrN_2O_2S_2$, $M_r = 543.53$, tetragonal, space group $P\bar{4}2_1c$ (No. 114), $a = 22.8183(10)$, $b = 22.8183(10)$, $c = 9.3500(4)\,\text{Å}$, $\alpha = 90.00°$, $\beta = 90.00°$, $\gamma = 90.00°$, $V = 4868.3(4)\,\text{Å}^3$, $Z = 8$, $D_{\text{calcd}} = 1.483\,\text{g cm}^{-3}$, BRUKER APEX II KY CCDC, The final R_1 and wR_2 were 0.0422 and 0.1298. CCDC reference No. 856991.