Easy Preparation and Prominent Gelation of New Gelator Based on L-Lysine

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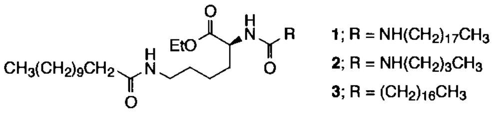
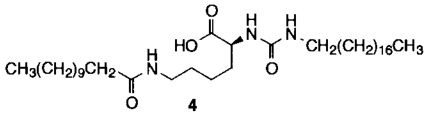
A new prominent gelator **1**, N^{ε}-lauroyl-N^{α}-stearylaminocarbonyl-L-lysine ethyl ester was effortlessly prepared by esterification of N^{ε}-lauroyl-L-lysine and addition of *n*-octadecyl isocyanate in a total yield of 89%. Gelator **1** was capable of gelling up a wide variety of organic fluids. A comparison of the gelation ability of structurally related compounds clarified that not only the introduction of long-chain alkyl but also more importantly the ureylene segment connecting the α-amino group and the alkyl chain are required for effective gelation.

Recent discoveries of low molecular weight compounds gelling up fluids have stimulated considerable interest in not only academic investigations but also technological applications. Although dozens of different categories of gelators have so far been identified,[1,2] the gelators made for practical use to date have been, to the best of our knowledge, limited to the following compounds: 12-hydroxystearic acid as a hardener of cooking oils, *N*-lauroyl-L-glutamic-α,γ-dibutylamide as a hardener of spilled oils and cosmetics, 1,3:2,4-dibenzylidene-D-sorbitol for spilled fluids, and 4,4'-bis(*n*-octylureido)diphenylmethane as a thickener of grease. Besides the above gelators, several all-powerful gelators have been reported capable of gelling up a wide variety of fluids.[3] However, the interest here has been restricted to laboratory usage. In this communication, we report a new gelator based on L-lysine that is obtained from available materials by a comfortable method in a moderate yield and exhibits a prominent gelation ability.

A new gelator **1**, N^{ε}-lauroyl-N^{α}-stearylaminocarbonyl-L-lysine ethyl ester, was prepared by esterification of commercially available N^{ε}-lauroyl-L-lysine, followed by addition of *n*-octadecyl isocyanate.[4] We emphasize that the gelator **1** was easily prepared via two reaction steps in a total yield of 89% from N^{ε}-lauroyl-L-lysine.


1; R = $NH(CH_2)_{17}CH_3$
2; R = $NH(CH_2)_3CH_3$
3; R = $(CH_2)_{16}CH_3$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The results of gelation tests of **1** and structurally-related compounds **2**–**4** are summarized in Table 1, where the values denote the minimum gel concentrations (g L^{-1}) necessary for gelation. Surprisingly, **1** could form physical gels and harden a wide variety of organic fluids, including hydrocarbons, alcohols, ketones, esters, ethers, aprotic polar compounds, aromatic compounds, mineral oils, and edible oils. The gels were transparent, translucent, or opaque (see Table 1).

Table 1. Gelation test of **1-4** and minimum gel concentration necessary for gelation at 25 °C[a]

Organic liquids	1	2	3	4
Hexane	45 (translucent)	insol.	insol.	cryst.
Cyclohexane	30 (translucent)	25	insol.	insol.
MeOH	30 (opaque)	soln.	cryst.	cryst.
EtOH	70 (opaque)	soln.	soln.	cryst.
Ethyl acetate	25 (translucent)	20	insol.	cryst.
Acetone	40 (opaque)	30	cryst.	cryst.
2-Butanone	45 (translucent)	65	cryst.	cryst.
Cyclohexanone	50 (translucent)	35	cryst.	cryst.
THF	60 (translucent)	65	insol.	cryst.
1,4-Dioxane	23 (translucent)	25	insol.	cryst.
Benzene	27 (transparent)	15	insol.	>100
Toluene	30 (transparent)	25	insol.	>100
Chlorobenzene	30 (transparent)	15	insol.	40
Nitrobenzene	17 (transparent)	15	cryst.	cryst.
DMF	40 (translucent)	soln.	cryst.	cryst.
DMA	80 (translucent)	soln.	soln.	cryst.
DMSO	25 (translucent)	45	25	cryst.
$CHCl_3$	>100 (translucent)	soln.	soln.	cryst.
CCl_4	80 (translucent)	30	insol.	cryst.
Pyridine	35 (transparent)	soln.	cryst.	soln.
Acetonitrile	25 (translucent)	24	cryst.	cryst.
PC	25 (translucent)	12	20	cryst.
Kerosene	30 (translucent)	30	cryst.	cryst.
Light oil	20 (translucent)	10	cryst.	cryst.
Silicone oil	3 (transparent)	10	insol.	soln.
Salad oil	6 (transparent)	6	26	cryst.
Soybean oil	6 (transparent)	5	18	cryst.

[a] insol. = almost insoluble, soln. = solution, cryst. = crystallization, PC = propylene carbonate. The gel formation was judged by test tube tilting method after standing at 25 °C for 2 h.. Values mean minimum gel concentration, whose unit is g L^{-1} (gelator/liquid).

A gelation ability comparable with **1** has been found in 1,3:2,4-dibenzylidene-D-sorbitol,[5] *n*-octadecylamide of *N*-benzyloxycarbonyl-L-valyl-L-valine,[6a] *trans*-(1*R*,2*R*)-bis(dodecanoylamino)cyclohexane,[6b] *trans*-(1*R*,2*R*)-bis(octadecylureido)cyclohexane,[6c] and *N*-*n*-octyl-D-gluconamide-6-benzoate[7] as far as we can judge from results in the literature. For instance, the amount of **1** necessary to gel one liter of cyclohexane, ethanol, ethyl acetate, benzene, DMF, acetonitrile, kerosene, silicone oil, and soybean oil are 30 g, 65 g, 25 g, 27 g, 30 g, 25 g, 30 g, 3 g, and 6 g, respectively. A mixed solvent of methanol (500 mL) and toluene (500 mL) was also gelled by 75 g of **1**, and a mixed solvent of DMF (500 mL) and acetonitrile (500 mL) was gelled by 26 g of **1**. Neither N^{ε}-lauroyl-L-lysine as the starting material nor N^{ε}-lauroyl-L-lysine ethyl ester as the precursor can gel any liquids, though N^{ε}-lauroyl-N^{α}-stearylaminocarbonyl-L-lysine methyl ester exhibits a gelation ability comparable to **1**.

N^{ε}-Lauroyl-N^{α}-butylaminocarbonyl-L-lysine ethyl ester (**2**), N^{ε}-lauroyl-N^{α}-cyclohexylaminocarbonyl-L-lysine ethyl ester, and N^{ε}-lauroyl-N^{α}-benzylaminocarbonyl-L-lysine ethyl ester as gelators were found to be appreciably inferior to **1**. It is interesting to note that N^{ε}-lauroyl-N^{α}-stearylcarbonyl-L-lysine ethyl ester (**3**) was found to have only a slight gelation ability due to insolubility or good crystallinity. The amide segment in **3** may be advantageous to the molecular packing for crystallization. These results led us to conclude that not only the introduction of long-chain alkyl but also more importantly the ureylene segment connecting the α-amino group and the alkyl chain are required for effective gelation.

It is also noteworthy that N^{ε}-lauroyl-N^{α}-stearylaminocarbonyl-L-lysine (**4**), in which the carboxyl group was substituted for the ethyl ester of **1**, was found to afford crystals in most of the organic liquids and hardly acted as a gelator. IR spectra of **4**, recrystallized from ethanol, was characterized by 1716 cm^{-1} of C=O stretching vibration for the carboxyl, indicating the formation of a cyclic dimer. It seems that the intermolecular hydrogen bonding between the carboxyl groups, leading to the formation of the cyclic dimer, was so strong that **4** tended to crystallize out of the solution instead of gel. If compounds are solvated, with consequent being highly soluble in solvents, they do not work as gelators. On the contrary, they reveal an insoluble character towards solvents or good crystallinity, when the intermolecular interactions of compounds are extremely strong in comparison with the solvation. Physical gelation occurs for low molecular weight compounds from the delicate balance between the tendency for the compounds to dissolve in the solvents upon solvation and the tendency to crystallize through the intermolecular interactions.[8]

We imagine that gelation is a phenomenon related more closely to crystallization than dissolution. This is because the formation of molecular aggregates through non-covalent interactions among gelators is primarily indispensable for gelation. When a three-dimensional network is formed by juxtaposing and interlocking aggregates, the liquids are entrapped in the three-dimensional network and gelation occurs. However, the self-aggregation usually results in the formation of a crystal lattice leading to the precipitation of crystals, making it difficult to design new gelators. The fact that gels fail to form when the ureylene segment in **1** is replaced with an amide segment (compare **1** with **3** in Table 1) relates to us the delicate balance between crystallization and gelation.

The hydrogen bonds participating in the formation of the molecular aggregates was confirmed by FT-IR spectroscopy. The FT-IR spectrum of the cyclohexane gel of **1** was characterized by bands at 3294, 1639, and 1622 cm^{-1}, which were assigned to N–H (amide and ureylene), C=O (amide), and C=O (ureylene) hydrogen bonding stretching vibrations.

In conclusion, we have developed a new gelator **1**, which is prepared by esterification of N^{ε}-lauroyl-L-lysine and addition of *n*-octadecyl isocyanate. The gelator **1** exhibits a prominent gelation ability and can gel up a wide variety of organic fluids, including protic liquids to aprotic ones, including polar liquids to nonpolar ones.

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