Chiral Gelators Constructed from 11-Aminoundecanoic (AUDA), Lauric and Amino Acid Units. Synthesis, Gelling Properties and Preferred Gelation of Racemates vs. the Pure Enantiomers

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A new class of efficient low molecular weight gelator molecules has been designed by combining 11-aminoundecanoic acid (AUDA), lauric acid and aromatic and aliphatic amino acid units in the same molecule. This yields a special class of fatty acid amphiphiles with core chiral centres and hydrogen bonding sites. Some of the compounds with terminal carboxylic acid and sodium carboxylate functions exhibited ambidextrous gelation properties, being able to form gels both with highly polar solvents (water, DMSO) and also with highly lipophilic solvents, including two hydrocarbon fuels. At variance with several recent observations that the enantiomers are generally more efficient gelators than the corresponding racemates, some of the racemic gelators prepared in this work were found to be capable of gelling up to 16 times larger volumes of certain solvents than the pure enantiomers. Temperature-dependent FTIR and ^{1}H NMR studies of the gels formed by derivatives with terminal carboxylic acid groups and lipophilic solvents revealed that intermolecular hydrogen bonding between amidic and carboxylic acid units was involved in the self-assembly of gel aggregates. Additional strong stabilization of the aggregates was observed in the gelators possessing terminal sodium carboxylate groups, and this was attributed to the electrostatic and ion-dipole interactions between the sodium carboxylate groups. This additional stabilization appears to be responsible for considerably higher thermal stability of the latter gels in relation to those formed by gelators with terminal carboxylic acid groups.

1. Introduction

Gelation of various organic fluids and water by low molecular mass organic compounds represents a fascinating supramolecular phenomenon. Formation of a gel is the consequence of molecular self-assembly and constitutes a macroscopic manifestation thereof.[1,2] Gels formed by small organic compounds of highly diverse structures have attracted much recent attention as a unique type of nanostructured organic materials with dynamic properties and many possible applications.[1−3] A major challenge is presented by the elaboration of novel design strategies enabling the synthesis of versatile gelator molecules with predictable properties. In this respect, structurally simple compounds,[4,5] easy to synthesize and available in large amounts from cheap starting materials, are desirable from the practical standpoint. Several design approaches based on the use of various self-complementary organisational units have already proven successful.[6−13] It has recently been shown that simple urethane, amide or urea derivatives of 11-aminoundecanoic acid (AUDA) act as efficient and selective gelators of polar organic solvents when the carboxylic acid function is deprotonated and when the *N*-acyl substituent contains an aromatic terminal moiety.[14] Here we report on the preparation of a new class of chiral gelator molecules based on 11-aminoundecanoic acid (AUDA), lauric acid and the core peptidic unit. The combination of these structural fragments should provide properties favourable for gelation: the presence of two core amidic functions would be expected to induce self-assembly through unidirectional cooperative hydrogen bonding, and the presence of the chiral centre and long aliphatic chain of the lauroyl amide should decrease the crystallization tendency of such derivatives. The structures represent a special class of amphiphiles containing hydrogen bonding cores, offering the potential for rather rare ambidextrous gelation of both highly polar and lipophilic solvents.[8,15−17] Here we report on the synthesis and versatile gelation capability of this class of molecules and provide ^{1}H NMR and FTIR evi-

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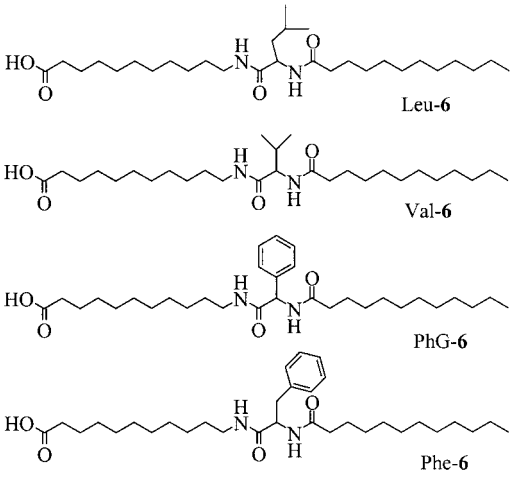
dence of their organisation by intermolecular hydrogen bonding. Experimental evidence that gelators with terminal carboxylic acid groups form thermally sensitive gels and those with terminal sodium carboxylates thermally stable ones is provided. At variance with most recent reports, we report on the most intriguing observation that some of the racemates are capable of gelling up to 16 times larger volumes of certain solvents than pure enantiomers.

2. Results and Discussion

Four long-chain aliphatic acid derivatives, each incorporating an amino acid unit in the central part of the molecule, were prepared. Leucine and valine were selected as aliphatic amino acid representatives, while phenylglycine and phenylalanine represented aromatic amino acids.

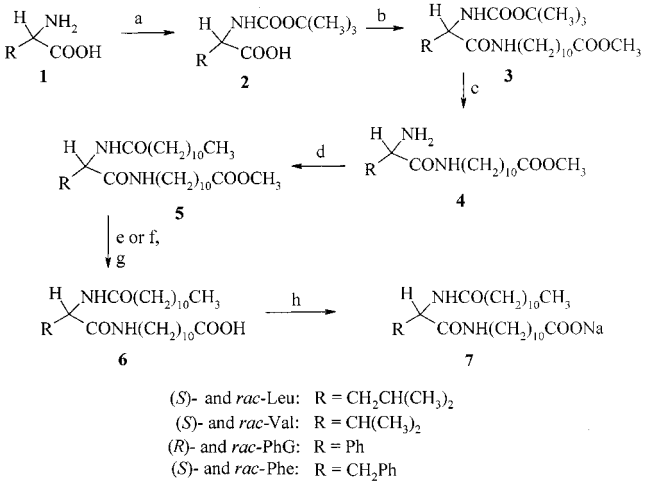


Two sets of compounds were synthesized: the pure enantiomers starting from the optically active amino acid precursors, and the racemates prepared from the racemic amino acids. The gelling properties of the optically active and racemic acid derivatives, as well as those of their corresponding sodium salts, were tested against water, 14 organic solvents and two hydrocarbon fuels, and their properties compared.

2.1. Synthesis

The racemic amino acids **1** were protected with $(Boc)_2O$ in dioxane/water (2:1), giving protected derivatives **2**[18] in quantitative yields (Scheme 1). The optically active Boc-protected amino acids are commercially available.

The first long aliphatic chain was introduced by DCC-condensation of **2** with methyl 11-aminoundecanoate hydrochloride, in the presence of DCC, Et_3N and DMAP, giving the amide derivatives **3** in high yields (76−96%). The Boc protecting groups of **3** were removed by treatment with TFA in CH_2Cl_2, which gave amino compounds **4** in yields of 83−100%. The second amide linkage was introduced by treatment of **4** with lauroyl chloride in dry CH_2Cl_2 in the presence of Et_3N. The ester-amides **5** were obtained in yields of 78−94%. Saponification of the methyl ester group



Scheme 1. Reagents and conditions: (a) $(Boc)_2O$, NaOH/dioxane/water, (b) $H_2N(CH_2)_{10}COOCH_3$, DCC, Et_3N, DMAP/CH_2Cl_2, (c) TFA/CH_2Cl_2, (d) $ClCO(CH_2)_{10}CH_3$, Et_3N/CH_2Cl_2, (e) LiOH/CH_2Cl_2/MeOH, (f) 10% KOH/MeOH, (g) HCl, (h) NaOH/CH_2Cl_2/MeOH

was performed with 1 M LiOH in methanol/CH_2Cl_2 solution for optically active derivatives or with KOH in methanol for racemic ones. The free acids **6** were obtained in 95−100% yields. The corresponding sodium salts **7** were prepared by the use of an equivalent quantity of 1 M aqueous NaOH in dichloromethane/methanol mixtures.

The alternative shorter synthetic route starting with direct Schotten−Baumann condensation of an amino acid and dodecanoyl chloride in aqueous alkaline conditions was not selected for two reasons: firstly, racemisation may occur with optically active amino acids, and secondly, the long-chain carboxylic acid amides of amino acids are known as efficient organic solvent gelators and hydrogelators,[19−21] so possible formation of gels might complicate isolation of the products.

2.2. Gelling Properties

Optically active and racemic free acids **6** and the corresponding sodium salts **7** were tested for gelation with 14 varied solvents and two hydrocarbon fuels. Gelation properties were determined with 10 mg of tested substance in 10 mm diameter tubes; the results, expressed as minimal gel concentrations, are collected in Table 1 and 2.

The Leu derivative (*S*)-Leu-**6** failed to gel any of the tested fluids. The optically active acids (*S*)-Val-**6**, (*R*)-PhG-**6** and (*S*)-Phe-**6** and the Na-salts (*S*)-Leu-**7**, (*S*)-Val-**6**, (*R*)-PhG-**7** and (*S*)-Phe-**7** showed only moderate gelation of the polar solvents DMSO and DMF, giving fully thermoreversible opaque gels; water was also weakly gelled only by the latter group of compounds. In the solvents of low and medium polarity, such as hexane, dichloromethane, acetonitrile, acetone and ethyl acetate, both the acids and the Na-salts are either insoluble or crystallise from hot solutions, but moderate gelation of THF was observed for the Leu and Phe Na-salts (*S*)-Leu-**7**, and (*S*)-Phe-**7**, respectively. Of the group of aromatic solvents tested, benzene

Table 1. Gelation properties of optically active acids and Na-salts expressed as minimal gel concentrations (10^{-2} mol·dm^{-3}) of tested compound[a][b]

Solvent	(*S*)-Leu-**6**	(*S*)-Leu-**7**	(*S*)-Val-**6**	(*S*)-Val-**7**	(*R*)-PhG-**6**	(*R*)-PhG-**7**	(*S*)-Phe-**6**	(*S*)-Phe-**7**
water	sol.	1.93	sl.sol.	1.98	ins.	1.55	ins.	1.21
DMSO	sol.	3.86	4.14	0.66	sol.	1.55	sol.	0.75
DMF	sol.	6.43	2.07	0.28	sol.	1.55	sol.	1.21
EtOH	sol.	sol.	sol.	3.30	cryst.	sol.	sol.	cryst.
THF	sol.	0.38	6.90	ins.	sol.	1.33	sol.	0.30
benzene	sol.	ins.	sol.	ins.	4.84 gel and t.v.s.	4.64	t.v.s.	ins.
toluene	sol.	2.41	sol.	1.98	3.23	1.69	t.v.s.	ins.
p-xylene	sol.	0.96	0.74	6.19	3.23	1.86	t.v.s.	ins.
tetralin	sol.	0.175	0.122*	0.165	1.29	0.241	0.753	0.181
decalin	sol.	1.28	0.690	1.16	0.293	0.84	0.325	0.297
petroleum ether	ins.	ins.	ins.	ins.	4.84	3.09	9.42	ins.
oil (Diesel)	ins.	6.43	ins.	ins.	1.29	ins.	18.8	ins.

[a] Gelation tests performed with 10 mg of tested substances in test tubes of 10 mm diameter.* Determined with 2.5 mg of tested substance. [b] Abbreviations: sol.: soluble, sl.sol.: slightly soluble, ins.: insoluble, cryst.: crystalline, t.v.s.: turbid viscous solution.

Table 2. Gelation properties of racemic acids and salts expressed as minimal gel concentrations (10^{-2} mol·dm^{-3}) of the tested compound[a][b]

Solvent	*rac*-Leu-**6**	*rac*-Leu-**7**	*rac*-Val-**6**	*rac*-Val-**7**	*rac*-PhG-**6**	*rac*-PhG-**7**	*rac*-Phe-**6**	*rac*-Phe-**7**
water	ins.	cryst.	ins.	1.98	ins.	2.32	ins.	1.88
DMSO	cryst.	cryst.	10.4	2.48	sol.	1.69	18.8	18.1
DMF	cryst.	cryst.	20.7	3.96	sol.	3.09	sol.	1.21
p-xylene	t.v.s.	ins.	ins.	ins.	cryst.	0.115*	sol.	0.113*
tetralin	6.71	0.138**	cryst.	ins.	t.v.s.	0.155*	sol.	0.134
decalin	t.v.s.	ins.	t.v.s.	0.291	t.v.s.	0.103*	t.v.s.	0.090**

[a] Gelation tests performed with 10 mg of tested substances in test tubes of 10 mm diameter.* Determined with 2.5 mg of tested substance. ** Determined with 5.0 mg of tested substance. [b] Abbreviations: sol.: soluble, sl.sol.: slightly soluble, ins.: insoluble, cryst.: crystalline, t.v.s.: turbid viscous solution.

could be weakly gelled only by (*R*)-PhG-**7**, while toluene and *p*-xylene were gelled with moderate efficiency by the Na-salts of (*S*)-Leu-**7**, (*S*)-Val-**7** and (*R*)-PhG-**7** derivatives and by the Val acid (*S*)-Val-**6**. However, the same gelators exhibited very efficient gelation of tetralin, forming gels at mM concentrations. Weak gelation of hydrocarbon fuels was also observed with the Na salts (*S*)-Leu-**7** and (*R*)- PhG-**7** and the acids (*R*)-PhG-**6** and (*S*)-Phe-**6**.

Table 2 shows that the racemic derivatives *rac*-Leu-**6**, *rac*-Val-**6**, *rac*-PhG-**6** and *rac*-Phe-**6** and the Na-salts *rac*-Leu-**7**, *rac*-Val-**7**, *rac*-PhG-**7** and *rac*-Phe-**7** were generally less versatile gelators than the corresponding optically active forms. The racemates failed to gel hexane, benzene, toluene, dichloromethane, acetonitrile, THF, acetone, ethyl acetate, ethanol and hydrocarbon fuels. Most of the racemates are either insoluble in these solvents or tend to crystallize from hot solutions. Striking differences, however, were observed for the Na salts *rac*-Leu-**7**, *rac*-PhG-**7** and *rac*-Phe-**7**, which showed excellent gelation of tetralin and decalin while their optically active isomers exhibited much weaker gelation [see Table 1 for (*S*)-Leu-**7**, (*R*)-PhG-**7** and (*S*)-Phe-**7**]. For example, the racemic *rac*-PhG-**7** was capable of gelling a 16 times larger volume of *p*-xylene then (*R*)-PhG-**7**, and the racemic *rac*-PhG-**7**, and *rac*-Phe-**7** were capable of gelling much larger volumes of decalin than the pure enantiomers (*R*)-PhG-**7** and (*S*)-Phe-**7**. Several earlier observations showed that pure enantiomers are generally more efficient gelators than the corresponding racemates, which tend to crystallize.[22−27] In contrast, the results from Table 2 clearly show that in some solvents racemates can be much more efficient gelators than the corresponding pure enantiomers. The same observation was also reported very recently for some racemates and enantiomers of bis(amino alcohol) oxalamide gelators.[28]

The thermal properties of the gels prepared from two enantiomer/racemate pairs were examined by determination of their gel melting temperatures (T_g). The first (*S*)-Val-**7**/*rac*-Val-**7** pair represents a case in which the enantiomer (*S*)-Val-**7** is capable of gelling a 14 times larger volume of DMF than the racemate *rac*-Val-**7**, while the second (*R*)-PhG-**7**/*rac*-PhG-**7** pair represents the opposite case, the racemate *rac*-PhG-**7** being capable of gelling a 16 times larger volume of *p*-xylene than the enantiomer (*R*)-PhG-**7** (Table 3).

The results show that, at the same concentrations of the enantiomer and the racemate, considerably higher T_g values are obtained for the enantiomer (*S*)-Val-**7** and the racemate *rac*-PhG-**7**, both being capable of immobilising larger volumes of solvents than their counterparts. This suggests that different types of aggregation occur in the enantiomer and in the racemate gels of the (*S*)-Val-**7**/*rac*-Val-**7** and (*R*)-PhG-**7**/*rac*-PhG-**7** pairs, giving more stable aggregates in the

Table 3. T_g values and concentrations (c_g) of the gels prepared from pure enantiomers (*S*)-Val-**7** and (*R*)-PhG-**7** and the racemates *rac*-Val-**7** and *rac*-PhG-**7**

Gelator/solvent	c_g (mol·dm^{-3})	T_g (°C); freshly prepared gel	T_g (°C); aged for 1 day
(*S*)-Val-**7***/* DMF	1.98×10^{-2}	126	–
rac-Val-**7***/* DMF	1.98×10^{-2}	107	–
(*R*)-PhG-**7**/ *p*-xylene	1.86×10^{-3}	28	30
rac-PhG-**7***/ p*-xylene	1.86×10^{-3}	75	119

enantiomer (*S*)-Val-**7** and the racemate *rac*-PhG-**7** gels. The significant difference in the T_g values determined for the freshly prepared and for 1 day aged *rac*-PhG-**7** gels (T_g of 75 °C and 119 °C, respectively) and only a slight one for the enantiomer (*R*)-PhG-**7** gels (T_g values 28 °C and 30 °C) suggests a slower aggregation process for the racemate. The peculiar observed behaviour of the racemic gelators, which are either insoluble or tend to crystallize from the majority of the tested solvents, but are capable of forming stable gels with certain solvents and of immobilising larger volumes than the enantiomer, is highly intriguing. Although additional work is needed to clarify these observations, it should be noted that the "chiral bilayer effect" formulated for chiral amphiphilic hydrogelators predicts formation of the enantiomeric bilayers in the stable hydrogels of racemates.[26] The same explanation was recently also proposed for the racemic bis(amino alcohol) oxalamide gelators, which tend to form inverse bilayers in the lipophilic solvent gels.[28]

2.3. FTIR and ^{1}H NMR Investigation

Temperature-dependent FTIR spectra of an (*S*)-Leu-**6** toluene solution and of toluene gels of (*S*)-Leu-**7**, (*R*)-PhG-**6** and (*R*)-PhG-**7** were recorded to check for the presence of the intermolecular hydrogen bonding interactions in the aggregates. The positions of NH and amide I bands at room temperature and at 95−100 °C are collected in Table 4.

Table 4. Positions of NH and amide I bands ($\tilde{\nu}$, cm^{-1}) in the FTIR spectra of (*S*)-Leu-**6** toluene solution and (*S*)-Leu-**7**, (*R*)-PhG-**6** and (*R*)-PhG-**7** toluene gels at 25 and 100 °C

Compound[a]	ν(NH)		ν(amide I)	
	25 °C	100 °C	25 °C	100 °C
(*S*)-Leu-**6**	3285	3408; 3302	1636	1650
(*S*)-Leu-**7a**	3291	3297	1637	1637
(*R*)-PhG-**6**	3292	3403 br	1640	1675
(*R*)-PhG-**7**	3291	3299	1630	1630

[a] Concentrations: (*S*)-Leu-**6**, 0.080; (*S*)-Leu-**7**, 0.041; (*R*)-PhG-**6**, 0.048; (*R*)-PhG-**7**, 0.020 mol·dm^{-3}.

In the spectra of the (*S*)-Leu-**6** solution and of the (*R*)-PhG-**6** gel, the NH and amide I bands at lower wavenumbers, corresponding to hydrogen-bonded amide groups, gradually diminish with increasing temperature, and new bands corresponding to non-hydrogen bonded amidic groups appear at higher wavenumbers (Table 4). In contrast, the spectra of (*S*)-Leu-**7** and (*R*)-PhG-**7** gels showed only very slight changes in the positions of NH and amide I bands with increasing temperature, despite the fact that the NH and amide I bands appeared in the range characteristic of hydrogen-bonded peptidic groups in the spectra of gels at room temperature. These observations show that the aggregates present in the (*S*)-Leu-**6** solution and (*R*)-PhG-**6** gel disaggregate at higher temperatures by breakage of intermolecular amidic hydrogen bonds, while the gels formed by the sodium salts remain practically unchanged in the 25−100 °C temperature range. The thermal behaviour of the (*S*)-Leu-**7** and (*R*)-PhG-**7** gels reveals that besides the intermolecular hydrogen bonding between amidic groups an additional intermolecular interaction must be operative in this case. Since both (*S*)-Leu-**7** and (*R*)-PhG-**7** possess structural characteristics of amphiphiles, intermolecular interactions between lipophilic parts and between highly polar parts would be expected.[29] In the micellar fibres formed by the amphiphilic *N*-dodecyl-tartaric acid monoamide sodium salt[30] and in the bilayered crystal structure of potassium palmitate[31] electrostatic and ion-dipole interactions between sodium or potassium carboxylates were found. Hence, for the (*S*)-Leu-**7** and (*R*)-PhG-**7** gel aggregates, the same type of interactions may account for the observed additional stabilization, particularly in toluene, due to its poor ability to solvate ions. The gel melting temperatures (T_g) of the free acid (*R*)-PhG-**6** and of the sodium salt (*R*)-PhG-**7** toluene gels at the same gelator concentrations ($c_{(R)\text{-PhG-}\mathbf{6}} = c_{(R)\text{-PhG-}\mathbf{7}} = 2.0 \times 10^{-2}$ mol·dm^{-3}) were determined to be 40 °C for the first and 130 °C for second. The results show that the transformation of the terminal free carboxylic acid group into the sodium carboxylate group gives the gelator the capability to form the toluene gel with a *Tg* 90 °C higher than that produced by the free acid gelator.

Temperature-dependent ^{1}H NMR spectra of the phenylglycine derivatives (*R*)-PhG-**6** and (*R*)-PhG-**7** [D$_8$]toluene gels were also investigated. In previous work we and others have shown that the observed spectrum of a gel is produced by gelator molecules, aggregated or free, dissolved in the entrapped fluid, while signals of gelator molecules assembled in the rigid gel network cannot be observed because of their long correlation times.[32−34] However, heating of gel samples in some cases results in an increase in the gelator signals due to dissociation of the network into smaller NMR-observable aggregates and disaggregated molecules. On the other hand, some gels are thermally stable in the temperature range available for the common

NMR solvents and no increase of gelator signals could be observed by heating of NMR samples.[35] NMR samples of (*R*)-PhG-**6** and (*R*)-PhG-**7** [D_8]toluene gels ($c_{(R)\text{-PhG-}6}$ = 0.0133 mol·dm^{-3}; $c_{(R)\text{-PhG-}7}$ = 0.0174 mol·dm^{-3}) were prepared with 1,1,2,2-tetrachloroethane (0.5 mol/mol of the gelator) as the internal standard. In the spectra of the gels taken at room temperature the concentrations of the NMR-observable aggregates were calculated from the intensities of selected gelator signals and that of the internal standard. The results show that for the (*R*)-PhG-**6** and (*R*)-PhG-**7** gels, 21% and only 3.8% of the total gelator concentration, respectively, can be observed by NMR spectroscopy. Thus, the sodium salt derivative (*R*)-PhG-**7** is significantly more aggregated (96%) than the free acid gelator (*R*)-PhG-**6**, which is 80% aggregated. An increase in the temperature from 25 to 80 °C failed to produce any significant increase in the gelator signals for both samples. This shows that both gels are stable in the specified temperature range and that no significant disaggregation of the network into dissolved, NMR-observable aggregates could be detected.

Analysis of chemical shift changes induced by thermal disaggregation may give valuable information on the weak intermolecular interactions stabilizing the aggregates and possibly on the existing self-assembly motifs. To obtain such information, the temperature dependence of the (*R*)-PhG-**6** and (*R*)-PhG-**7** chemical shifts was studied at concentrations just below their minimal gelation concentrations (mgc values, determined for (*R*)-PhG-**6** and (*R*)-PhG-**7** and [D_8]toluene in NMR tubes). At concentrations slightly lower than their mgc values (1.45×10^{-2} and 1.48×10^{-2} mol·dm^{-3}, respectively), both (*R*)-PhG-**6** and (*R*)-PhG-**7** give highly viscous toluene solutions indicative of the presence of highly aggregated species that should possess organisation closely resembling that in their gel aggregates. In the spectra of the acid derivative (*R*)-PhG-**6** measured over the 40−80 °C temperature interval, both amide NH protons, (C*−NH and NH−CH_2), the carboxylic acid proton (COOH) and the methyne proton (C*H) are all shifted upfield with increasing temperature (Figure 1, a). The high NH temperature coefficients ($\Delta\delta_{NH}/\Delta T$) of 11.1×10^{-3} and 6.5×10^{-3} ppm·K^{-1} determined for C*−NH and NH−CH_2, respectively, are characteristic of amidic NH moieties engaged in hydrogen bonding; the coefficient for C*−NH amide protons, almost twice as high as for NH(CH_2), shows that the former experienced a larger chemical shift change by temperature-induced dissociation of the aggregates, which in turn points to a stronger hydrogen bond formed by the C*−NH moieties.

The carboxylic acid proton is also strongly shifted upfield ($\Delta\delta_{COOH}/\Delta T$ 19.4 $\times 10^{-3}$ ppm K^{-1}), which clearly shows that the carboxylic groups are also involved in hydrogen bonding that stabilises the aggregates. A significant upfield shift ($\Delta\delta_{C*H}/\Delta T = 7.3 \times 10^{-3}$ ppm·K^{-1}) is also observed for the C*H proton, being closest to the strong hydrogen bond formed by (C*H)NH. It seems plausible that C*H is deshielded in the aggregate by the close amide carbonyl oxygen of the second molecule and hence becomes shielded by disaggregation.

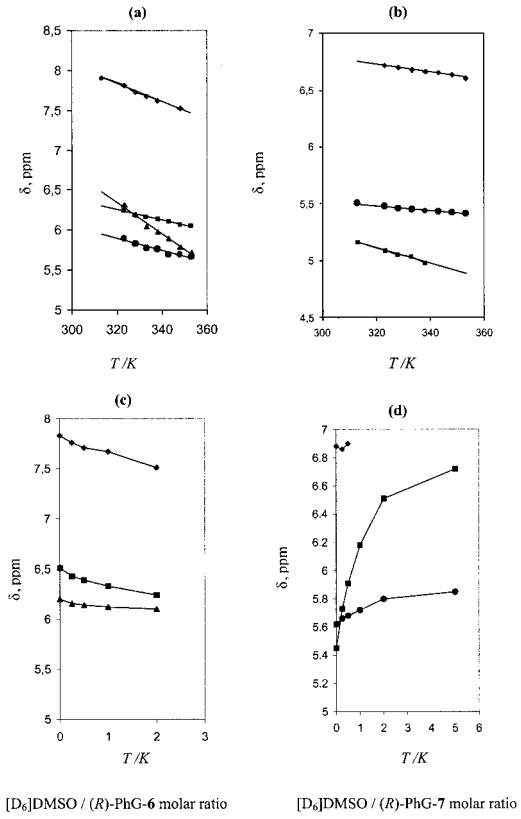


Figure 1. Temperature-induced shifts of (C*H)NH (filled diamonds), (CH_2)NH (filled squares), COOH (filled triangles) and C*H (filled circles) protons of (*R*)-PhG-**6** (a) and (*R*)-PhG-**7** (b) in [D_8]toluene, and [D_6]DMSO-induced shifts of the same protons of (*R*)-PhG-**6** (c) and (*R*)-PhG-**7** (d)

In sharp contrast, the C*−NH and C*H temperature coefficients of 3.6×10^{-3} and 1.7×10^{-3} ppm·K^{-1} measured for the sodium salt (*R*)-PhG-**7** (Figure 1, b) are three and two times lower than those of (*R*)-PhG-**6**, and that of NH−CH_2 (4.5×10^{-3} ppm·K^{-1}) is also smaller than that of (*R*)-PhG-**6**. These results clearly show that, at the same concentrations of gelators and within the same temperature range, the aggregates of the sodium salt (*R*)-PhG-**7** had undergone much less disaggregation than those of the free acid (*R*)-PhG-**6**. This is in agreement with the observations from the temperature-dependent FTIR revealing that (*R*)-PhG-**7** forms more stable aggregates than (*R*)-PhG-**6** in toluene gel.

In the next set of experiments, small volumes of [D_6]DMSO were gradually added to viscous deuterated toluene solutions of (*R*)-PhG-**6** and (*R*)-PhG-**7** and the changes in the gelator chemical shifts were monitored. Since DMSO is strong competitor for hydrogen bonds, its addition should result in dissociation of the hydrogen-bonded aggregates; the ^{1}H NMR spectra were recorded over a range of DMSO/gelator molar ratios from 0 to 5. In the spectra of (*R*)-PhG-**6**, the C*−NH, NH−CH_2 and C*H protons were significantly shifted upfield with increasing DMSO/(*R*)-PhG-**6** ratio (Figure 1, c). The trend in the chemical shifts (upfield) is the same as seen in the tempera-

ture-dependent spectra and can be explained in the same way by breakage of the intermolecular amidic hydrogen bonds and dissociation of the aggregates. Surprisingly, the opposite trend of chemical shifts (downfield) was observed in spectra of (*R*)-PhG-**7** with addition of DMSO (Figure 1, d); strong downfield shifts of the $(CH_2)NH$ (for 1 ppm) and C*H protons (for 0.2 ppm) could be observed in the spectra of (*R*)-PhG-**7** in $[D_8]$toluene upon successive additions of $[D_6]$DMSO. The shifts of the (C*H)NH protons could not be followed after the first two $[D_6]$DMSO additions since the signal overlaps with the residual nondeuterated toluene signal. The different behaviour of (*R*)-PhG-**6** and (*R*)-PhG-**7** toluene gels upon addition of DMSO could be explained by the fact that (*R*)-PhG-**6** is soluble in DMSO (Table 1) and that (*R*)-PhG-**7** is capable of gelling DMSO with a similar efficiency to toluene (Table 1). Consequently, the addition of DMSO to the first system results in partial disaggregation and dissolution of smaller aggregates, while in the second system the aggregation seems to be enhanced or another state of aggregation may form, resulting in enhanced intermolecular hydrogen bonding and deshielding of NH moieties, respectively.

The results of FTIR and ^{1}H NMR investigations clearly show that the intermolecular hydrogen-bonding interactions involving amidic and carboxylic acid groups and the electrostatic and ion-dipole interactions between sodium carboxylates contribute strongly to stabilization of the aggregates in toluene gels (Figure 2, a,b).

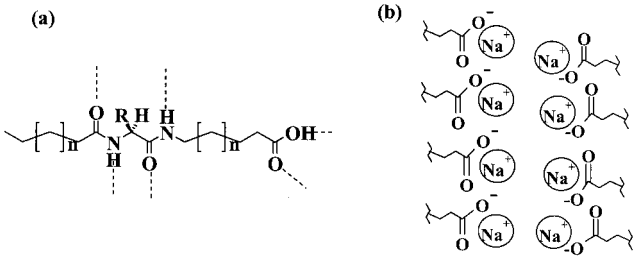


Figure 2. Schematic representation of hydrogen-bonding and electrostatic intermolecular interactions stabilizing gel aggregates: (a) hydrogen bonding between amidic and carboxylic groups and (b) electrostatic and ion-dipole interactions between sodium carboxylates

It should be noted that both the cooperative amidic hydrogen bonding and the interactions between sodium carboxylates may induce unidirectional self-assembly necessary for formation of fibrous aggregates.

2.4. TEM Investigation

TEM images of sufficient quality were obtained for the (*R*)-phenylglycine and phenylalanine derivatives (*R*)-PhG-**7** and (*S*)-Phe-**7** DMSO gels after staining with dipotassium phosphotungstate (PWK) (Figure 3, a,b). Both images show typical gel morphology consisting of entangled fibres with diameters in the 20−80 nm range. Closer examination of the (*S*)-Phe-**7** TEM image shows the fibres consisting of twisted ribbons. TEM of (*R*)-PhG-**7** gel shows the presence of much shorter fibres than in the (*S*)-Phe-**7** gel, forming a much denser network, although the twisted ribbon morphology of the fibres cannot be observed.

3. Conclusion

A new class of optically active and racemic gelators constructed from 11-aminoundecanoic acid (AUDA), lauric acid and various core amino acid units has been prepared and tested for gelation in the forms of the free acids and the sodium salts. The results of gelation experiments have shown that the ambidextrous gelation both of highly polar and of highly lipophilic fluids could be accomplished by some derivatives of the series. It was also found that some racemic salts could be much better gelators of certain solvents than the corresponding pure enantiomers; that racemic *rac*-PhG-**7**, for example, is capable of immobilising a 16 times larger volume of *p*-xylene that the *R* enantiomer (*R*)-PhG-**7**. This result is of great importance for the search for highly efficient chiral gelators, showing that, in contrast with previous findings,[22−27] racemates may gel much higher volumes of certain solvents than the pure enantiomers. Determination of gel melting temperatures (T_g) for two enantiomer/racemate pairs has shown that aggregates of different stability are formed in the enantiomer and in the racemate gels. Temperature-dependent FTIR and ^{1}H NMR studies of selected gels have shown that the intermo-

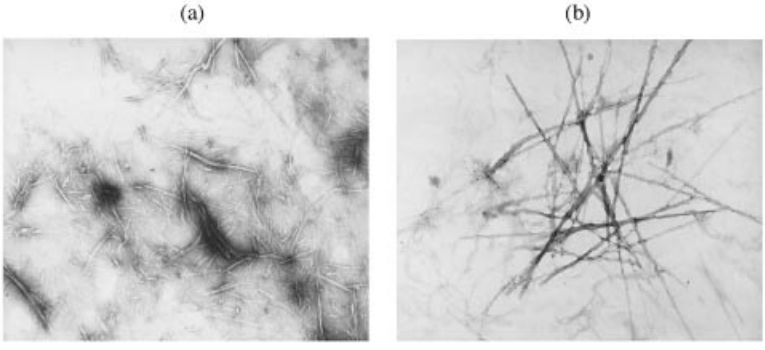


Figure 3. TEM images of (*R*)-PhG-**7** (a) and (*S*)-Phe-**7** (b) DMSO gels after staining with dipotassium phosphotungstate (PWK)

lecular hydrogen bonding between amidic and carboxylic units represent the dominating forces stabilising organisation in the gel fibres of free acid derivatives. The gelators form considerably more stable aggregates in the form of their sodium salts than in their free acid forms. In the latter aggregates, besides amidic intermolecular hydrogen bonding, additional strong stabilization originating from multiple intermolecular electrostatic and ion-dipole interactions between carboxylates and sodium cations is also present. These interactions would be expected to be very strong in lipophilic solvents, because of their poor capability to solvate ions. This finding appears highly relevant for the preparation of gels with desired thermal characteristics. It points toward the carboxylic acid salt as an important unit in the gelator structure, capable of strong stabilization of the aggregates in lipophilic solvents and of providing gels with enhanced thermal stability.

Experimental Section

General: All solvents were dried and redistilled shortly before use. Flash chromatography was performed on Merck 60 silica gel (0.2−0.63 mm), with CH_2Cl_2/MeOH solvent mixtures as eluents. Thin layer chromatography was performed on plastic sheet silica gel (Merck 60 F_{254}). Spots were viewed under a UV lamp (254 nm) or with the aid of iodine vapour. Melting points were determined with a Kofler hot-bench apparatus and were not corrected. IR Spectra ($\tilde{\nu}$ in cm^{-1}) were taken with a Perkin−Elmer 257 spectrometer in KBr pellets. NMR spectra (δ in ppm rel. to Me_4Si as an internal standard) were taken with a Varian XL-300 Gemini spectrometer and Bruker. NMR spectroscopic data are given in Table 5−8. All spectroscopic and analytical data of racemic compounds, except for the $[\alpha]_D$ values, were identical to those of the corresponding optically active derivatives. Optical activity was determined with an Optical Activity AA-10 Automatic Polarimeter in a 1-dm cell at λ = 589 nm. The yields have not been optimized.

Preparation of Boc-Amino Acids 2: Amino acid **1** (10 mmol) was dissolved in dioxane/water (2:1, 30 mL), which was made alkaline with NaOH (1 M, 10 mL) and cooled in an ice-bath, and $(Boc)_2O$ (3.272 g, 15 mmol) and $NaHCO_3$ (840 mg, 10 mmol) were added. The reaction mixture was stirred overnight at room temp. and was then evaporated to half the volume. The residue was diluted with EtOAc (40 mL), cooled in an ice-bath and acidified to pH = 2.5−3 with $KHSO_4$ (1 M). The layers were separated, the aqueous fraction was extracted with EtOAc (2 × 20 mL), and the combined extracts were washed with water, dried and evaporated, leaving products **2** as colourless oils in quantitative yields. These were used for the condensation step without any purification.

DCC-Condensation with Methyl 11-Aminoundecanoate. General Procedure for Preparation of 3: Methyl 11-aminoundecanoate hydrochloride (2.518 g, 10 mmol) was added to a Boc-protected amino acid **2** (10 mmol) dissolved in dried CH_2Cl_2 (50 mL). The mixture was cooled in an ice-bath, and DCC (2.063 g, 10 mmol), Et_3N (1.40 mL, 1.012 g, 10 mmol) and DMAP (122 mg, 1.0 mmol) were added. After the mixture had been stirred at room temperature overnight the precipitated DCHU was filtered off and the cake was washed with CH_2Cl_2 (50 mL). The filtrate was washed with AcOH (10%, 10 mL), water, $NaHCO_3$ (5%) and again water, dried and evaporated, leaving products **3** as colourless oils that were purified chromatographically on silica (CH_2Cl_2/MeOH, 19:1 and 9:1). ^1H NMR spectra are given in Table 5, and ^{13}C NMR spectra in Table 6.

Methyl 11-({(2*S*)-2-[(*tert*-Butoxycarbonyl)amino]-4-methylpentanoyl}amino)undecanoate [(*S*)-Leu-3]: The product (*S*)-Leu-**3** (1.197 g, 84%) was obtained from (*S*)-Leu-**2** (767 mg, 3.316 mmol). IR: $\tilde{\nu}$ = 3333, 2923, 2851, 1732, 1686, 1647, 1526, 1173, 1049 cm^{-1}.

Table 5. ^1H NMR spectra of Boc-amino compounds **3** and amino derivatives **4** (taken in $CDCl_3$, with TMS as an internal standard, δ in ppm, *J* in Hz)

	Ph	*CHCON*H*	*CHN*H*	*CH	OCH_3	NH−C*H*$_2$ (*J* in Hz)	CH_2CO t (*J* in Hz)	$NHCH_2CH_2$ and CH_2CH_2CO m (*J* in Hz)	$C(CH_3)_3$	other CH_2 and CH	$CH(CH_3)_2$ (*J* in Hz)
Leu-**3**	–	6.10 m	4.87 m	4.04 m	3.67 s	3.24 dt as q (6.87)	2.31 (7.69)	1.70−1.59	1.45 s	1.27 m	0.94 dd (2.20; 6.32)
Leu-**4**[a]	–			3.54 m	3.74 s	3.41−3.19 m	2.40 (7.33)	1.81−1.51	–	1.40 m	1.04 dd as t (6.59)
Val-**3**	–	6.39 m	5.22 d (8.79)	3.85 dd (6.60, 8.79)	3.63 s	3.28−3.14 m	2.27 (7.69)	1.68−1.03	1.40 s	1.68−1.03 m	0.90 dd as t (6.87; 9.10)
Val-**4**	–	7.32 m	4.68 m	3.29−3.19 m	3.67 s	3.29−3.19 m	2.30 (7.69)	1.62 t (7.14), 1.50 t (6.87)	–	1.28 m	0.99, 0.82 dd (6.87)
PhG-**3**	7.42−7.28 m	6.06 m	5.94 d (5.77)	5.15 d	3.66 s	3.19 q (6.59)	2.30 (7.69)	1.61 t (7.14)	1.40 s	1.33−1.08 m	–
PhG-**4**	7.38−7.28 m	7.16 m	4.60 m	4.48 m	3.64 s	3.21 q (6.59)	2.29 (7.69)	1.60 m,1.46 m	–	1.24 m	–
Phe-**3**	7.31−7.19 m	5.90 m	5.23 m	4.29 (6.86)	3.67 s	3.20−3.01 m	2.30 (7.69)	1.61 t (6.87)	1.40 s	1.27−1.16 m	–
Phe-**4**	7.29−7.20 m	6.40 m	4.65 m	3.87 m	3.65 s	3.19−3.07 m and 2.90 dd (7.42;12.91)	2.29 t (7.42)	1.60 m	–	1.36−1.23 m	–

[a] Taken in CD_3OD.

Table 6. ^{13}C NMR spectra of Boc-amino compounds **3** and amino derivatives **4** (taken in $CDCl_3$, with TMS as an internal standard, δ in ppm)

	COO	*CH*C*ONH	*CHNH*C*O	Ph	*C*(CH$_3$)$_3$	*CH	OCH$_3$	*CH*C*H$_2$	NHCH$_2$	*C*H$_2$CO	other CH$_2$ and CH	C(*C*H$_3$)$_3$	CH(*C*H$_3$)$_2$
Leu-**3**		172.26	155.20	–	80.01	52.85	51.26	43.30	39.36	33.94	33.98, 29, 28, 29.20, 28.98, 26.63	29.08	26.65, 24.80
Leu-**4**		176.17	–	–	–	54.37	52.17	44.83	40.65	34.29	30.73, 30.63, 30.30, 28.10, 26.14, 25.96, 23.24, 22.76	–	30.49
Val-**3**	174.13	171.36	155.75	–	79.50	59.94	51.26	–	39.24	33.91	29.35, 29.23, 29.23, 29.01, 28.91, 26.69, 24.23	28.13	19.12
Val-**4**		174.10	–	–	–	59.92	51.21	–	38.75	33.86	29.46, 29.20, 29.10, 29.01, 28.88, 26.70, 19.53, 15.76	–	24.70
PhG-**3**	174.19	169.92	155.051	138.48 C-1′ 128.73 C-3′ 128.03 C-4′ 126.98 C-2′	79.81	58.31	51.29	–	39.31	33.92	29.18. 29.12, 29.01, 28.93, 26.48, 24.75	28.13	–
PhG-**4**	174.10	172.62	–	140.96 C-1′ 128.54 C-2′ 127.68 C-4′ 126.64 C-3′	–	59.58	51.22	–	39.01	33.86	29.29, 29.18, 29.08, 28.96, 28.86, 26.60, 24.70	–	–
Phe-**3**	174.19	170.91	155.26	136.70 C-1′ 129.15 C-3′ 128.44 C-2′ 126.69 C-4′	79.91	55.88	51.31	38.67	39.31	33.92	29.23, 29.18, 29.03, 28.95, 26.58, 24.76	28.11	–
Phe-**4**	174.20	171.40	–	136.27 C-1′ 129.17 C-2′ 128.56 C-3′ 126.93 C-4′	–	55.61	51.29	39.46	39.19	33.91	29.23, 29.17, 29.05, 28.93, 26.65, 24.75	–	–

Methyl 11-({(2*R*,*S*)-2-[(*tert*-Butoxycarbonyl)amino]-4-methylpentanoyl}amino)undecanoate (*rac*-Leu-3): The product *rac*-Leu-**3** (5.356 g, 74%) was obtained from *rac*-Leu-**2** (3.890 g, 16.892 mmol).

Methyl 11-({(2*S*)-2-[(*tert*-Butoxycarbonyl)amino]-3-methylbutanoyl}amino)undecanoate [(*S*)-Val-3]: The product (*S*)-Val-**3** (1.851 g, 93%) was obtained from (*S*)-Val-**2** (1.048 g, 4.824 mmol). IR: $\tilde{\nu}$ = 3326, 2918, 2850, 1735, 1687, 1650, 1557, 1524, 1172 cm^{-1}.

Methyl 11-({(2*R*,*S*)-2-[(*tert*-Butoxycarbonyl)amino]-3-methylbutanoyl}amino)undecanoate (*rac*-Val-3): The product *rac*-Val-**3** (3.241 g, 95%) was obtained from *rac*-Val-**2** (1.762 g, 8.202 mmol).

Methyl 11-({(2*R*)-2-[(*tert*-Butoxycarbonyl)amino]-2-phenylethanoyl}amino)undecanoate [(*R*)-PhG-3]: The product (*R*)-PhG-**3** (8.586 g, 96%) was obtained from (*R*)-PhG-**2** (5.026 g, 20 mmol). IR: $\tilde{\nu}$ = 3328, 2927, 2851, 1733, 1647, 1524, 1367, 1250, 1172, 700 cm^{-1}.

Methyl 11-({(2*R*,*S*)-2-[(*tert*-Butoxycarbonyl)amino]-2-phenylethanoyl}amino)undecanoate (*rac*-PhG-3): The product *rac*-PhG-**3** (7.197 g, 98%) was obtained from *rac*-PhG-**2** (4.126 g, 16.420 mmol).

Methyl 11-({(2*S*)-2-[(*tert*-Butoxycarbonyl)amino]-3-phenylpropanoyl}amino)undecanoate [(*S*)-Phe-3]: The product [(*S*)-Phe-**3** (7.066 g, 76%) was obtained from (*S*)-Phe-**2** (5.306 g, 20.0 mmol). IR: $\tilde{\nu}$ = 3349, 2929, 2851, 1733, 1685, 1655, 1435, 1296, 1172, 698 cm^{-1}.

Methyl 11-({(2*R*,*S*)-2-[(*tert*-Butoxycarbonyl)amino]-3-phenylpropanoyl}amino)undecanoate (*rac*-Phe-3): The product *rac*-Phe-**3** (8.371 g, 91%) was obtained from *rac*-Phe-**2** (5.306 g, 20.0 mmol).

Removal of Boc Protecting Group. General Procedure for Preparation of 4: TFA (5 mL) was added to the starting compound **3** (5.0 mmol) dissolved in CH_2Cl_2 (5−10 mL) and cooled in an ice-bath, and the mixture was stirred overnight at room temperature. The solution was evaporated, and some diethyl ether or CH_2Cl_2 (50 mL) and 10% $KHCO_3$ (10 mL) were added with cooling and stirring. The layers were separated, the aqueous layer was extracted with additional ether or CH_2Cl_2 (2 × 25 mL), and the combined extracts were washed with $KHCO_3$ (5%) and water, dried and evaporated, affording deprotected amino compounds **4**. ^1H NMR spectra are given in Table 5, and ^{13}C NMR spectra in Table 6.

Methyl 11-{[(2*S*)-2-Amino-4-methylpentanoyl]amino}undecanoate [(*S*)-Leu-4]: The product (*S*)-Leu-**4** (605 mg, 94%) was obtained from (*S*)-Leu-**3** (844 mg, 1.969 mmol). IR: $\tilde{\nu}$ = 3292, 2928, 2855, 1740, 1654, 1557, 1437, 1368, 1201, 1010 cm^{-1}.

Methyl 11-{[(2*R*,*S*)-2-Amino-4-methylpentanoyl]amino}undecanoate (*rac*-Leu-4): The product *rac*-Leu-**4** (4.088 g, 100%) was obtained from *rac*-Leu-**3** (5.356 g, 12.496 mmol).

Methyl 11-{[(2*S*)-2-Amino-3-methylbutanoyl]amino}undecanoate [(*S*)-Val-4]: The product (*S*)-Val-**4** (1.305 g, 95%) was obtained from (*S*)-Val-**3** (1.808 g, 4.361 mmol). IR: $\tilde{\nu}$ = 3318, 2927, 2851, 1735, 1638, 1541, 1466, 1373, 1176 cm^{-1}.

Methyl 11-{[(2*R*,*S*)-2-Amino-3-methylbutanoyl]amino}undecanoate (*rac*-Val-4): The product *rac*-Val-**3** (2.233 g, 91%) was obtained from *rac*-Val-**3** (3.241 g, 7.818 mmol),.

Methyl 11-{[(2*R*)-2-Amino-2-phenylethanoyl]amino}undecanoate [(*R*)-PhG-4]: The product (*R*)-PhG-**4** (5.520 g, 83%) was obtained from (*R*)-PhG-**3**. IR: $\tilde{\nu}$ = 3320, 2926, 2851, 1735, 1647, 1541, 1437, 1173, 699 cm^{-1}.

Methyl 11-{[(2*R*,*S*)-2-Amino-2-phenylethanoyl]amino}undecanoate (*rac*-PhG-4): The product *rac*-PhG-**4** (5.038 g, 90%) was obtained from *rac*-PhG-**3** (7.197 g, 16.043 mmol).

Methyl 11-{[(2*S*)-2-Amino-3-phenylpropanoyl]amino}undecanoate [(*S*)-Phe-4]: The product (*S*)-Phe-**4** (5.495 g, 100%) was obtained from (*S*)-Phe-**3** (7.010 g, 15.153 mmol). IR: $\tilde{\nu}$ = 3290, 2928, 2855, 1739, 1671, 1564, 1437, 1201, 700 cm^{-1}.

Methyl 11-{[(2*R*,*S*)-2-Amino-3-phenylpropanoyl]amino}undecanoate (*rac*-Phe-4): The product *rac*-Phe-**4** (6.470 g, 96%) was obtained from *rac*-Phe-**3** (8.371 g, 18.095 mmol).

Treatment with Lauroyl Chloride. General Procedure for Preparation of 5: Et_3N (1.4 mL, 1.012 g, 10 mmol) and lauroyl chloride (2.4 mL, 2.188 g, 10 mmol) were added to a solution of an amino compound **4** (10 mmol) in dry CH_2Cl_2 (25 mL), which was cooled in an ice bath, and the mixture was stirred overnight at room temperature. The solution was diluted with additional CH_2Cl_2 and cooled, and some water was added. The layers were separated, the aqueous one was extracted twice with CH_2Cl_2, the combined extracts were washed with aqueous $NaHCO_3$, water, HCl (0.1 M) and water and dried, and the solvents were evaporated. ^1H NMR Spectra are given in Table 7, and ^{13}C NMR spectra in Table 8.

Methyl 11-{[(2*S*)-2-(Dodecanoylamino)-4-methylpentanoyl]amino}-undecanoate [(*S*)-Leu-5]: The product (*S*)-Leu-**5** (1.347 g, 94%) was obtained from (*S*)-Leu-**4** (917 mg, 2.793 mmol). IR: $\tilde{\nu}$ = 3292, 2921, 2852, 1732, 1636, 1542, 1466, 1174, 722 cm^{-1}. $[\alpha]_D^{22}$ = −24 (*c* = 0.996, CH_2Cl_2). $C_{30}H_{58}N_2O_4$ (510.8): calcd. C 70.54, H 11.45, N 5.48; found C 70.31, H 11.45, N 5.54.

Methyl 11-{[(2*R*,*S*)-2-Amino-3-phenylpropanoyl]amino}undecanoate (*rac*-Leu-5): The product *rac*-Leu-**5** (5.829 g, 92%) was obtained from *rac*-Leu-**4** (4.088 g, 12.445 mmol).

Methyl 11-{[(2*S*)-2-(Dodecanoylamino)-3-methylbutanoyl]amino}-undecanoate [(*S*)-Val-5]: The crude product was obtained from (*S*)-Val-**4** (1.257 g, 3.997 mmol) and purified by FC on silica (CH_2Cl_2/MeOH 33:1and 24:1), giving (*S*)-Val-**5** (1.712 g, 86%). M.p. 90−93 °C. IR: $\tilde{\nu}$ = 3291, 2921, 2851, 1739, 1634, 1542, 1467, 1388, 1174, 721 cm^{-1}. $[\alpha]_D^{22}$ = −15 (*c* = 1.036, CH_2Cl_2). $C_{29}H_{56}N_2O_4$ (496.8): calcd. C 70.12, H 11.36, N 5.64; found C 69.98, H 11.17, N 5.44.

Methyl 11-{[(2*R*,*S*)-2-(Dodecanoylamino)-3-methylbutanoyl]amino}-undecanoate (*rac*-Val-5): The product *rac*-Val-**5** (2.757 g, 78%) was obtained from *rac*-Val-**4** (2.233 g, 7.101 mmol).

Methyl 11-{[(2*R*)-2-(Dodecanoylamino)-2-phenylethanoyl]amino}-undecanoate [(*R*)-PhG-5]: The product (*R*)-PhG-**5** (8.071 g, 97%) was obtained from (*R*)-PhG-**4** (5.485 g, 15.740 mmol); after recrystallization from 96% EtOH it was 6.267 g (78%), m.p. 116−119 °C. IR: $\tilde{\nu}$ = 3288, 2918, 2850, 1736, 1635, 1541, 1468, 1378, 1175, 700

Table 7. ^1H NMR spectra (for **5** and **6** taken in $CDCl_3$, **7** in CD_3OD, with TMS as an internal standard, δ in ppm, *J* in Hz)

	Ph m	*CHCON*H*	*CHN*H*	*CH	OCH_3	NH−CH_2	2 × CH_2CO t	other CH_2 and CH m	$CH(CH_3)_2$ dd	CH_3 t
Leu-**5**	−	6.80 m	6.61 d (8.52)	4.49 dt (6.04)	3.66 s	3.27−3.10 m (6.04)	2.29 (7.69), 2.17 (7.69)	1.60−1.09	0.92 (6.32)	0.87 (6.87)
Leu-**6**	−	7.15 t	6.99 d (8.51)	4.55 q (7.69)	−	3.25−3.08 m	2.30 (7.69), 2.16 (7.97)	1.59−1.23	0.92−0.84 m	
Leu-**7**	−			4.45 dd (6.35, 8.79)	−	3.26 t (7.08)	2.39−2.21 m	1.69−1.22	1.06−0.97 m	
Val-**5**	−	7.09 t	6.80 d (8.79)	4.30 t (7.96)	3.65 s	3.32−3.05 m	2.28 (7.96), 2.20 (8.24)	CH 2.14−2.01 CH_2 1.59−1.25	0.94−0.84 dd + s (6.32, 11.54)	
Val-**6**	−	7.31 d (9.06)	7.22 d (8.79)	4.33 dd as t (8.52)	−	3.28−3.07 m	2.31 (7.69), 2.21 m	CH 2.00 q (6.87) CH_2 1.62−1.25	0.89 (6.59, 15.11)	
Val-**7**	−			4.19 d (7.81)	−	3.26 ddt (7.08)	2.35 (7.33), 2.24 (7.33)	CH 2.12 dt (6.84) CH_2 1.69−1.22	1.01 (6.59)	
PhG-**5**	7.38−7.23	6.65 t	7.12 d (7.31)	5.73 (7.69)	3.66 s	3.21 dt (6.50)	2.28 (7.42)	1.62−1.20	−	0.88 (6.84)
PhG-**6**	7.38−7.27	6.82 t	7.50 m	5.71 (7.41)	−	3.19 dd as t (6.32)	2.30 (7.42), 2.26 (7.69)	1.61−1.20	−	0.88 (6.59)
PhG-**6**[a]	7.67−7.16	7.1 m	7.76 d (7.06)	6.13 d (7.84)	−	3.16 ddt (6.32)	2.33−1.91 m	1.61−1.15		0.97 (6.34)
PhG-**7**	7.52−7.39			4.20 q (7.33)	−	3.25 ddt (6.59)	2.38 dt (4.64, 7.33), 2.24 (7.33)	1.69−1.33	−	0.99 (6.84)
PhG-**7**[a]	7.58−7.23	6.40 m	7.1 m	5.92 d (7.31)	−	3.11 ddt (6.28)	1.87 m	1.55−1.16	−	0.93 (6.74)
Phe-**5**	7.26−7.19	6.31 t	6.69 d (7.42)	4.69 q (7.42)	3.67 s	3.16 quint. (6.59) and 3.04 m (7.69)	2.30 (7.42), 2.16 (7.14)	1.61−1.25	−	0.88 (6.59)
Phe-**6**	7.29−7.18	6.87 m	7.35 d (8.57)	4.75 q (7.69)	−	3.01 d (7.42)	2.36 (7.42), 2.17 (7.42)	1.65 t (6.87), 1.60−1.24	−	0.88 (6.87)
Phe-**7**	7.38−7.29			4.66 (6.59)	−	3.18 d+t (7.33) and 2.98 dd (8.79, 13.67)	2.24 t+t (6.84)	1.69−1.38	−	0.97 (6.84)

[a] In $[D_8]$toluene.

Table 8. ^{13}C NMR spectra (for **5** and **6** taken in $CDCl_3$, **7** in CD_3OD, with TMS as an internal standard, δ in ppm)

	COO	NHCO	Ph	*CH	OCH_3	$NHCH_2$	*$CHCH_2$	CH_2CO	other CH_2 and CH	$CH(CH_3)_2$	CH_3
Leu-**5**	174.20	173.39, 172.27	–	51.44	51.33	40.98	39.43	36.35, 33.94	31.77, 29.49, 29.30, 29.20, 29.08, 28.98, 26.70, 25.56, 24.78, 24.65, 22.66, 22.54, 22.18		13.97
Leu-**6**	177.16	173.39, 172.52	–	51.41	–	41.01	39.36	36.20, 33.89	31.72, 29.45, 29.37, 29.20, 29.06, 26.70, 25.55, 24.75, 24.60, 22.57, 22.49, 22.16		13.92
Leu-**7**	183.23	176.31, 174.95	–	53.33	–	42.27	40.52	39.48, 37.00	33.23, 31.03, 30.85, 30.64, 30.54, 30.42, 28.11, 27.99, 27.14, 26.12, 23.90, 23.59, 22.18		14.64
Val-**5**	174.10	173.20, 171.43	–	58.39	51.24	39.29	–	36.41, 33.89	31.72, 31.00, 29.44, 29.35, 29.29, 29.20, 28.95, 26.75, 25.63, 24.75, 22.49	19.07, 18.39	13.92
Val-**6**	177.31	173.69, 171.69	–	58.62	–	39.38	–	36.30, 34.03	33.92, 33.43, 31.75, 30.85, 29.47, 29.37, 29.20, 29.10, 28.93, 28.83, 26.69, 25.67, 25.34, 24.76, 24.70, 22.52	19.07, 18.51	13.96
Val-**7**	183.23	176.34, 173.79	–	60.60	–	40.47	–	39.46, 37.00	33.23, 31.87, 31.04, 30.85, 30.63, 28.16, 27.98, 27.21, 23.90	19.92, 19.02	14.62
PhG-**5**	174.15	172.59, 170.02	138.43 C-1′ 128.54 C-3′ 127.76 C-4′ 126.84 C-2′	56.42	51.29	39.62	–	36.34, 33.92	31.75, 29.45, 29.35, 29.23, 29.15, 29.05, 28.95, 26.58, 25.46, 24.76, 22.52	–	13.96
PhG-**6**	174.20	172.78, 170.14	138.31 C-1′ 128.61 C-2′ 127.86 C-4′ 126.89 C-3′	56.46	–	39.68	–	36.32, 33.96	31.78, 29.49, 29.37, 29.22, 29.16, 26.58, 25.46, 24.78, 22.56	–	13.99
PhG-**7**	183.26	175.92, 172.60	139.38 C-1′ 129.85 C-2′ 129.32 C-4′ 128.73 C-3′	58.92	–	40.62	–	39.48, 36.83	33.23, 30.90, 30.81, 30.63, 30.4, 27.98, 27.06, 23.90	–	14.64
Phe-**5**	174.17	173.06, 170.86	136.70 C-1′ 129.12 C-3′ 128.34 C-2′ 126.67 C-4′	54.38	51.29	39.33	38.61	36.34, 33.93	31.75, 29.47, 29.34, 29.20, 29.05, 26.60, 25.46, 24.76, 22.52	–	13.96
Phe-**6**	177.72	173.62, 171.42	136.55 C-1′ 129.14 C-3′ 128.34 C-2′ 126.69 C-4′	54.43	–	39.36	38.56	36.27, 33.91	31.78, 29.35, 29.22, 28.98, 28.93, 28.79, 28.71, 26.45, 25.48, 24.60, 22.56	–	13.99
Phe-**7**	183.36	176.31, 173.72	138.82 C-1′ 130.59 C-3′ 129.69 C-2′ 128.03 C-4′	56.40	–	40.70	39.60	37.18, 33.38	31.18, 31.05, 30.98, 30.78, 30.57, 28.13, 27.21, 24.05	–	14.77

cm^{-1}. $[\alpha]_D^{22} = -59$ ($c = 0.998$, CH_2Cl_2). $C_{32}H_{54}N_2O_4$ (530.8): calcd. C 72.41, H 10.25, N 5.28; found C 72.25, H 9.99, N 5.49.

Methyl 11-{[(2*R*,*S*)-2-(Dodecanoylamino)-2-phenylethanoyl]amino}-undecanoate (*rac*-PhG-5):The product *rac*-PhG-**5** (7.192 g, 93%) was obtained from *rac*-PhG-**4** (5.038 g, 14.457 mmol).

Methyl 11-{[(2*S*)-2-(Dodecanoylamino)-3-phenylpropanoyl]amino}-undecanoate [(*S*)-Phe-5]: The crude product (*S*)-Phe-**5** (7.688 g, 94%) was obtained from (*S*)-Phe-**4** (5.440 g, 15.006 mmol) and crystallised from MeOH, m.p. 86–88 °C (6.099 g, 79%). IR: $\tilde{\nu}$ = 3293, 2930, 2846, 1734, 1641, 1541, 1466, 1380, 1204, 699 cm^{-1}. $[\alpha]_D^{22} = -3$ ($c = 1.014$, CH_2Cl_2). $C_{33}H_{56}N_2O_4$ (544.8): calcd. C 72.25, H 10.36, N 5.14; found C 72.52, H 10.07, N 5.21.

Methyl 11-{[(2*R*,*S*)-2-(Dodecanoylamino)-3-phenylpropanoyl]-amino}undecanoate (*rac*-Phe-5): The product *rac*-Phe-**5** (7.903 g, 81%) was obtained from *rac*-Phe-**4** (6.470 g, 17.848 mmol).

Saponification of the Methyl Ester Group. General Procedure for Preparation of 6: For optically active compounds: LiOH (1 M, 30 mL, 30 mmol) was added to a solution of methyl ester (*S*)-Leu-**5,** (*S*)-Val-**5**, (*R*)-PhG-**5** or (*S*)-Phe-**5** (10 mmol) in methanol/CH_2Cl_2 (5:1, 100 mL). For racemic compounds: KOH/MeOH (10%, 30 mL) was added to a solution of methyl ester *rac*-Leu-**5**, *rac*-Val-**5**, *rac*-PhG-**5** or *rac*-Phe-**5** (10 mmol) in CH_2Cl_2 (50 mL). After stirring at room temperature for 2–4 days, the mixture was neutralised with HCl (1 M) and evaporated, some water was added, and the mixture was acidified to pH = 2–2.5 with HCl (1 M). The precipitated acid was collected, washed with water and air-dried. ^1H NMR Spectra are given in Table 7, and ^{13}C NMR spectra in Table 8.

11-{[((2*S*)-2-(Dodecanoylamino)-4-methylpentanoyl]amino}-undecanoic Acid [(*S*)-Leu-6]: The product [(*S*)-Leu-**6** (492 mg, 93%) was obtained from (*S*)-Leu-**5** (542 mg, 1.061 mmol). M.p.160–162

°C. IR: ṽ = 3294, 2929, 2851, 1729, 1655, 1606, 1544, 1122, 616 cm^{-1}. $[\alpha]_D^{22} = -22$ ($c = 0.984$, CH_2Cl_2). $C_{29}H_{56}N_2O_4$ (496.8): calcd. C 70.12, H 11.36, N 5.64; found C 69.89, H 11.31, N 5.86.

11-{[(2*R*,*S*)-2-(Dodecanoylamino)-4-methylpentanoyl]amino}-undecanoic Acid (*rac*-Leu-6): The product *rac*-Leu-**6** (5.634 g, 100%) was obtained from *rac*-Leu-**5** (5.817 g, 11.388 mmol).

11-{[(2*S*)-2-(Dodecanoylamino)-3-methylbutanoyl]amino}undecanoic Acid [(*S*)-Val-6]: The product (*S*)-Val-**5** (1.457 g, 88%) was obtained from (*S*)-Val-**5** (1.712 g, 3.446 mmol). IR: ṽ = 3291, 2920, 2851, 1741, 1635, 1560, 1466, 1388, 1234 cm^{-1}. $[\alpha]_D^{22} = -16.5$ ($c = 1.030$, CH_2Cl_2/MeOH, 1:1). $C_{28}H_{54}N_2O_4$ (482.7): calcd. C 69.67, H 11.27, N 5.80% found C 69.37, H 11.16, N 5.59.

11-{[(2*R*,*S*)-2-(Dodecanoylamino)-3-methylbutanoyl]amino}-undecanoic Acid (*rac*-Val-6): The product *rac*-Val-**6** (2.652 g, 99%) was obtained from *rac*-Val-**6** (2.755 g, 5.546 mmol.

11-{[(2*R*)-2-(Dodecanoylamino)-2-phenylethanoyl]amino}undecanoic Acid [(*R*)-PhG-6]: The product (*R*)-PhG-**6** (1.188 g, 95%) was obtained from (*R*)-PhG-**5** (1.287 g, 2.425 mmol). M.p. 103−105 °C (MeCN). IR: ṽ = 3292, 2919, 2850, 1735, 1635, 1541, 1468, 697 cm^{-1}. $[\alpha]_D^{22} = -34$ ($c = 1.026$, CH_2Cl_2). $C_{31}H_{52}N_2O_4$ (516.8): calcd. C 72.05, H 10.14, N 5.42; found C 72.30, H 9.97, N 5.23.

11-{[(2*R*,*S*)-2-(Dodecanoylamino)-2-phenylethanoyl]amino}-undecanoic Acid (*rac*-PhG-6): The product *rac*-PhG-**6** (2.827 g, 90%) was obtained from *rac*-PhG-**5** (3.216 g, 6.059 mmol).

11-{[(2*S*)-2-(Dodecanoylamino)-3-phenylpropanoyl]amino}-undecanoic Acid [(*S*)-Phe-6]: The product (*S*)-Phe-**6** (2.029 g, 98%) was obtained from (*S*)-Phe-**5** (2.123 g, 3.897 mmol). M.p. 75−77 °C (MeCN). IR: ṽ = 3301, 2925, 2846, 1697, 1639, 1543, 1469, 1271, 1220, 1109, 945, 701 cm^{-1}. $[\alpha]_D^{22} = -3$ ($c = 1.000$, CH_2Cl_2). $C_{32}H_{54}N_2O_4$ (530.8): calcd. C 72.41, H 10.25, N 5.28; found C 72.15, H 9.95, N 5.05.

11-{[(2*R*,*S*)-2-(Dodecanoylamino)-3-phenylpropanoyl]amino}-undecanoic Acid (*rac*-Phe-6): The product *rac*-Phe-**6** (3.507 g, 96%) was obtained from *rac*-Phe-**5** (3.741 g, 6.867 mmol).

General Procedure for Preparation of Sodium Salts 7: Acid **6** (1.0 mmol) was dissolved in CH_2Cl_2/MeOH (10 mL), and NaOH (1 M, 1.0 mL) was added. After short stirring, the solvents were evaporated and dried to give salt **7.** ^{1}H NMR spectra are given in Table 7, and ^{13}C NMR spectra in Table 8.

Sodium 11-{[(2*S*)-2-(Dodecanoylamino)-4-methylpentanoyl]amino}-undecanoate [(*S*)-Leu-7]: The product (*S*)-Leu-**7** (288 mg, 97%) was obtained from (*S*)-Leu-**6** (284 mg, 0.572 mmol),. M.p. 149−152 °C. IR: ṽ = 3292, 2922, 2851, 1745, 1634, 1561, 1466, 1222, 1171, 722 cm^{-1}.

Sodium 11-{[(2*R*,*S*)-2-(Dodecanoylamino)-4-methylpentanoyl]amino}-undecanoate (*rac*-Leu-7): The product *rac*-Leu-**7** (288 mg, 100%) was obtained from *rac*-Leu-**6** (276 mg, 0.555 mmol).

Sodium 11-{[(2*S*)-2-(Dodecanoylamino)-3-methylbutanoyl]amino}-undecanoate [(*S*)-Val-7]: The product (*S*)-Val-**7** (350 mg, 100%) was obtained from (*S*)-Val-**6** (336 mg, 0.696 mmol). IR: ṽ = 3291, 2922, 2851, 1636, 1564, 1443 cm^{-1}.

Sodium 11-{[(2*R*,*S*)-2-(Dodecanoylamino)-3-methylbutanoyl]amino}-undecanoate (*rac*-Val-7): The product *rac*-Val-**7** (375 mg, 100%) was obtained from *rac*-Val-**6** (359 mg, 0.744 mmol).

Sodium 11-{[(2*R*)-2-(Dodecanoylamino)-2-phenylethanoyl]amino}-undecanoate [(*R*)-PhG-7]: The product (*R*)-PhG-**7** (246 mg, 100%) was obtained from (*R*)-PhG-**6** (237 mg, 0.458 mmol). M.p.199−201 °C. IR: ṽ = 3303, 2922, 2851, 1638, 1565, 1445, 697 cm^{-1}.

Sodium 11-{[(2*R*,*S*)-2-(Dodecanoylamino)-2-phenylethanoyl]amino}-undecanoate (*rac*-PhG-7): The product *rac*-PhG-**6** (307 mg, 100%) was obtained from *rac*-PhG-**6** (296 mg, 0.572 mmol).

Sodium 11-{[(2*S*)-2-(Dodecanoylamino)-3-phenylpropanoyl]amino}-undecanoate [(*S*)-Phe-7]: The product (*S*)-Phe-**7** (615 mg, 100%) was obtained from (*S*)-Phe-**6** (589 mg, 1.110 mmol). M.p. 208−210 °C. IR: ṽ = 3297, 2923, 2851, 2467, 1637, 1565, 1444, 1241, 1119, 699 cm^{-1}.

Sodium 11-{[(2*R*,*S*)-2-(Dodecanoylamino)-3-phenylpropanoyl]amino}-undecanoate (*rac*-Phe-7): The product *rac*-Phe-**7** (383 mg, 100%) was obtained from *rac*-Phe-**6** (367 mg, 0.691 mmol).

Determination of Gelling Properties: The tested substance (10 mg) was placed in a test tube, and the solvent was added by microsyringe in 100−500 μL portions. After each addition the mixture was gently heated until the substance dissolved, and was then allowed to cool spontaneously to room temperature and formation of gel checked by test tube inversion. The procedure was repeated until sample fluidity was restored at room temperature.

Determination of Gel Melting Temperatures (T_g): Gels of exact concentrations were prepared in capped NMR tubes, and the samples were heated in the thermostatted bath with a temperature increase rate of 2 °C/min. The temperature that restored fluidity on tube inversion was taken as T_g.

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