New Low-Molecular-Mass Gelators Based on L-Lysine: Amphiphilic Gelators and Water-Soluble Organogelators

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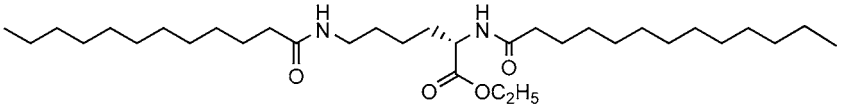
The new L-lysine alkali-metal salts **1**–**5** ($M^+ = Na^+$ and K^+) with different alkyl groups at the N^{α}-position were easily synthesized, and their hydro- and organogelation properties were investigated. All compounds were H_2O-soluble, and some salts, especially the potassium salts, functioned as a hydrogenator that could gel water below 2 wt-%. These salts also had organogelation abilities for many organic solvents.

1. Introduction. – Hydrogels are used for many applications, ranging from food, cosmetic thickeners, and textile fibers to support matrices for drug delivery and tissue replacement [1–3]. These polymers can include synthetic polyalcohols and ethers such as PVA (poly(vinyl alcohol)) and PEG/PEO (poly(ethylene glycol)/poly(ethylene oxide)) [4], biopolymers such as collagen and polysaccharides [5], polyacids [6], bimimetic polymers, and globular proteins [7]. In hydrogels, these polymers form a three-dimensional network through covalent or noncovalent cross-linkings. Each of these classes of polymers can be selected for a particular set of network properties required for the materials (biodegradability, biocompatibility, and nontoxicity). Most gels formed by entanglements and the cross-linking of high-molecular-mass polymers exhibit similar morphological properties, and there is no controllable ordering or discernible nano- and micro-structures of the gel matrix materials beyond the local intermolecular association on the molecular level.

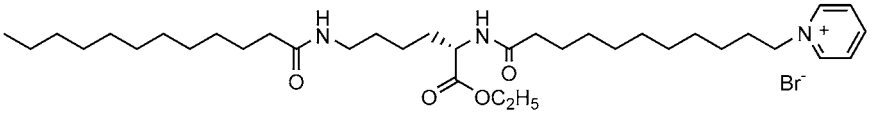
Recently, supramolecular self-assembly has been used for the formation of hydrogels by using diblock and triblock oligomers such as copolypeptides [8] as well as low-molecular-mass compounds (hydrogelators) [9]. Particularly, hydrogel formation by hydrogelators has been of considerable interest, and the supramolecular mechanism has been explored. Most hydrogelators have a good gelation ability for H_2O and form a hydrogel through a mechanism similar to the formation of an organogel by organogelators (for excellent reviews, see [10]; for recent literature, see [11]). However, the molecular structures and synthetic procedures of the hydrogelators are still complicated.

We have focused on the self-assembling properties of organogelators in organic solvents and challenged the development of them as hydrogelators. Organogelators generally have not only amphiphilic groups such as amide, urea, carboxylic acid, and hydroxy functions but also hydrophobic segments such as long alkyl chains and aromatic rings; therefore, most organogelators are H_2O-insoluble. One of the simplest strategies to form hydrogelators is the introduction of charge into organogelators. The

successful conversion of L-lysine-based organogelators (see **A**) into hydrogelators is achieved by linking it to positively charged groups (see **B**) [9]. Another approach is the introduction of a negative charge that is simply achieved by conversion of the ester to a carboxylate (alkali-metal salt). In this paper, we describe new amphiphilic gelators and H_2O-soluble organogelators based on L-lysine with a negative charge, *i.e.* alkali-metal salts thereof.



A **L**-lysine-based organogelator



B **L**-lysine-based hydrogelator

2. Results and Discussion. – *Hydrogelation Properties.* The hydrogelation properties of **1**–**5** (*Fig. 1*) and their minimum gel concentration (*MGC*) necessary for gelation are listed in *Table 1*. All compounds were H_2O-soluble. For the sodium salts **1a**–**5a**, only **1a** functioned as a hydrogelator that could gel water at 2 wt-%. The salts **2a** and **3a** produced a viscous aqueous solution above 2 wt-% (VS in *Table 1*). Moreover, **4a** and **5a** were very soluble in H_2O, and even at 5 wt-%, their aqueous solutions were isotropic but not viscous (S in *Table 1*). In contrast, the potassium salts tended to function as hydrogelators; except for **2b**, they formed a hydrogel. Especially **3b** was an excellent

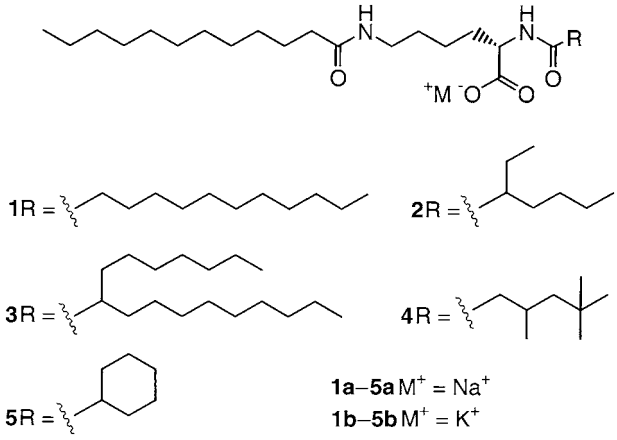


Fig. 1. *Chemical structures of* L-*lysine derivatives*

Table 1. *Gelation Test for* **1**–**5** *in Water and Various Organic Solvents*

Solvent	*MGC*[a])[b])									
	Na^+ salt					K^+ salt				
	1a	**2a**	**3a**	**4a**	**5a**	**1b**	**2b**	**3b**	**4b**	**5b**
H_2O	20	VS	VS	S	S	20	S	3	20	20
Hexane	PG	Ins	7	5	Ins	Ins	Ins	PG	20	Ins
Cyclohexane	2	7	7	10	PG	20	VS	8	VS	PG
AcOEt	17	5	5	P	5	Ins	Ins	12	8	Ins
Acetone	Ins	7	7	P	Ins	Ins	Ins	20	8	Ins
Cyclohexanone	10	PG	PG	12	3	3	7	15	15	3
THF	PG	10	7	S	5	15	10	PG	PG	7
1,4-Dioxane	25	5	5	22	7	8	1	10	2	1
Benzene	5	10	5	8	5	12	3	7	VS	7
Toluene	2	7	10	8	5	8	2	2	VS	15
Chlorobenzene	5	7	7	12	7	4	2	3	VS	4
Nitrobenzene	VS	7	3	VS	3	15	3	2	7	0.7
DMF	PG	S	15	S	PG	25	PG	12	S	25
DMSO	PG	S	20	S	30	25	S	10	S	PG
$CHCl_3$	PG	S	S	S	25	15	PG	S	VS	30
CCl_4	2	30	7	20	PG	15	PG	10	VS	PG

[a]) *MGC* = minimum gel concentration necessary for gelation (mg/ml). [b]) S = Solution at 5 wt-%; Ins = almost insoluble; PG = partial gel at 3 wt-%; VS = viscous solution at 2 wt-%.

hydrogelator that could gel H_2O at 0.3 wt-%. As K^+ has a lower hydration number than Na^+, the potassium salts were more hydrophobic than the sodium salts; therefore, the hydrophilic-hydrophobic balance in the gelator molecules may be suitable for functioning as a hydrogelator. In addition, these hydrogelation properties were strongly affected by the counter cation rather than by the alkyl groups at the N^{α}-position.

Organogelation Properties. Compounds **1**–**5** had organogelation abilities for many organic solvents (*Table 1*). Among the Na^+ salts, **3a** gelled most organic solvents at relatively low concentrations (< 1 wt-%), such as poor solvents (hexane, cyclohexane), cyclic ethers (THF, dioxane), aromatic solvents, polar solvents (DMF, DMSO), and CCl_4. The K^+ salt **3b** also gelled most organic solvents. Although no dramatic influence of the alkyl groups at the N^{α}-position on their organogelation abilities were observed, the counter cations affected the organogelation abilities, especially in case of **1** and **4**. Compared with **1a**, **1b** had a good organogelation ability that could gel polar solvents (DMF, DMSO) and $CHCl_3$. In contrast, the organogelation abilities of **4a** and **4b** were quite different; **4b** had no organogelation ability for aromatic solvents such as benzene, toluene, and chlorobenzene and could effectively gel AcOEt and acetone. These gelation properties indicate that **1a**, **1b**, and **3b**–**5b** function as amphiphilic gelators that can gel not only H_2O but also many organic solvents, while other compounds are H_2O-soluble organogelators.

Transmission Electron Microscopy (TEM). To obtain visual insights into the aggregation mode of these gelators in hydrogels and organogels, we took TEM images of the hydrogel and organogel. *Fig. 2* shows the TEM images of **1a**, **2a**, and **2b** in H_2O

and **3a**, **2b**, and **4b** in CCl_4[1]). In water, **1a** and **2a** created three-dimensional network structures by entanglement of the self-assembled nanofibers with a diameter of *ca.* 30 nm – 50 nm (*Fig. 2*, *a* and *b*), while **2b**, having no hydrogelation ability, formed spherical aggregates with a diameter of *ca.* 200 nm (*Fig. 2*, *c*). In the CCl_4 gels, three-dimensional network structures formed by the self-assembled nanofibers of the gelators were observed (*Fig. 2*, *d* – *f*). These results indicate that the hydrogels and organogels are formed by entrapping solvent molecules into the spaces of the three-dimensional network.

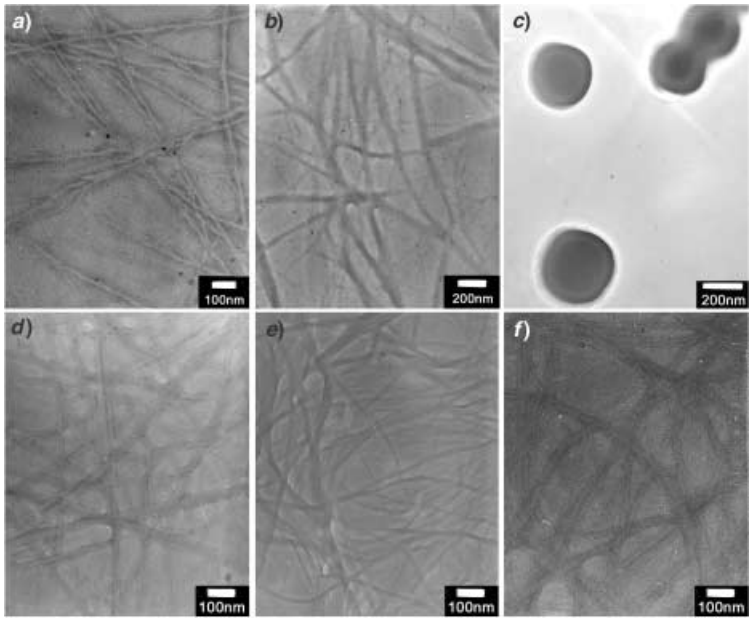


Fig. 2. *TEM Images of* a) **1a**, b) **2a**, *and* c) **2b** *in water, and* d) **3a**, e) **2b**, *and* f) **4b** *in* CCl_4

Fluorescence Study. The fluorescence spectra of 8-anilinonaphthalene-1-sulfonate (ANS) sodium salt as a probe of the hydrophobic environment were measured in aqueous solutions at various concentrations of **4b**. *Fig. 3* shows the dependence of the fluorescence-maximum wavelength (λ_{max}) and fluorescence intensity of ANS on the concentration of **4b**. Up to 5 mg/ml of **4b**, the λ_{max} blue-shifted from 528 to 494 nm, and the further addition increased the luminescence intensity but produced only a slight blue-shift in the λ_{max} values. Such luminescence behavior is frequently observed when the ANS molecules are incorporated into a hydrophobic environment; namely, the interior of the strands in the self-assembled nanofibers is hydrophobic. Therefore, these results establish that one of the driving forces for the self-assembly of **4b** into nanofibers is a hydrophobic interaction, and the self-assembly begins below the *MGC* (20 mg/ml). In addition, this fact agrees with a previous report about amino acid-based hydrogelators.

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[1]) In H_2O, **1a**, **2a**, and **2b** were a hydrogel, viscous solution, and isotropic solution at 20 wt-%, respectively. In CCl_4, **3a**, **2b**, and **4b** were a gel, partial gel, and viscous solution at 10 wt-%, respectively.

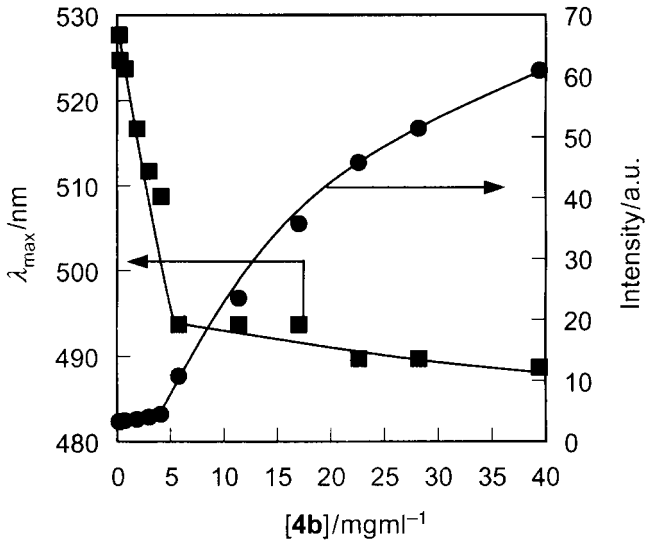

Fig. 3. *Fluorescence behavior of 8-anilinonaphthalene-1-sulfonate* (ANS) *in water containing various concentrations of* **4b**. ● = Fluorescence intensity, ■ = maximum wavelength of fluorescence spectra of ANS. Excitation wavelength is 365 nm.

FT-IR Study. The driving forces for self-assembly into a nanofiber were evaluated by an FT-IR study. *Fig. 4* shows the FT-IR spectra of **4b** in (D_6)DMSO solution and the D_2O hydrogel. The FT-IR spectrum in (D_6)DMSO, in which no self-assembly of **4b** occurred, showed absorption bands at 1660, 1546, and 1605 cm^{-1}, characteristic of the non-H-bonding C=O (amide I) stretching vibration, H-bonded N–H (amide II) bending vibration, and carboxylate (CO_2^-) stretching vibration, respectively. These facts indicate that **4b** underwent a H-bonding interaction with (D_6)DMSO ($(CD_3)_2S{=}O\cdots H{-}N$) but no interaction of the amide carbonyl group of **4b**, *i.e.*, no self-assembly. In the D_2O solution (5 mg/ml) and hydrogel (20 mg/ml), the absorption bands were observed at 1620 cm^{-1} for amide I and 1588 cm^{-1} for the carboxylate group. Compared with those in (D_6)DMSO, the IR peaks of the amide and carboxylate groups shifted to lower frequency. Such spectral shifts are compatible with the presence of intermolecular H-bonded amide groups and suggest that one of the driving forces for self-assembly into the nanofibers is H-bonding. Because the IR peaks were independent of the **4b** concentrations, **4b** underwent intermolecular H-bonding even at 5 mg/ml. In addition, the carboxylate groups should also participate in the self-assembling process by some interactions.

The FT-IR measurements also provided information on the alkyl groups of **4b** in D_2O. The absorption bands of the antisymmetric ($\tilde{\nu}_{as}$) and symmetric ($\tilde{\nu}_s$) CH_2 stretching vibrations of **4b** appeared at 2930 ($\tilde{\nu}_{as}$ (C–H)) and 2857 cm^{-1} ($\tilde{\nu}_s$ (C–H)) in $CHCl_3$[2]), but in D_2O, they shifted to 2923 and 2846 cm^{-1}. Such a lower-frequency shift is induced by restriction of the alkyl chains in **4b** [12]. Therefore, the alkyl groups

[2]) In $CHCl_3$, the alkyl groups have no interaction.

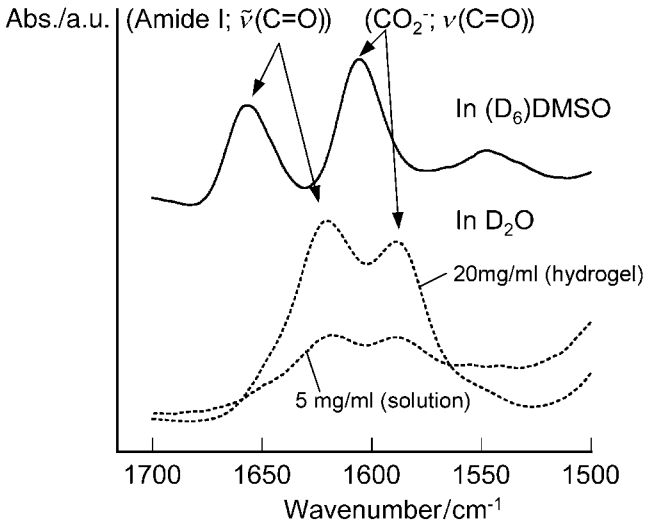

Fig. 4. *FT-IR Spectra of* **4b** *in (D₆)DMSO* ([**4b**] = 20 mg/ml) *and* D_2O ([**4b**] = 5 mg/ml and 20 mg/ml).

of **4b** strongly organized in the self-assembled nanofibers through a hydrophobic interaction, which was supported by the results of the fluorescence studies.

On the other hand, in the CCl_4 gel of **4a** (organogel), the IR peaks arising from the H-bonded amide groups were observed at 3292 (amide A; $\tilde{\nu}$(N–H)), 1640 (amide I; $\tilde{\nu}$(C=O)), and 1550 cm^{-1} (amide II; δ(N–H)). In addition, the absorption band of the interacting carboxylate group was at 1586 cm^{-1}. The FT-IR results are consistent with those of common organogelators [10][11].

^{1}H-NMR Study. Fig. 5 shows the amide-proton region of the ^{1}H-NMR spectra of **4b** in (D_6)DMSO (20 mg/ml of **4b**) and D_2O/H_2O 1:9 (*v*/*v*; 5 mg/ml and 20 mg/ml of **4b**). In (D_6)DMSO, the δ of the two amide protons were observed at 7.11 ppm for H_a–N and 7.09 ppm for H_b–N (see *Table 2*). Amide protons devoid of interaction with solvents and between each other appear at δ *ca.* 5.8 for H–N^{ε} and 6.2 for H–N^{α}[3]). Thus, the two amide protons of **4b** underwent H-bonding with (D_6)DMSO (S=O···H–N). On the other hand, in D_2O/H_2O, the δ of the amide protons of **4b** were shifted downfield compared with those in (D_6)DMSO, especially that of H_b–N (7.09 → 7.67 ppm), indicating intermolecular H-bonding in water. Furthermore, these chemical shifts slightly depended on the concentration of **4b**: they shifted to lower field with increasing concentration (see *Table 2*). This indicates the presence of intermolecular H-bonding at low **4b** concentrations, which was supported by the IR results.

Hydrogelation Mechanism. The above results suggest the following mechanism for the hydrogelation: After allowing the solution to stand at room temperature, followed by dissolution of the gelator in H_2O with heating, the gelator self-assembles into some aggregates through first the hydrophobic interaction between long alkyl groups and

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[3]) N^{α},N^{ε}-Bis(lauroyl)-L-lysine ethyl ester (lauroyl = 1-oxododecyl) was used as a model compound for ^{1}H-NMR measurement in $CDCl_3$. This compound showed no gelation and self-assembly in any of the organic solvents.

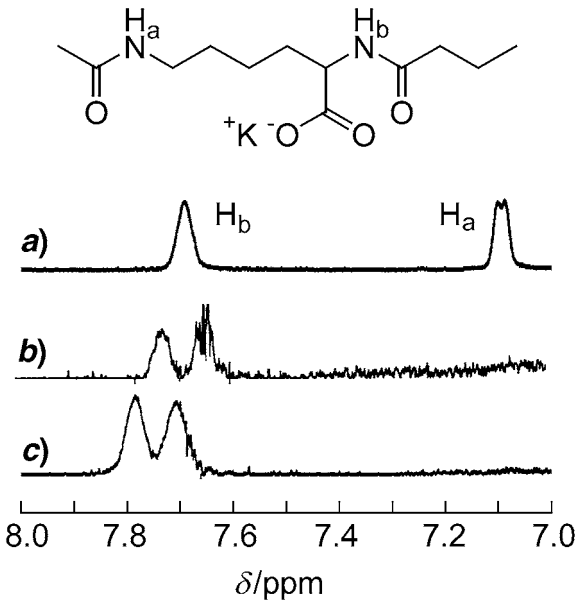

Fig. 5. *^{1}H-NMR Spectra of* **4b** a) *in (D$_6$)DMSO* ([**4b**] = 20 mg/ml) *and* b) c) *in D$_2$O/H$_2$O 1:9* (*v*/*v*) ([**4b**] = 5 mg/ml and 20 mg/ml).

Table 2. *^{1}H-NMR Chemical Shifts* δ [ppm] *of Amide Protons of* **4b** *in (D$_6$)DMSO and D$_2$O/H$_2$O*

	(D$_6$)DMSO	D$_2$O/H$_2$O (5 mg/ml)	D$_2$O/H$_2$O (20 mg/ml)
H$_a$–N	7.70	7.73	7.79
H$_b$–N	7.09	7.67	7.71

then H-bonding between the amide groups. It is noteworthy that the H-bonding between the amide groups occurs in the hydrophobic environment usually the amide groups interact with H_2O. These aggregates then self-assemble into nanofibers through H-bonding and hydrophobic interactions. Finally, the entangling nanofibers create a three-dimensional network, which leads to hydrogelation.

Conclusion. – We revealed the successful development of L-lysine-based organogelators into hydrogelators by introduction of a negative charge such as a carboxylate group (alkali-metal salts). After dissolution of these salts in solvents, some salts can gel not only H_2O but also various organic solvents, and others can gel only organic solvents; therefore, the former salts act as amphiphilic gelators, while the latter are H_2O-soluble organogelators. FT-IR, ^{1}H-NMR, TEM, and fluorescence studies demonstrate that the formation of hydrogels by these hydrogelators involves two self-assembling processes, *i.e.*, the formation of some aggregates and their growth into nanofibers. Moreover, the driving forces for the self-assemblies are the hydrophobic interactions between the alkyl groups and H-bonding between the amide groups.

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Experimental Part

1. *General.* N^{ε}-Lauroyl-L-lysine (lauroyl = 1-oxododecyl) was from *Ajinomoto Co., Inc.* All acyl chlorides were purified by distillation just before use. The other chemicals were of the highest commercially available grade and used without further purification. All solvents used in the syntheses were purified, dried, or freshly distilled as required.

UV/VIS Spectra: *Jasco V-570* UV/VIS/NIR spectrometer. Fluorescence Spectra: *Jasco FP-750* spectrofluorometer, λ_{max} in nm; $[ANS] = 1.0 \cdot 10^{-5}$ M and [gelator] = 0–40 mg/ml; 1 cm × 1 cm cell; excitation wavelength 365 nm, corresponding to the absorption maximum. FT-IR Spectra: *Jasco FS-420* spectrometer; in cm^{-1}; (D_6)DMSO and D_2O (20 mg ml^{-1} of gelators) solns.; 2-cm^{-1} resolution with 32 scans; cell with a CaF_2 window and 25-μm spacers. ^{1}H-NMR Spectra: *Bruker Avance-400* spectrometer; δ in ppm rel. to $SiMe_4$ as standard, *J* in Hz; solns. of **4b** in (D_6)DMSO and D_2O/H_2O 1:9. Elemental analyses: *Perkin-Elmer II* CHNS/O analyzer *2400*.

2. *Gelation Test*. A mixture of a weighed gelator in H_2O (1 ml) in a sealed test tube was heated until a clear soln. appeared. After allowing the soln. to stand at 25° for 6 h, the state of the soln. was evaluated by the 'stable to inversion of a test tube' method.

3. *TEM Images. Jeol-IEM-2010* electron microscope at 200 kV; the solns. (20 wt-% in H_2O and 10 wt-% in CCl_4) of the gelators were dropped on a collodion- and carbon-coated 400-mesh copper grid and immediately dried under vacuum for 24 h; after dropping a 2 wt-% phosphotungstic acid soln. on them, the grids were dried under vacuum for 24 h.

4. *Syntheses.* N^{α},N^{ε}-*Bis(1-oxododecyl)*-L-*lysine Sodium Salt* (**1a**). N^{ε}-(1-Oxododecyl)-L-lysine (60.9 mmol) was dissolved in an aq. soln. (1 l) containing NaOH (0.3 mol), and Et_2O was then added. Dodecanoyl chloride (80 mmol) was slowly added to the Et_2O layer. The biphasic soln. was vigorously stirred at 0° for 1 h and then at r.t. for 20 h. The resulting soln. was carefully acidified with conc. HCl soln. (pH *ca.* 1). The white precipitate was filtered, washed with H_2O, and dried. The N^{α},N^{ε}-bis(1-oxododecyl)-L-lysine (10 mmol) was dissolved in MeOH (100 ml), and then an aq. NaOH soln. (10 mmol/10 ml) was added. The resulting mixture was stirred at r.t. for 3 h and evaporated and the residue purified by recrystallization from MeOH/Et_2O: **1a** (90%). M.p. 177–178°. IR (KBr): 3322 (N–H, amide A), 1641 (C=O, amide I), 1598 (C–O, CO_2^-), 1548 (N–H, amide II). ^{1}H-NMR (400 MHz, $CDCl_3$, 25°): 0.88 (*t*, *J* = 6.6, 2 Me); 2.16–2.26 (*m*, 2 CH_2CONH); 4.07 (br., *CH*NH), 6.87 (br., H–N^{ε}); 7.42 (br., H–N^{α}). Anal. calc. for $C_{30}H_{57}N_2NaO_4$ (532.72): C 67.63, H 10.78, N 5.26; found: C 67.66, H 11.41, N 5.28.

N^{α}-*(2-Ethyl-1-oxohexyl)*-N^{ε}-*(1-oxododecyl)*-L-*lysine Sodium Salt* (**2a**). As described for **1a**, with 2-ethylhexanoyl chloride: **2a** (90%). M.p. 144–146°. IR (KBr): 3309 (N–H, amide A), 1642 (C=O, amide I); 1592 (C–O, CO_2^-), 1546 (N–H, amide II). ^{1}H-NMR (400 MHz, $CDCl_3$, 25°): 0.84–0.89 (*m*, 2 Me); 2.16–2.26 (*m*, CH_2CONH, NHCOC*H*); 3.23 (*q*, *J* = 6.3, NHCH_2); 4.12 (*m*, *CH*NH); 6.82 (*d*, *J* = 16.2, H–N^{ε}); 7.34, 7.14 (*d*, *J* = 6.6, H–N^{α}). Anal. calc. for $C_{26}H_{49}N_2NaO_4$ (476.67): C 65.51, H 10.36, N 5.88; found: C 65.61, H 10.87, N 5.92.

N^{α}-*(2-Heptyl-1-oxoundecyl)*-N^{ε}-*(1-oxododecyl)*-L-*lysine Sodium Salt* (**3a**). As described for **1a**, with 2-heptylundecanoyl chloride: **3a** (90%). M.p. 120–122°. IR (KBr): 3307 (N–H, amide A), 1642 (C=O, amide I), 1588 (C–O, CO_2^-), 1549 (N–H, amide II). ^{1}H-NMR (400 MHz, $CDCl_3$, 25°): 0.86–0.89 (*m*, 3 Me); 2.14 (*t*, *J* = 8.1, CH_2CONH, NHCOC*H*); 3.05–3.21 (*m*, NHCH_2); 4.12 (*m*, *CH*NH); 6.60 (br., H–N^{ε}); 6.99 (br., H–N^{α}). Anal. calc. for $C_{36}H_{69}N_2NaO_4$ (616.93): C 70.09, H 11.27, N 4.54; found: C 70.12, H 11.27, N 4.57.

N^{ε}-*(1-Oxododecyl)*-N^{α}-*(3,5,5-trimethyl-1-oxohexyl*-L-*lysine Sodium Salt* (**4a**). As described for **1a**, with 3,5,5-trimethylhexanoyl chloride: **4a** (92%). M.p. 120–122°. IR (KBr): 3312 (N–H, amide A), 1643 (C=O, amide I), 1583 (C–O, CO_2^-), 1556 (N–H, amide II). ^{1}H-NMR (400 MHz, $CDCl_3$, 25°): 0.86–0.96 (*m*, 5 Me); 2.01–2.18 (*m*, 2 CH_2CONH); 3.08–3.21 (*m*, NHCH_2); 4.09 (br., CH); 6.84 (br., H–N^{ε}), 7.46 (br., H–N^{α}). Anal. calc. for $C_{27}H_{51}N_2NaO_4$ (490.69): C 66.09, H 10.48, N 5.71; found: C 66.12, H 10.99, N 5.75.

N^{α}-*(Cyclohexylcarbonyl)*-N^{ε}-*(1-oxododecyl)*-L-*lysine Sodium Salt* (**5a**). As described for **1a**, with cyclohexanecarbonyl chloride (90%). M.p. 150–152°. IR (KBr): 3312 (N–H, amide A), 1643 (C=O, amide I), 1593 (C–O, CO_2^-), 1547 (N–H, amide II). ^{1}H-NMR (400 MHz, $CDCl_3$, 25°): 0.88 (*t*, *J* = 6.8, Me); 2.17 (*t*, *J* = 7.6,

CH_2CONH, NHCOC*H*); 3.15 (br., NHCH_2); 4.23 (br., CH); 6.67 (br., H–N$^{\varepsilon}$); 6.99 (br., H–N$^{\alpha}$). Anal. calc. for $C_{25}H_{45}N_2NaO_4$ (460.63): C 65.19, H 9.85, N 6.08; found: C 65.31, H 10.03, N 6.11.

N$^{\alpha}$,N$^{\varepsilon}$-*Bis(1-oxododecyl)*-L-*lysine Potassium Salt* (**1b**). As described for **1a**, with KOH: **1b** (91%). M.p. 161–163°. IR (KBr): 3310 (N–H, amide A), 1643 (C=O, amide I), 1587 (C–O, CO_2^-), 1553 (N–H, amide II). ^{1}H-NMR (400 MHz, $CDCl_3$, 25°): 0.88 (*t*, *J* = 6.8, 2 Me); 2.14–2.23 (*m*, 2 NHCOCH_2); 3.11–3.20 (*m*, NHCH_2), 4.00 (br., CH); 6.82 (br., H–N$^{\varepsilon}$); 7.38 (br., H–N$^{\alpha}$). Anal. calc. for $C_{30}H_{57}KN_2O_4$ (548.88): C 65.65, H 10.47, N 5.10; found: C 65.66, H 10.88, N 5.16.

N$^{\alpha}$-*(2-Ethyl-1-oxohexyl)*-N$^{\varepsilon}$-*(1-oxododecyl)*-L-*lysine Potassium Salt* (**2b**). As described for **2a**, with KOH: **2b** (90%). M.p. 146–148°. IR (KBr): 3302 (N–H, amide A), 1642 (C=O, amide I), 1585 (C–O, CO_2^-), 1552 (N–H, amide II). ^{1}H-NMR (400 MHz, $CDCl_3$, 25°): 0.84–0.89 (*m*, 2 Me); 2.16–2.26 (*m*, CH_2CONH, NHCOC*H*); 3.08–3.22 (*m*, NHCH_2); 4.03 (br., C*H*NH); 6.77 (br., H–N$^{\varepsilon}$); 7.16, 7.39 (br., H–N$^{\alpha}$). Anal. calc. for $C_{26}H_{49}KN_2O_4$ (492.78): C 63.37, H 10.02, N 5.68; found: C 63.44, H 10.52, N 5.66.

N$^{\alpha}$-*(2-Heptyl-1-oxoundecyl)*-N$^{\varepsilon}$-*(1-oxododecyl)*-L-*lysine Potassium Salt* (**3b**). As described for **3a**, with KOH: **3b** (91%). M.p. 143–145°. IR (KBr): 3310 (N–H, amide A), 1644 (C=O, amide I), 1584 (C–O, CO_2^-), 1548 (N–H, amide II). ^{1}H-NMR (400 MHz, $CDCl_3$, 25°): 0.85–0.89 (*m*, 3 Me); 2.15 (*t*, *J* = 7.3, CH_2CONH, NHCOC*H*); 3.03–3.24 (*m*, NHCH_2); 4.01 (br., C*H*NH); 6.54 (br., H–N$^{\varepsilon}$); 6.93 (br., H–N$^{\alpha}$). Anal. calc. for $C_{36}H_{69}KN_2O_4$ (633.04): C 68.30, H 10.99, N 4.43; found: C 68.33, H 11.37, N 4.45.

N$^{\alpha}$-*(3,5,5-Trimethyl-1-oxohexyl)*-N$^{\varepsilon}$-*(1-oxododecyl)*-L-*lysine Potassium Salt* (**4b**). As described for **4a**, with KOH: **4b** (91%). M.p. 137–139°. IR (KBr): 3304 (N–H, amide A), 1644 (C=O, amide I), 1589 (C–O, CO_2^-), 1551 (N–H, amide II). ^{1}H-NMR (400 MHz, $CDCl_3$, 25°): 0.85–0.91 (*m*, 5 Me); 2.01–2.18 (*m*, 2 CH_2CONH); 3.05–3.24 (*m*, NHCH_2); 4.02 (br., CH); 6.66 (br., H–N$^{\varepsilon}$); 7.34 (br., H–N$^{\alpha}$). Anal. calc. for $C_{27}H_{51}KN_2O_4$ (506.80): C 63.99, H 10.14, N 5.53; found: C 64.04, H 10.24, N 5.55.

N$^{\alpha}$-*(Cyclohexylcarbonyl)*-N$^{\varepsilon}$-*(1-oxododecyl)*-L-*lysine Potassium Salt* (**5b**). As described for **5a**, with KOH: **5b** (91%). M.p. 153–155°. IR (KBr): 3326 (N–H, amide A), 1644 (C=O, amide I), 1577 (C–O, CO_2^-), 1548 (N–H, amide II). ^{1}H-NMR (400 MHz, $CDCl_3$, 25°): 0.87 (*t*, *J* = 6.3, Me); 2.18 (br., CH_2CONH, NHCOC*H*); 3.14 (br., NHCH_2); 4.18 (br., CH); 6.83 (br., H–N$^{\varepsilon}$); 7.09 (br., H–N$^{\alpha}$). Anal. calc. for $C_{25}H_{45}KN_2O_4$ (476.73): C 62.98, H 9.51, N 5.88; found: C 63.11, H 10.23, N 5.91.

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