

Two-component, Small Molecule Gelling Agents

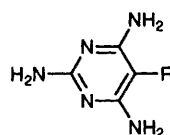
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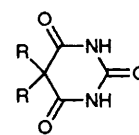
A 1 : 1 mixture of 5-hexadecyl-2,4,6-triaminopyrimidine and 5,5-didodecylbarbituric acid can cause physical gelation in organic liquids; the gel phenomenon is investigated by FTIR spectroscopy, TEM (transmission electron microscopy) and X-ray diffraction.

Recently we have reported that a long-chain alkylamide of *N*-benzyloxycarbonyl-L-valyl-L-valine is an excellent gelling agent for a wide variety of organic liquids at very low concentrations.¹ We assumed that the driving factors for physical gelation are intermolecular hydrogen bonding interactions which build up macromolecule-like aggregates and van der Waals interactions which juxtapose and interlock the large aggregates. In addition, particular attention has also been paid to self-assembly systems by molecular recognition through intermolecular hydrogen bonding between two different and independent components.²⁻⁶ Although almost all the

small molecular gelling agents were discovered by chance,⁷⁻¹² new types of gelling agent may be made based on the concept of self-assembling systems, because the intermolecular inter-



1; R = C₁₂H₂₅
2; R = C₁₆H₃₃



3; R = C₁₂H₂₅
4; R = C₁₆H₃₃

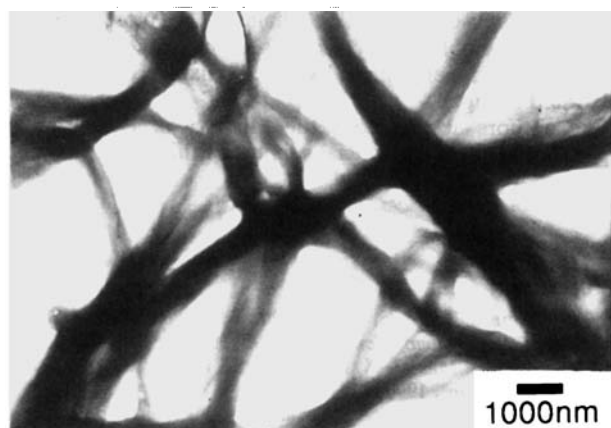


Fig. 1 TEM of a cyclohexane gel formed by a 1 : 1 mixture of **1** and **4**, negatively stained by osmic acid

Table 1 Gelation test of a 1 : 1 mixture of 5-alkyl-2,4,6-triaminopyrimidine **1** or **2** and 5,5-dialkyl barbituric acid **3** or **4** toward several organic liquids at 25 °C

	1 + 3	1 + 4	2 + 3	2 + 4
<i>N,N</i> -Dimethylformamide	Cocrystal	Gel-like ^a	Gel	Cocrystal
Chloroform	Cocrystal	Solution	Gel	Solution
Tetrachloromethane	Solution	Cocrystal	Gel	Solution
Cyclohexane	Gel	Gel	Gel	Gel

^a 'Gel-like' means a highly viscous fluid.

Table 2 Minimum gel concentration of a 1 : 1 mixture of **2** and **3** necessary for gelation at 25 °C

Solvent	$c_{\min}/\text{mol dm}^{-3a}$
<i>N,N</i> -Dimethylformamide	0.10
Chloroform	0.10
Tetrachloromethane	0.16
Cyclohexane	0.04

^a Total concentration of **2** and **3**.

actions between dissimilar components for self-assembly are consistent with the driving factor for physical gelation presumed by us. In this paper we report the first example of a two-component type of small molecule gelling agent with the concept of self-assembly in mind.

We focused on a 1 : 1 mixture of 5-alkyl-2,4,6-triaminopyrimidine and 5,5-dialkylbarbituric acid which were reported to form extended arrays based on three hydrogen bonds.² We synthesized the 2,4,6-triaminopyrimidine derivatives **1** and **2** and the barbituric acid derivatives **3** and **4** bearing *n*-dodecyl or *n*-hexadecyl groups.

A typical procedure for gelation testing is as follows: a weighed equimolar mixture of the 2,4,6-triaminopyrimidine and barbituric acid derivatives was mixed with the organic liquid (1 cm³) in a septum-capped test tube and the mixture was heated until the solid dissolved. The resulting solution was cooled at 25 °C for 2 h and then the gelation was checked visually. When it is 'formed', the gel is stable and the tube can be inverted without change of shape of the gel. The gel is normally so stable that it did not change to a viscoelastic fluid after several months. The results for gelation tests for several liquids are summarized in Table 1. All four equimolar mixtures of the two components can form a thermoreversible gel with cyclohexane; a mixture of **2** and **3** specifically can gel

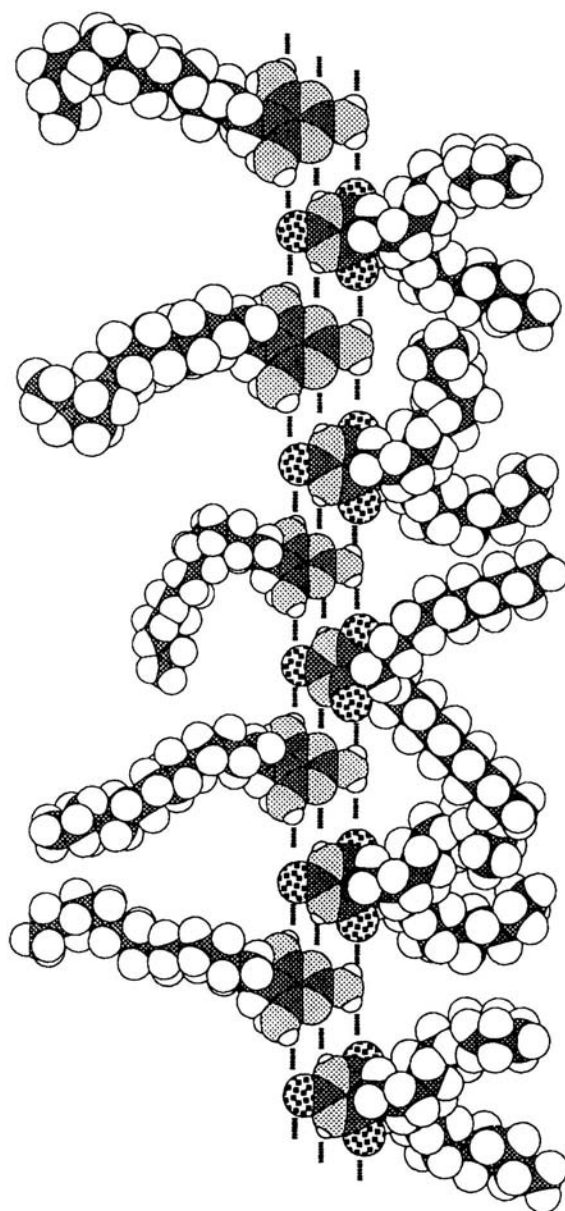


Fig. 2 The most plausible molecular assembling structure of a gel formed by a 1 : 1 mixture of **2** and **3**

and harden *N,N*-dimethylformamide, chloroform, tetrachloromethane and cyclohexane. It is noteworthy that mixtures of binary components only in a precise 1 : 1 molar ratio have a strong gelling ability. Most equimolar mixtures of the two components gave cocrystals with methanol, ethanol, propan-1-ol, acetone, ethyl acetate and benzene, which contained equimolar amounts of each component (from the results of elemental analysis). The minimum gel concentrations of a 1 : 1 mixture of **2** and **3** necessary for gelation are summarized in Table 2. The minimum gel concentrations of 0.04 mol dm⁻³ for cyclohexane and 0.10 mol dm⁻³ for chloroform mean that a molecular pair of **2** and **3** can harden 460 molecules of cyclohexane and 250 molecules of chloroform, respectively.

The FTIR spectrum of a chloroform gel formed by a mixture of **2** and **3** is characterized by broad bands at 3340 and 1640 cm⁻¹ assigned to N-H and C=O intermolecular hydrogen bonding stretching vibrations. It should be noted here that the FTIR spectrum of each component as a homogeneous solution shows bands at 3440 cm⁻¹ (N-H stretch, non-hydrogen bonding) for **2**, and 1700 (C=O stretch, non-hydrogen bonding) and 3400 cm⁻¹ (N-H stretch, non-hydrogen bond-

ing) for **3**. The FTIR spectrum (KBr) of the cocrystal precipitated from a mixture of **1** and **3** in acetone also contains broad bands at 3345 and 1645 cm^{-1} sharing the existence of intermolecular hydrogen bonding. These spectral data correspond to what is expected if association by hydrogen bonding between the NH_2 and the six-membered N of **2** and the C=O and NH of **3** occurs in both gel and cocrystal.

The transmission electron micrograph of a cyclohexane gel formed by a mixture of **1** and **4**, negatively stained by osmic acid, is shown in Fig. 1. It reveals a three-dimensional gathering of intertwined and interlocked fibres immobilizing the liquid. Considering that the diameter of the smallest fibre is *ca.* 80 nm, it seems that even the smallest fibre is an aggregate consisting of numerous molecules.

A xerogel was obtained as a translucent film by slow evaporation of a cyclohexane gel formed by a mixture of **1** and **3**. The X-ray diffraction pattern of the xerogel is characterized by four narrow reflections in the low-angle region and their spacings are exactly in the ratio 1:1/2:1/3:1/4, which is a characteristic of a layered structure. The interlayer distance corresponding to separation of the (100) planes is 19.2 Å. The diffraction pattern of the cocrystal containing **1** and **3** from acetone is also characterized by four reflections for a layered structure, which correspond to the (100), (200), (300) and (400) planes. However, the interlayer distance (27.6 Å) of the cocrystal is considerably larger than that of the xerogel. These results suggest that the xerogel possesses a similar layered structure to the cocrystal which is probably formed by accumulation of so-called 'molecular tapes',^{5,6} but the alkyl chains of the two components are randomly folded and bent (Fig. 2), in contrast to the extended alkyl chain of the cocrystal. It can be said that the gel is a metastable ordered state¹³ which cannot transfer to the crystalline state owing to

the movement of long alkyl chains. The most plausible molecular assembling structure, based on X-ray results in the literature,² of a gel formed by a 1:1 mixture of **2** and **3** is illustrated in Fig. 2.

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